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Local feed resources for pig, poultry and fish production in Papua New Guinea

Edited by Phil Glatz

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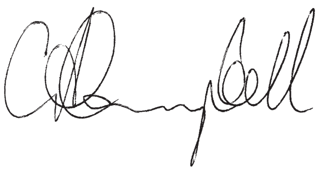
Foreword

It is widely recognised that Papua New Guinea (PNG) has livestock feed resources that are either unutilised or their use has been limited by variability in nutrient quality, high fibre content, anti-nutritional properties and unreliable supply. However some local feeds and by-products in PNG are currently being used to feed village poultry, pigs and inland pond fish.

In PNG in the last 10 years commercial livestock feed prices have increased by up to 110%. The high and rising cost of commercial feeds and the availability of a range of potential local feed resources including agro-industrial by-products has resulted in a considerable ACIAR research focus on use of local feeds to feed livestock and pond fish. The key strategy to mitigate the effects of the high cost of commercial feed is to substitute imported feed grains with locally available alternatives such as sweetpotato, cassava, coconut, banana, taro and agro-industrial by-products including copra meal, palm kernel meal, fishmeal, millrun and rice bran.

ACIAR has funded a number of projects in PNG that have focused on developing improved and lower cost feeding systems for smallholder semi-commercial and commercial poultry, pig and pond fish production that maximise the use of local feed ingredients. This research has led to, among other things, the development of concentrates for blending with local feed ingredients for broilers, layers, pigs and tilapia; adapting the ensiling technique to make sweetpotato and cassava silage to feed pigs; and the introduction of mini feed mills to enhance feed processing and manufacturing.

This monograph provides details of this research and its outcomes. The results presented will be a valuable addition to ACIAR's efforts to encourage greater use of local feed resources, to provide farmers with ways to produce more and healthy food, to create more jobs, and to increase real incomes of the estimated 600,000 smallholder livestock and aquaculture farmers in PNG.



Professor Andrew Campbell
Chief Executive Officer, ACIAR

Contents

Acknowledgments

The papers in this monograph are based on research carried out under the following ACIAR-funded projects:

- LPS/2001/077, 'Poultry feeding systems in PNG'
- ASEM/2005/094, 'Improving the profitability of village broiler production in PNG'
- ASEM/2010/053, 'Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea'

The project teams would like to thank the numerous partners involved with these projects, and especially the PNG and Australian scientists who have contributed to this monograph. Particular thanks go to Dr Workneh Ayalew and Dr Pikah Kohun from the PNG National Agricultural Research Institute and Dr Gariba Danbaro from PNG University of Technology for supporting PNG staff to write the papers, and Dr Caroline Lemerle and Dr Jayne Curnow from ACIAR for their encouragement to prepare the monograph. We are grateful to Robyn Henderson for organising publication of the monograph, Anne Moorhead for her rigorous and professional editing of the papers, and SARDI staff in the Pig and Poultry Science Group for their advice on papers.

The concentrate diets developed by Tony Carey have had a huge impact on lowering the costs of feeding pigs and poultry in PNG. The researchers are grateful for his wise counsel and his skills in formulating practical diets to feed village pigs and poultry using local ingredients.

During the preparation of this monograph Dr Ian Black (agricultural economist) passed away after a long illness. Ian developed the feed mill and enterprise models for pigs, poultry and aquaculture for use by PNG farmers, NGOs and institutes to predict the profitability of their enterprises. Ian was born in Rabaul, PNG, and was passionate about providing support for PNG colleagues with his skills in economic analysis.

Preface

Smallholder and semi-commercial aquaculture, pig and poultry farming are making an important contribution to the livelihoods of rural households in Papua New Guinea (PNG). The sector currently employs about 600,000 smallholder farmers and has a market value of around A$200m/annum, and it is growing as the demand for high-quality protein increases in the country.

Local feed resources are available that could be utilised better to feed fish, pigs and poultry. This monograph reports results on feeding trials with growing pigs, meat chickens, laying hens and tilapia using local feed resources blended with a concentrate produced by a mini-mill or a commercial feed mill. Recommendations on the most profitable feeding systems are highlighted, and papers on the socio-economic and market aspects that influence the uptake of feeding systems and adoption of mini-mills are included.

In the first section, overview papers set the scene by discussing the contribution of livestock and livestock research to development in PNG; the use of agro-industrial by-products for livestock feed; the technical and economic feasibility of using local feeds; the potential for using sweetpotato silage for feeding pigs; and chemical analysis of feed ingredients and feeds. The final three papers in the section cover additional research needs, and the challenges in formulating local feeds for pigs, poultry and fish in PNG.

In the second section, on the socio-economics of local feed production and use, the first three papers model cost and profitability of mini-mills and various village enterprises. The models show that the prices of mini-mill concentrates are highly competitive with concentrates offered by the large feed mills for the village broiler and layer industries. When these concentrates are mixed with sweetpotato or cassava to create a village enterprise feed, the combination is also thought to be highly competitive with the complete feed equivalent offered by the large feed mills and by companies that import feed directly from overseas. The fourth paper reports on a survey that investigated farmers' knowledge, attitudes and constraints to using mini-mills, finding that farmers had a very positive attitude towards the technology, but limited knowledge about the mill, and need training and support.

The remaining papers are separated into animal groups, focusing on the use of local feeds for pig, layer, broiler and fish production respectively.

Two papers report on pig production and husbandry systems in Morobe Province, finding that traditional extensive pig husbandry is evolving towards greater use of supplementary feeding, better housing, and external inputs such as formulated feeds, medicaments and tools for increasing production and investment returns. A third paper looks at pig performance when fed sweetpotato silage blended with high-energy and low-energy poultry concentrates, finding that the diets provide sufficient nutrition for good growth.

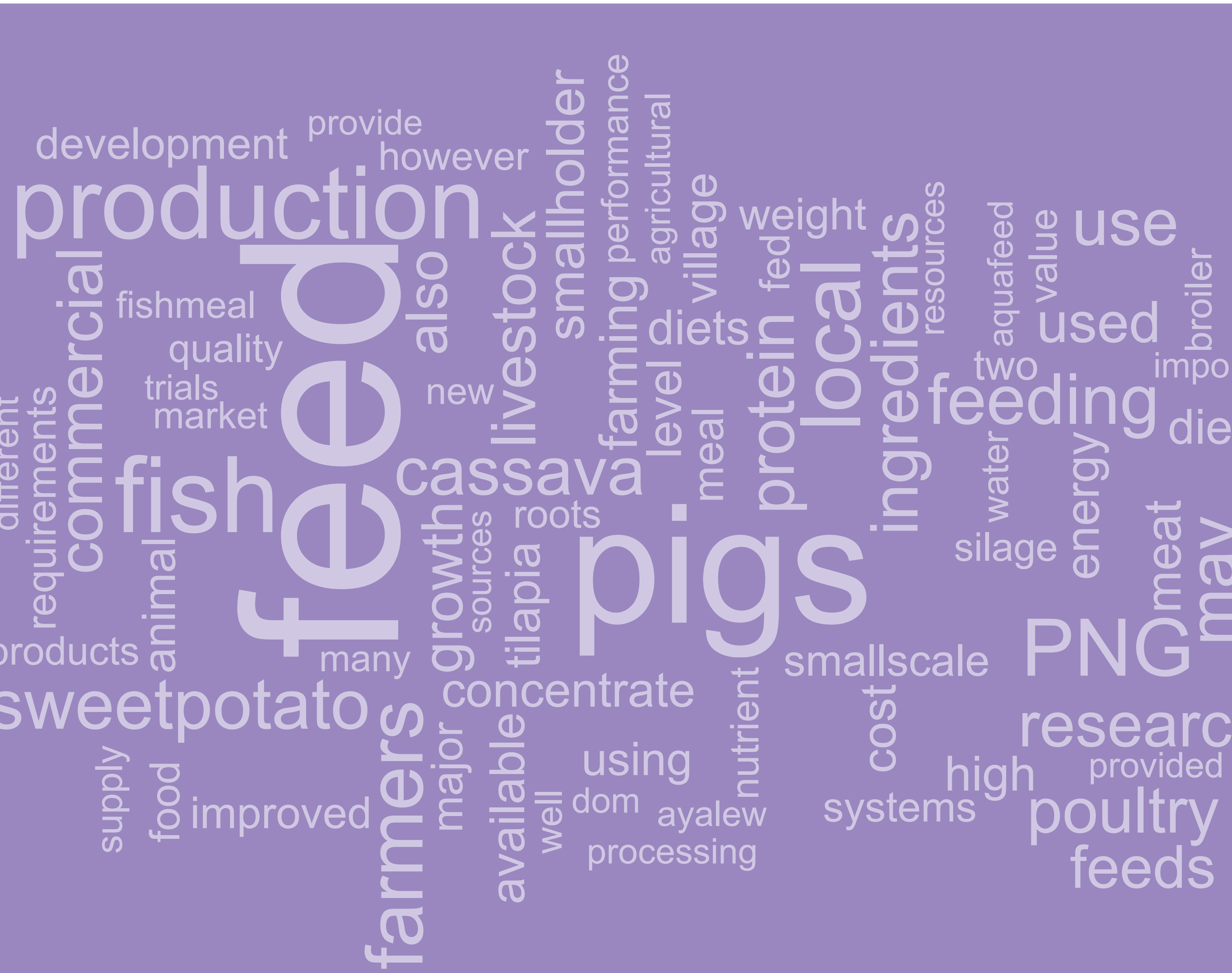
Six papers present results from layer feeding trials. Spent commercial layers, which are often purchased by smallholder farmers for a second period of egg production, are found to be productive on a local diet, which is much cheaper than commercial feed. Several papers compare egg production and egg quality of hens fed sweetpotato- and cassava-based diets blended with a protein concentrate with hens fed a standard layer commercial diet.

The results suggest that feeds containing the local feedstuffs can be used by farmers to produce eggs from both exotic and local chickens.

The following section reports similar feeding trials with broiler chickens. Feed formulations containing mashed or milled sweetpotato are compared and both are found to be appropriate for broiler growth; while rice bran is shown to be a suitable alternative energy source that can replace wheat and maize in a poultry diet. Diets with different proportions of cassava and sweetpotato are investigated in on-station and farmer trials, with positive results particularly at 50% inclusion. The final paper in this section describes a protein concentrate made at a mini-mill, and evaluated against concentrate made by the National Agricultural Research Institute. The paper reports good results with the mini-mill product, which may be especially useful in isolated parts of PNG.

Three papers on feed for tilapia comprise the final section of the monograph. The first evaluates broiler concentrate as a basis for fish food. Mixed with either sweetpotato or cassava, results were promising. The second paper examines the use of rice bran as an energy source in fish feed, again with positive results. The final paper evaluates a locally produced protein concentrate mixed with sweetpotato or cassava, and finds good growth rates of tilapia, as well as low cost compared with commercial fish feed.

1 Overview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The contribution of livestock and livestock research to development in Papua New Guinea

Michael Dom[1] *and Janet Pandi*[2]

Abstract

Prospects for livestock farmers in Papua New Guinea (PNG) are extremely good, due to the mineral and energy resources boom and an increasingly affluent urban population demanding more animal protein as meat, milk and eggs. This will create opportunities for local primary production. The goal of livestock research and development is to revitalise and expand the livestock and apiculture industries to improve the welfare and livelihoods of rural communities and to contribute to the general economy of the country. Two innovations in animal feed science and technology are especially promising for PNG's smallholder livestock systems: (1) ensiling sweetpotato for pig feeding; and (2) low/high energy broiler feed formulations that combine sweetpotato and cassava with protein concentrate. This bodes well for at least 580,000 small-scale pig and poultry farmers and a further three to six million household members who are supported by rural farming activities.

INTRODUCTION

Subsistence and smallholder agricultural production in Papua New Guinea, practised by at least 580,000 small-scale pig and poultry farmers and supporting a further three to six million household members, consists of mixed crop–livestock systems. These traditional low-input systems are relatively flexible to household demands, and the capacity of family members to provide the needed labour for farming available land. The smallholder farming sector is growing rapidly, in line with overall development and an ever-increasing population. This is despite a decreasing availability of arable land at household level, environmental challenges, and local and global economic changes. The livestock subsector is an important contributor to the development of the Papua New Guinea (PNG) agricultural economy (Moat 2012).

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There is a recognised shortfall in the supply of meat, milk and eggs for both urban and rural populations in PNG, and the country is a net importer of these products. Pork and chicken are the two most popular meat proteins in the diets of most urban and rural people, and the demand for pork and chicken meat and eggs is growing faster than can be supplied by local commercial farms. This provides an opportunity for PNG's smallholder livestock farmers to capitalise on this growth in demand, supported by timely and appropriate agricultural technologies.

The PNG government recognises that subsistence agriculture play a critical role in enhancing rural livelihoods and culture, and that opportunities exist in food production, namely vegetables and fresh meat, for the domestic market (NSPTF 2009). It also admits that how to do this remains a challenge (Dom and Pandi 2011).

This paper presents two livestock feeding technologies for pigs and poultry, released by the National Agricultural Research Institute (NARI), that have the potential to revitalise PNG's smallholder and subsistence agricultural systems. The major challenge of farming pigs and poultry is providing animals with the appropriate nutritional feed that gives good growth performance and economic productivity. The two innovative feeding technologies—ensiling sweetpotato for pig feeding, and low/high energy broiler feed formulations that combine sweetpotato and cassava with protein concentrate—are resource-efficient and cost-effective means of improving productivity among small-scale, semi-commercial and even commercial farms.

THE CONTRIBUTION OF AGRICULTURE TO PNG DEVELOPMENT

Livestock contributes around 12.9% of global calories and 27.9% of protein through provision of meat, milk, eggs and offal, and also contributes to crop production through the provision of transport and manure (FAO 2011). In addition, livestock contributes to farmer wealth and in many countries, including PNG, animals serve the socio-cultural needs of farming communities. FAO reports that, driven exclusively by gains in poultry and pig meat production, global meat output is set to expand by nearly 2% to 302 million tonnes in 2012, and most of the sector's growth is likely to be in developing countries. This global trend has implications on PNG's food security and income generation by subsistence farmers and smallholders.

Put simply, food security is about people having enough nutritious food to eat on a day-to-day basis; particularly important is having adequate protein in the diet. Today, the population of PNG is over 7 million, and with an average annual growth of 3.2% per annum (NSO 2002), there is an urgent need to enhance the productivity and resilience of agricultural systems if we intend to feed an additional 8 million people by 2050. It is unrealistic to assume that the traditional Melanesian safety net of village life and subsistence agriculture will continue to provide for both the household income and food security needs of these future Papua New Guineans.

Agriculture contributes to achieving PNG development targets under four broad areas (Figure 1). The agriculture sector directly affects food security, income generation, employment and sustainable resource use. The National Agriculture Development Plan (NADP) defines the government's sectoral priorities for agriculture (Moat 2012). The vision of NADP is sustainable transformation of the country's agriculture sector into a vibrant and productive economic sector that contributes to economic growth, social wellbeing, national food security and poverty alleviation (MoAL 2009). The targets in this area are defined by real per capita gross domestic product and an improvement in PNG's score on the Human Development Index (HDI; NSPTF 2009; Table 1).

The 2050 targets are to more than double the GDP per capita by 2030 and 2050, and to move PNG up the HDI from 148 in 2010 to 98 by 2030 and 50 by 2050 (Table 1). These are high targets, but with current and future gas and mineral resource developments bringing in much-needed revenue, there is great potential for these targets to be achieved.

THE ROLE OF LIVESTOCK RESEARCH AND DEVELOPMENT

The goal of livestock research and development is to revitalise and expand the livestock and apiculture industries to improve the welfare and livelihoods of rural communities and to contribute to the general economy of the country (MoAL 2009). As the mandated research organisation for smallholder agriculture, NARI contributes directly towards achieving the second objective of the NADP, which is to improve livestock production, processing and marketing (MoAL 2009).

NARI's strategic objective is to enhance productivity, efficiency and stability of agricultural systems (NARI 2011). Under the subprogram objective of effectively integrated crops, livestock and aquaculture for smallholder farmers, two major research projects have delivered improved feeding systems for pigs and poultry in 2010 and 2011. These two feeding technologies make full use of sweetpotato and cassava as major components of feed for pigs and poultry, replacing commercial feeds and thereby lowering costs of feed at the farm level.

Pigs and poultry are by far the most favoured meat protein sources in PNG, while demand for fish from inland fish farming is also on the rise. Total livestock production in PNG is estimated at some 57,000 tonnes per year (Bourke and Harwood 2009) with pig and poultry products making up 95% of production. Based on indicative figures of the 2000 PNG National

Census (NSO 2002), half of rural households and 10% of urban households in PNG are engaged in some kind of livestock production. This includes about 360,000 pig farmers, 220,000 poultry farmers and 20,000 fish farmers (Ayalew 2011).

Gibson (2001) estimated the total value of household agricultural production in PNG was 1.3 to 1.6 billion kina per annum. This provides 80% of calories, with sweetpotato the major contributor at 65% of total calorie intake. Pigs and poultry contribute at least 3% of the total calorie intake in PNG, but this figure may be very inaccurate given the lack of recent data (Gibson 2001). Quartermain (2001) foresees growth at 5% per annum for production of meat

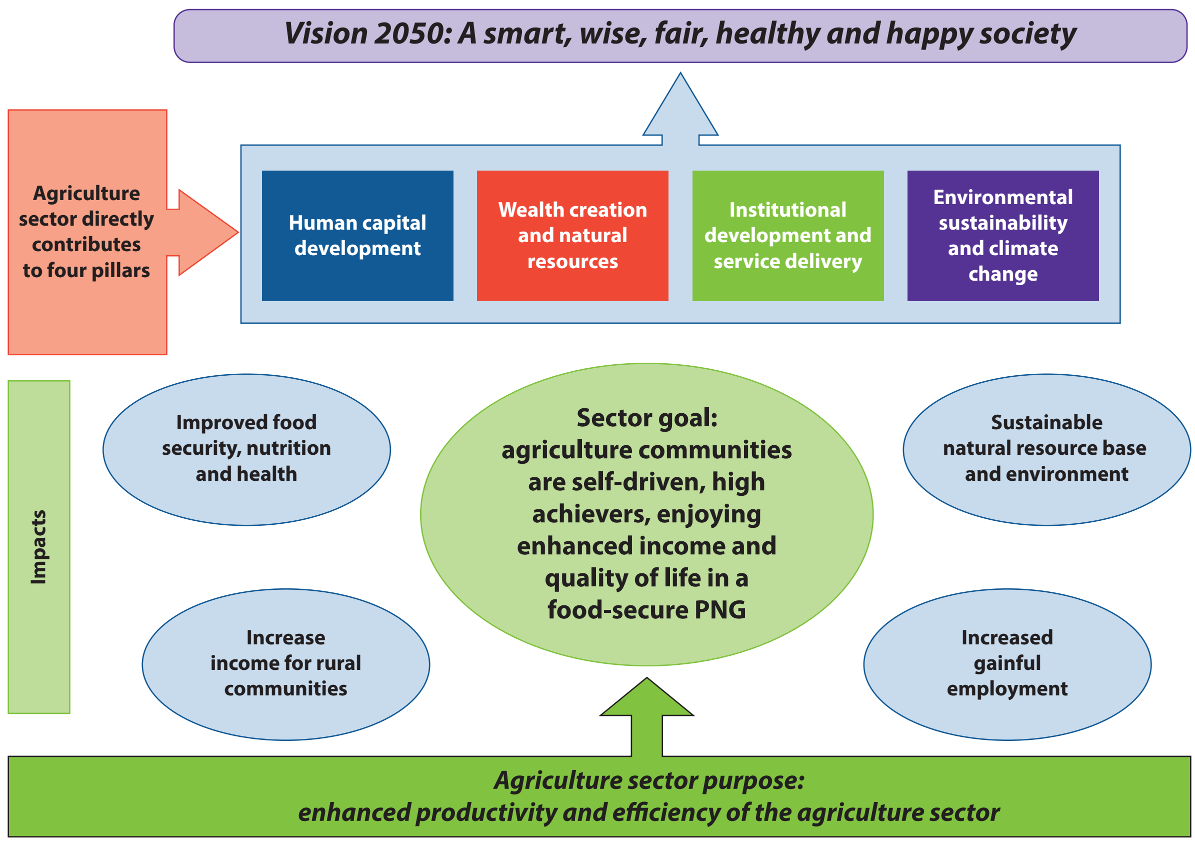

Figure 1. Linkage of the PNG agriculture plan to the National Vision 2050. Source: Moat (2012).

Table 1. Strategic goals for PNG National Vision 2050.

Year	Human Development Index score	Life expectancy (years)	Real per capita GDP (kina)	Adult literacy rate (%)	Basic education gross enrolment (%)
2010	148	58.0	1,919.8	58	85.5
2020	123	63.0	2,744.4	70	90.0
2030	98	68.0	3,663.5	80	96.5
2040	73	72.0	6,178.6	90	98.0
2050	50	77.0	10,420.5	100	100.0

Source: NSPTF (2009).

for household consumption commensurate with a population growth of 2.0–2.5% per year and continued increasing affluence. With the recent explosion of resource development in PNG this estimate requires urgent review.

Expansion and sustainability of the smallholder livestock farming subsector is dependent on encouraging more people to go into broiler bird and grower pig production through providing support with critical inputs, such as lowered feed cost, animal health services and regular extension contact, thereby making it attractive and profitable (Dom and Pandi 2011).

In a paper presented at the Food Security Policy Conference on High Food Prices in PNG in 2011, Ayalew (2011) pointed out that improved pig and poultry feeding technologies contribute to improved food security at household level by:

1. Enhancing use of local feed resources as partial substitutes to imported grains, thereby significantly reducing the cost of feeding;
2. Opening up viable value addition opportunities for garden produce, as sweetpotato and cassava can also be marketed to support livestock production;
3. Encouraging localised marketing of forage and fodder for livestock feed, as is already happening in the highlands;
4. Creating employment opportunities for household members who can work part or full time preparing these local livestock feeds; and
5. Enhancing total farm production and sustainability, for example, manure is an efficient organic fertiliser to return nutrients back to the soil.

Sweetpotato silage for feeding pigs, and high- and low-energy poultry protein concentrates, were two livestock feeding technologies delivered to the public at the annual agricultural innovations show hosted by NARI. The improved feed technologies have had great appeal to individual farmers and farming communities in different rural settings across the country. Project activities—including on-station and on-farm research trials, out-grower feeding trials, mini-mill development and training and technology demonstrations—have taken place in Morobe, Eastern Highlands, Jiwaka, Western Highlands, Western and East New Britain Provinces.

A BRIEF DESCRIPTION OF THE IMPROVED ANIMAL FEED TECHNOLOGIES

Sweetpotato silage for storing and feeding to pigs

Smallholder and village farmers predominantly maintain their pigs on sweetpotato and cassava, both of which are very suitable sources of dietary energy in animal feed, provided that the starchy roots are cooked (Dom and Pandi 2011). Ensiled sweetpotato forage was tested as a feed preservation technique to provide nutritious, highly digestible (fermented) feed, maximise the use of tuber and vine, reduce the labour in daily pig-feeding chores (especially for women) and eliminate the use of cooking fuel (Dom and Ayalew 2009).

Dom and Ayalew (2010) showed that while the growth performance of crossbred pigs fed mixed sweetpotato silage diets was significantly lower than those fed on commercial grower pig ration in terms of daily gain and body weight gain, the sweetpotato silage made locally resulted in improved unit carcass sale prices in both formal and informal markets (Table 2). They further pointed out that the improved carcass quality delivers a premium price on pork meat cuts. More importantly, unit price on live weight gain offered incrementally improved returns on costs of raising growing pigs to slaughter weight.

High- and low-energy broiler concentrate feeds

Sweetpotato and cassava were combined with broiler finisher concentrates as complementary sources of higher and lower energy, respectively. The formulated diets met the critical dietary requirement of high metabolisable energy, providing values as high as 15.39 MJ/kg and 15.87 MJ/kg for sweetpotato and cassava, respectively. These values were higher than the standard commercial finisher diet, which in this case was 11.30 MJ/kg (Dom and Pandi 2011). Broiler bird performances on the sweetpotato and cassava diets were not significantly different to those on the standard finisher ration (Dom and Pandi 2011; Table 3). Furthermore, farmer evaluation trials showed that overall performance of broilers on the cassava/high-energy diet and sweetpotato/low-energy diet were very good, as birds were able to attain target market weight of over 2 kg from week five (Pandi et al. 2017).

A very important outcome of this research was providing proof that the sweetpotato/low-energy diet compared very well with the commercial finisher pellet. This led to Niugini Tablebirds Ltd manufacturing two protein concentrate mixtures, for blending with either sweetpotato or cassava, to provide an energetically and nutritionally effective finisher ration (Dom and Pandi 2011). Additionally, the broiler concentrate is appropriate for feeding pigs and fish in appropriately formulated rations. This is being investigated further in ongoing research.

Table 2. Growth performance, carcass measures and economic returns for grower pigs fed three test diets in low- and high-altitude locations at Labu Station, Morobe and Tambul District, respectively.

Diet	DMI (g/day)	ADG (g/day)	FCR	Carcass weight (kg)	Carcass yield (%)	Back fat depth (mm)	Sale value (kina)*	Unit price on live weight (kina/kg)
Low-altitude trial (on-station)								
STD	1694	730	2.33	48	70.6	22.28	322	4.74
SPctfv	1553	502	3.09	37	72.5	13.19	259	5.08
SPS	1190	540	2.21	45	76.3	10.2	315	5.34
High-altitude trial (on-farm)								
STD	1886	592	3.18	50	66.7	30.0	350	4.67
FFO	1145	368	3.10	48	77.4	24.7	336	5.42
SPS	1329	398	3.33	48	78.7	15.7	336	5.51

* Based on a wholesale/abattoir price of 7.00 kina per kilogram of frozen fresh carcass.
STD = standard commercial pig grower diet; SPctfv = sweetpotato cooked tubers and fresh vine; SPS = sweetpotato silage; SPS and SPctfv are test diets of mixed rations with pig grower; FFO = farm feed only, which was SPS combined with fishmeal and copra meal; DMI = dry matter intake; ADG = average daily gain; FCR = feed conversion ratio.
Source: adapted from Dom and Ayalew (2010).

Table 3. Summary of production of broiler birds from day 21 to 28 collated from three apparent metabolisable energy bioassays in 2003.

Feed source	Weight gain/bird/day (g)	Daily intake/bird (g)	Feed conversion ratio (FCR)
Sweetpotato tuber	38.1^{d}	$82.4^{b,c}$	2.2^{c}
Cassava root	$41.4^{c,d}$	79.5^{c}	$2.0^{c,d}$
Sago	34.1^{d}	76.1^{c}	2.3^{c}
Wheat	$53.0^{b,c}$	87.6^{b}	1.7^{d}
Sorghum	48.0^{c}	85.0^{b}	1.8^{d}
Soybean	$54.0^{b,c}$	$83.3^{b,c}$	$1.5^{d,c}$
Copra meal	36.5^{d}	76.6^{c}	2.2^{c}
Pyrethrum marc	35.5^{d}	75.4^{c}	2.2^{c}
Flame broiler starter	39.0^{d}	92.6^{b}	$2.0^{c,d}$
Flame broiler finisher	$44.3^{c,d}$	85.4^{b}	1.7^{d}

Means with the same superscript within the same column are not significantly different ($P > 0.05$) from each other.
Source: Glatz (2007).

CONCLUSION

PNG's medium-term development strategy envisions a world-class agricultural sector that is responsive to international and domestic markets for a diverse range of products and provides the best available income and job opportunities, providing "high quality of life for all Papua New Guineans" and for "PNG to be a prosperous middle income-earning country".

By current estimates, 600,000 farmers are actively involved in smallholder livestock production in PNG. They operate in challenging business environments, despite the potential for expansion. Given the current rate of population growth and demand from more affluent consumers, livestock production may need to at least triple to meet development targets. Increased importation of meat and eggs may not be a viable option, and indeed this option is rejected by major stakeholders in the livestock sector. Therefore, the authors advocate for PNG to be more proactive in developing its smallholder agriculture and livestock sector, by taking advantage of outputs from research and development, and by creating and/or implementing appropriate enabling policies and national development plans.

While NARI and other agriculture stakeholders will continue their efforts towards the defined targets of Vision 2050 through their respective sector plans, it is paramount that future government budgets focus on enabling the most productive use of limited land, available labour and local business interests. It is the authors' firm belief that, with the appropriate support and incentives, smallholder agriculture can become a vehicle for moving PNG towards real advances in development. This potential has been demonstrated by the improved animal feed technologies that have shown promise in revitalising livestock production at small scale level in a number of rural communities.

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Agro-industrial by-products for livestock feed in Papua New Guinea: an overview

Pikah Kohun[1], Workneh Ayalew[2] and Phil Glatz[3]*

Abstract

The high and rising cost of commercial feeds formulated from imported ingredients is the major constraint to livestock production, development and expansion in Papua New Guinea (PNG). This presents a strong economic imperative to maximise the use of local agro-industrial by-products as livestock feed to substitute for expensive imported ingredients, such as cereal grains and soybean meal. Major constraints to effective use of by-products are their limited availability, known anti-nutritional factors and perishability. Collaborative research and development with relevant industry groups will lead to ways of processing and packaging by-products so as to maintain their feeding and nutritional value, and convert them into more balanced rations to supply local commercial livestock farms. More effective and efficient utilisation of agro-industrial by-products will contribute to sustainable livestock feeding systems through reduced feeding costs and value addition which benefits producers and end users. Millrun, palm kernel meal, copra meal, fishmeal, rice bran, poultry offal meal and sugarcane molasses are the major agro-industrial by-products in PNG in terms of quantities. Most of the copra and palm kernel meal, and some of the fishmeal, are exported overseas as stock feed, while millrun and rice bran are all absorbed within the local feed milling industry. Appropriate policies are needed to regulate overseas sales, local access and prices. In addition, a subsidised price for smallholder farmers would encourage greater use of the by-products in livestock feeding.

INTRODUCTION

Conversion of agro-industrial by-products to animal feed adds value to the feed as an energy or protein source, reduces feed cost, and reduces competition with human food as feed. There is much interest in this work in developing countries, including countries in the Pacific (Ravindran 1991, 1992, 2012), and there is willingness by international donors to provide financial and technical support for research and development of these by-products into low-cost livestock feed. A number of by-products are available in Pacific countries (ALFID 2002; FAO 2012) and these could be utilised more effectively for feeding poultry in particular, as well as pigs and inland pond fish. Glatz (2012) noted that Pacific countries have feed resources that are either unutilised and wasted or used inefficiently. While most of these alternative feeds have potential, their use has been limited by variability in nutrient quality, high fibre content, anti-nutritional properties and unreliable supply.

Papua New Guinea (PNG) produces a range of agro-industrial by-products from crop and animal sources which could be more effectively and efficiently utilised. Research and development opportunities exist, and can be further explored, to add value to these by-products to maximise their utilisation in low-cost smallholder livestock feeding and possibly also commercial feed manufacturing. The lack of appropriate national policies designed to support easier access, lower prices and greater utilisation of these by-products by smallholder farmers is a major constraint. This has resulted in the continued rising cost of commercial feed based on imported ingredients; high cost of pork, chicken meat and eggs; narrowed profit margins; and import of cheap chicken meat,

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some of which is uncooked and poses a high risk to the local poultry industry (Ayalew 2011) and wildlife.

AGRO-INDUSTRIAL BY-PRODUCTS IN PNG

There is a wide range of agro-industrial by-products in PNG from poultry, beef and fish canneries, and copra, oil palm, sugarcane, coffee and cocoa processing, but they are mostly underutilised in livestock feeding (Kohun 2004). The major agro-industrial by-products in terms of quantities are millrun, palm kernel meal, copra meal, fishmeal, rice bran, poultry offal meal and sugarcane molasses. Figure 1 shows the location of these major by-products, and Table 1 shows that their combined estimated economic worth is over 96.8 million kina per year. The by-products are being used as ingredients in formulated stock feed (millrun, copra mill, palm kernel meal and fishmeal), as supplementary livestock feed at commercial and smallholder farms (copra meal, millrun, molasses, palm kernel meal and fishmeal) or are being exported as primary products. More recently, an increased volume of fishmeal is being used in the local feed mills to produce stock feed, though one company exports 70% of its product to Australia, Sri Lanka and Vietnam. Most of the palm kernel meal and 80% of the copra meal are exported for cattle and horse feed to Australia and New Zealand.

It is projected that quantities of oil palm kernel meal and fishmeal will significantly increase in PNG in the years ahead as a result of planned expansion of the oil palm and fish canning industries. Development in oil palm includes expansion of existing plantations as well as new areas in the Ramu Valley, Autonomous Region of Bougainville and the Sepik Plains. For fishmeal production, there are plans for two more tuna fish canneries in Lae (Nambawan Seafoods and Zhejiang Zhenyang Group) to join International Food

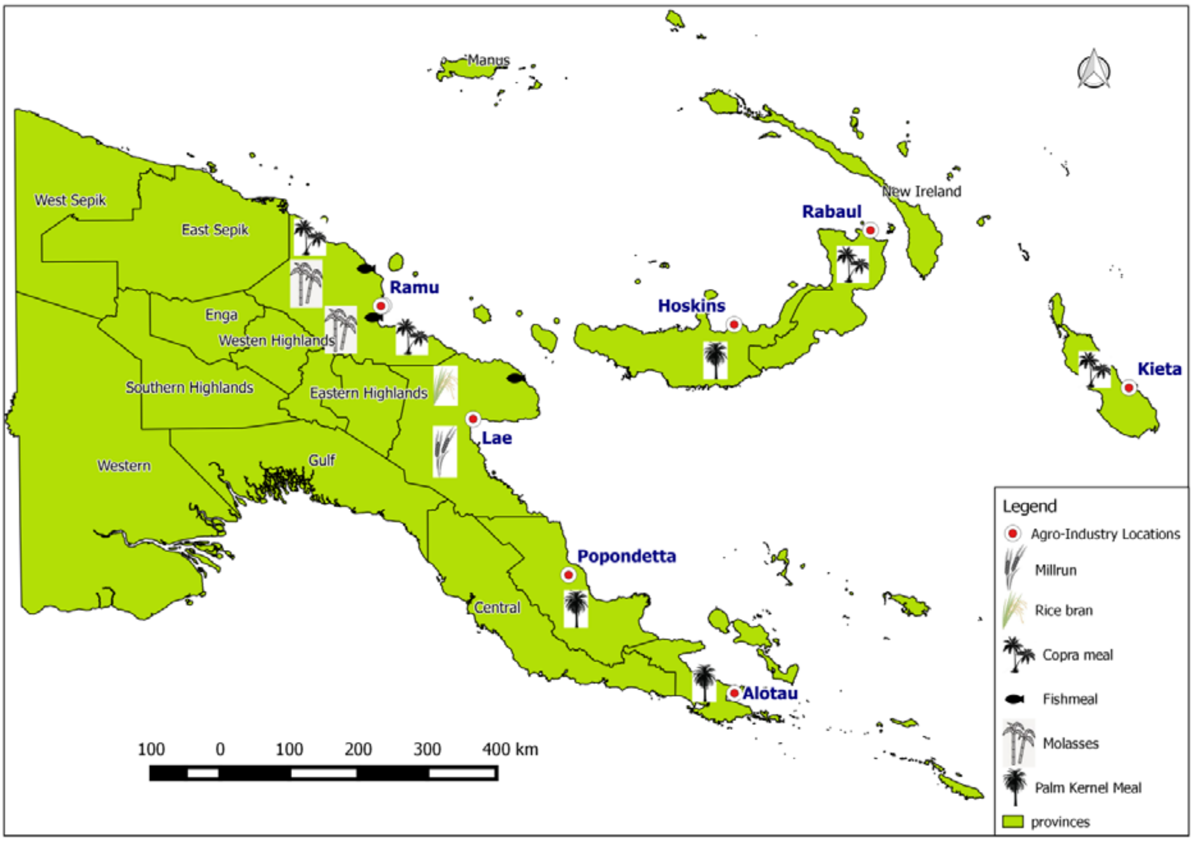

Figure 1. Location of agro-industrial by-products in PNG.

Table 1. Major agro-industrial by-products in PNG that can be used for feeding livestock.

By-product*	Estimated annual volume (tonnes)	Estimated value on site (million kina)	Projected supply
Millrun	33,000	24.8	Constant
Palm kernel meal	23,000	3.9	Increase
Copra meal	20,000	40.6	Constant
Fishmeal	8,000	20.9	Increase
Molasses	12,155	6.6	Constant
Total	96,155	96.8	

* Data are not available for poultry offal meal and rice bran, both of which are considered important feed resources.

Corporation, Century Canning and Frabelle which are already in operation. A tuna loining factory is also planned for Wewak in the near future.

While most of the copra and palm kernel meal and some of the fishmeal are exported overseas as stock feed, millrun and rice bran are all absorbed within the local feed milling industry. From the sugar industry, molasses is available but bagasse is all utilised in generating steam to power the sugar factory. If more of these by-products were available locally and at reasonable cost, they could be used by smallholder farmers in livestock feeding. Appropriate policies are needed to regulate overseas sales, local access and prices. A subsidised price for smallholder farmers would also encourage greater use of the by-products in livestock feeding.

RATIONALE FOR MAXIMISING USE OF BY-PRODUCTS IN LIVESTOCK FEEDING

The high and rising cost of commercial feeds (formulated from imported ingredients such as wheat, sorghum and soybean) and feed supplements is the major constraint to livestock production, development and expansion faced by smallholder semi-commercial and commercial poultry and pig farmers in PNG. The increase in global market prices of these essential feed grains has led to the high cost of commercial feeds, and in the last 10 years local feed prices have increased by 56–110% (Ayalew 2011). As a consequence, prices of animal food products have increased and profit margins have narrowed, especially in poultry and pig production. In light of the high and rising cost of commercial livestock rations, there is a strong economic imperative to maximise the use of local by-products as livestock feed to substitute expensive imported ingredients such as cereal grains and soybean meal.

Interest in reducing livestock feed cost by making more effective use of local feeds and by-products goes back many years. In 1982 and 1983, two national conferences were held to address how crop by-products can best be utilised, including as livestock feed. Despite these initiatives, and some promising research results from poultry feeding trials at Labu and pig feeding trials at Goroka and Tari carried out by the Department of Agriculture and Livestock (e.g. Springhall 1964; Springhall and Ross 1965a, b; Malynicz 1971, 1974; Rose and White 1980; Ranaweera and Nano 1981; Nano et al. 1986), the utilisation of by-products in livestock feeding has been minimal and has received little attention from relevant authorities. Up to now, there is no policy in place to guide or control the sale, price and use of by-products or other incentives to encourage their use by farmers in livestock feeding. There are, however, some farmers who use them when the opportunity arises.

RESEARCH ON USE OF LOCAL FEEDS AND BY-PRODUCTS AS LIVESTOCK FEED

The National Agricultural Research Institute (NARI) has placed high priority on research into the use of local feeds and by-products. In 2001, NARI conducted a preliminary survey of agro-industrial by-products and crop and livestock wastes in Morobe and Madang provinces in order to collect baseline information on the type, volume and use of some of these by-products. Agro-industrial by-products have been used extensively to feed livestock but mainly as sole supplementary feeds or in combination with other such feeds but without ensuring nutritionally balanced rations that support efficient production and reproduction of livestock. NARI research indicates that by-products can constitute a significant proportion of effective balanced diets of broiler chickens, layer chickens, pigs and even tilapia fish. Furthermore, major cost savings can be made by using the correct combinations of these local feed resources.

With funding support from ACIAR, NARI has been leading research into the development of alternative feeding systems for livestock, particularly for poultry (Ignatius and Quartermain 2002; Pandi 2005; Glatz 2007; Pandi et al. 2017; Besari et al. 2017) and more recently for pigs (Dom and Ayalew 2009a, b; Dom and Ayalew 2010; Dom et al. 2010) and inland pond fish (Sine et al. 2017). This research is developing the technologies and the knowledge and skills of farmers to use more of these by-products in the right combination with their local feed sources to produce a more balanced ration for their livestock. Opportunities exist for industries which produce these by-products, or other aspiring entrepreneurs, to develop ways to add value to the by-products for their use as major feed ingredients and to produce lower cost livestock feed.

SOME CONSTRAINTS TO USE OF BY-PRODUCTS IN LIVESTOCK FEED

One major constraint is that the by-products are available only in certain locations or are exported. Where they are available, indications suggest that farmers are not using them effectively either because there is a cost in transportation or there is a lack of knowledge and experience in feed formulation. Another important issue is that there are known anti-nutritional factors that limit the use of by-products in combination with other feeds. Also, some of the by-products are perishable and need to be properly processed and stored at the right temperature to minimise losses. Finally, understanding of the potential of these by-products needs to be changed as this is limiting their use.

ADDING VALUE TO BY-PRODUCTS TO MAXIMISE USE IN LIVESTOCK FEEDING

NARI has recently initiated collaboration with companies that produce the main agro-industrial by-products to explore opportunities for value addition. In particular, NARI is investigating how agro-industrial by-products can be more effectively and efficiently used in sustainable livestock feeding systems to reduce feeding costs, and how value can be added to the by-products to benefit producers and end users. Collaborative research and development will lead to ways of processing and packaging the by-products so as to maintain their feeding and nutritional value and convert them into more balanced rations to supply local commercial livestock farms.

CONCLUSION

The high and rising cost of commercial feed based on imported ingredients is the major constraint to smallholder livestock production. The key strategy to mitigate this is to substitute imported feed grains with locally available alternatives. Agro-industrial by-products are an important local source of feed resources and their effective utilisation, particularly in poultry, pig and pond fish diets, will lead to more affordable livestock feed for smallholder farmers. Many farmers have been trained to use some by-products in diet formulation, but access and cost of the by-products remain a major problem. There is a need for policies that regulate the sale of these by-products overseas so that sufficient quantities are available locally for use in the livestock industry. Policies are also required to regulate access, prices and other costs in order to maximise benefits to farmers. It is imperative that major investments be made in research and development to add value to these by-products as livestock feed, and in the process create employment and wealth for Papua New Guineans.

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Feasibility of farming poultry, pigs and fish using local feeds in Papua New Guinea

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Abstract

Poultry and pigs are major sources of animal protein in Papua New Guinea and consumption is rising. Although imported meat and eggs provide cheap products in urban centres, there is an opportunity for local farmers to sell livestock products to growing markets. Inland fish farming is increasing in many parts of the country and also has high potential to provide cheap household protein and income. Feed is the major cost in livestock farming, and projects at the National Agricultural Research Institute are researching appropriate cost-effective nutrition for different types of livestock. This paper reports that using the major local crops sweetpotato and cassava to feed pigs, poultry and fish is technically and economically feasible, provided the feed rations are formulated with other ingredients to balance essential amino acids and micronutrients which are lacking in these root crops. Practical experience and economic information available on value chains which supply feed to farms and food from farm to fork suggest that small-scale production of feed and livestock may be more competitive at district or provincial levels than at large-scale enterprise levels. Experience in village and peri-urban farm settings has demonstrated that local pig and poultry production may become more profitable when producers have access to facilities such as mini-mills, local slaughter houses, transport services, and packaging and freezer operators. Experience at community-run mini-mills demonstrated that small-scale feed production was feasible within limitations determined by market and socio-economic constraints.

INTRODUCTION

Sweetpotato and cassava are globally important root and tuber crops that play a significant role in maintaining food security, enhancing human nutrition and providing income-earning or cost-saving opportunities as well as mitigating the risks of climate change to smallholder mixed crop–livestock farmers (FAO 2011). The two crops are important staple foods for smallholder farming households in developing countries of Africa, Asia, South-East Asia and the Pacific, and their use as a livestock feed has increased in recent times (Scott et al. 2000). In Papua New Guinea (PNG), the traditional dual-purpose use of sweetpotato and cassava is an advantage to village and smallholder farmers producing poultry, pigs and fish, where excess harvest and waste forage provide a relatively cheap feed resource to produce valuable food protein as meat and eggs (Ayalew 2011).

Ongoing research at the PNG National Agricultural Research Institute (NARI), under the mandate to promote smallholder farming, aims

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to adapt existing and develop new methods of production, storage and processing of sweetpotato and cassava for human food and animal feed. Sweetpotato and cassava are valuable garden crops for the majority of village farmers (Bourke and Vlassak 2004; Bourke and Harwood 2009) and real economic gains may be achieved by the efficient processing of these perishable crops into, for example, flour, starch, dried chips, and milled and preserved feed, in addition to the existing local market for fresh produce. However, there is a recognised need to enhance production and supply chains and establish economies of scale based on household and smallholder objectives, together with the development of an appropriate agricultural development rationale (Moat 2012).

Feed is the major cost in livestock farming, and providing appropriate cost-effective nutrition for different types of livestock is a technical challenge being addressed by a major collaborative project (ASEM/2010/053: Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea) between NARI, the South Australian Research and Development Institute (SARDI) and the Australian Centre for International Agricultural Research (ACIAR). Poultry and pigs are two major sources of animal protein in PNG and consumption is rising (Gibson 2001). While imported meat and eggs provide cheaper products at urban centres, there is also an opportunity for local farmers to sell livestock products to growing markets. In addition, inland fish farming is increasing in popularity in many parts of the country and is providing a cheap source of household protein and cash income.

This paper summarises some of the key lessons learned from the research project. Experimental and farm-based trial results indicate possible outcomes, and technical, practical and economic advantages and disadvantages of using sweetpotato and cassava under PNG's predominantly small-scale agricultural food–feed production and supply chains are outlined. It is anticipated that increased utilisation of the root and tuber crops will be an advantage to current local production systems by diversifying and sustaining their marketability as food and feed products. This will deliver a collective gain for village farming households, smallholder farms and small to medium enterprises supplying agricultural needs, feeds and foodstuffs.

FEED VALUE OF SWEETPOTATO AND CASSAVA FOR POULTRY

Apparent metabolisable energy

Sweetpotato and cassava were combined with broiler finisher concentrates as complementary energy sources of high and low energy, respectively. The formulated diets met the critical dietary requirement of metabolisable energy (ME), providing values as high as 15.39 MJ/kg and 15.87 MJ/kg for sweetpotato and cassava, respectively (Table 1). These ME values were higher than standard commercial finisher diets, which in this case was 11.30 MJ/kg (Dom and Pandi 2011). The nutritional specification for finishing broilers of the Ross 308 strain is 13.40 MJ/kg. Broiler bird performances on the sweetpotato and cassava diets were not significantly different to those on the standard finisher rations. Broiler birds attained the target market weight of over 2 kg from week five (Pandi et al. 2017), two weeks short of the expected growing period. Therefore, sweetpotato and cassava may be used as alternative energy sources for finishing broilers, replacing cereal grains.

Growth and feed conversion

Farmer evaluation trials showed that the daily weight gain and feed conversion ratio (FCR) of Ross 308 broiler birds fed 50% cassava (50 CASS + 50 HEC) and 50% sweetpotato (50 SP + 50 LEC) diets were not different to birds fed a control broiler finisher feed (Table 2). The results confirmed that birds fed sweetpotato and cassava blended with low- and high-energy concentrates converted feed efficiently and were able to reach market weight of 2 kg or more at 42 days of age. Based on these results, sweetpotato and cassava are promoted as cost-effective potential energy sources for finishing off broiler chickens.

The implications of good broiler bird performance on locally made feeds extend to raising dual-purpose meat and egg-laying birds (e.g. Australorps, village chickens and their crossbreeds). The deciding factors appear to be the market popularity of the type of bird and the meat quality characteristics they develop. For example, most Asian consumers prefer village chicken-type birds, while at Finschaafen and a number of highlands trial locations, farmers and consumers were more impressed by the meat quality and yellow shanks in birds that result from carotenoids in copra meal included in the diet (F. Besari, pers. comm.). Local feeds may therefore not only reduce costs of feeding, but also improve the marketability of stock to producer preference and consumer taste.

FEED VALUE OF SWEETPOTATO AND CASSAVA FOR PIGS

Digestibility of nutrients

Sweetpotato and cassava roots and foliage have been well studied when fed to pigs in raw form (Rose

Table 1. Summary of apparent metabolisable energy values of feed from different sources, and broiler production data from day 21 to 28.

Feed source	AME of feed (MJ/kg)	Weight gain/bird/day (g)	Daily intake/bird (g)	FCR
Sweetpotato root	15.39	38.1[d]	82.4[b,c]	2.2[c]
Cassava root	15.87	41.4[c,d]	79.5[c]	2.0[c,d]
Sago	15.02	34.1[d]	76.1[c]	2.3[c]
Wheat	12.63	53.0[b,c]	87.6[b]	1.7[d]
Sorghum	12.76	48.0[c]	85.0[b]	1.8[d]
Soybean	10.82	54.0[b,c]	83.3[b,c]	1.5[d,c]
Copra meal	15.01	36.5[d]	76.6[c]	2.2[c]
Pyrethrum marc	13.63	35.5[d]	75.4[c]	2.2[c]
Flame broiler starter	11.06	39.0[d]	92.6[b]	2.0[c,d]
Flame broiler finisher	11.30	44.3[c,d]	85.4[b]	1.7[d]

AME = apparent metabolisable energy; FCR = feed conversion ratio.
Means with the same superscript within a variable are not significantly different ($P > 0.05$) from each other.
Source: adapted from Glatz (2007).

Table 2. Growth performance of Ross 308 broiler birds on finisher phase (days 21 to 42) fed blended diets of sweetpotato and cassava with low-energy (LE) and high-energy (HE) concentrates.

Parameter	Treatment means				$F_{pr.}$	CV (%)
	Control	50 SP + 50 LEC	50 CASS + 50 HEC	70 SP + 30 LEC		
Lowlands broiler feed trial						
Body weight (kg)	2.72[a]	2.34[b]	2.38[b]	1.79[c]	0.001	3.1
Weight gain* (kg)	0.712[a]	0.54[a,b]	0.52[a,b]	0.33[b]	0.043	15.7
Feed intake (g/day)	1.44	1.24	1.21	1.06	0.201	11.2
FCR	2.04[b]	2.30[b]	2.06[b]	3.67[a]	0.007	9.7
Highlands broiler feed trial						
Body weight (kg)	2.72[a]	2.28[b]	2.08[c]	1.51[d]	0.001	2.5
Weight gain* (kg)	0.74[a]	0.55[a,b]	0.52[a,b]	0.36[b]	0.045	15.4
Feed intake (g/day)	1.51	1.35	1.39	1.35	0.188	4.6
FCR	2.07[b]	2.47[b]	2.69[b]	3.79[a]	0.006	8.0

* Weight gain 21 days after starter phase.
FCR = feed conversion ratio.
Means with a common superscript are not significantly different at $P > 0.05$.
Source: onsite trial reports (ACIAR 2013: LPS/2005/094).

and White 1980; Lai and Rodriguez 1998), cooked (Ochetim 1993; Dom and Ayalew 2009a, b), dried and milled (Wu 1991; Ospina et al. 1995) and ensiled (Giang et al. 2004; An et al. 2004). In the current research, both root crops provided very high digestible energy, while other ingredients such as soybean meal, fishmeal and meat meal provided the required protein. Micronutrients and essential amino acids were supplied according to the nutrient requirements of pigs.

There was high digestibility for all nutrients with diets of sweetpotato as boiled roots with fresh vines (SPctfv) or as an ensiled mixture of root and vines (SPwou) when both forms were blended with 50% commercial pig grower feed as the protein component and fed to Landrace–Large White × Duroc grower pigs (Tomita et al. 1985; Dom and Ayalew 2009a, b) (Table 3). Additionally, nitrogen (N) retained, as a percentage of N intake and N digested, also appeared to be advantageous for sweetpotato blended diets compared to the standard feed without sweetpotato (SPnil), indicating effective conversion of feed protein to body growth (Giang et al. 2004; Dom and Ayalew 2009a).

Cassava also provided high nutrient digestibility (Ly et al. 2010). In ongoing experiments at NARI's Labu Station, commercial genotype pigs displayed high digestibility performance for cassava as boiled, milled or ensiled roots blended with a novel protein concentrate (Dom et al. 2014a). In previous experiments the existing standard pig grower feed was used as a protein supplement, but in the latest research trials a protein concentrate, dubbed PNG Pig Conc.1, was formulated to perfectly complement the nutrient deficiencies in cassava and sweetpotato roots. Preparation of the roots by boiling, ensiling or milling also reduced their antinutrients, for example tannins and phytates, cyanide in cassava, and dietary fibre (Cooke and Maduagwu 1978; Cardoso et al. 2005; Teka et al. 2013). Use of Pig Conc.1 (at 45% dry matter) maximised the amount of local root crops (55%) and reduced the total amount of imported wheat products compared to the standard pig grower feed which is 91.2% wheat.

Growth and feed conversion

On-station and on-farm small-scale pig feeding trials have been conducted at different locations in the lowlands and highlands. Sweetpotato silage mixed with pig grower at 50% and 75% of the ration, or with high- and low-energy poultry concentrates at 28% and 30% respectively, resulted in improved performance in local mixed-genotype pigs (Dom and Ayalew 2010a,b; Dom et al. 2011a,b, 2014b).

The results of two trials are shown in Table 4. Compared to the commercial pig grower feed, mixed rations of ensiled sweetpotato roots and vines and pig grower feed resulted in lower growth rates and feed conversion for mixed-genotype pigs kept on-station (Dom and Ayalew 2010a) and on-farm (Dom et al. 2010). The results were comparable to reported work in other countries. Substituting pig grower feed disadvantages pig performance regardless of digestibility because of the lowered nutrient levels in

Table 3. Digestibility of nutrients and N balance in sweetpotato diets fed to grower pigs.

Diet	DM	OM	NFE	Ash	CP (or N)	EE	CF	NDF	N retained (g/day)	% of N intake	% of N digested
SPnil	86.55	–	89.95	68.8	80.2	–	72	–	28.6	60.7	75.3
SPctfv	90.6	–	93.68	72.4	80.3	–	75.3	–	20.3	60.7	75.3
SPwou	87.53	–	91.43	68.3	74	–	67.8	–	11.8	49.4	65.8
50CMR	79.8	81.8	87.00	–	81	83.1	34.3	–	–	–	–
SPM50	76.1	79.8	–	–	67.8	–	47	57.2	9.8	39.8	–
SPS50	78.1	83.2	–	–	67.7	–	48.6	56.7	7.5	38	–

SPnil = maize + soybean standard feed; SPctfv = sweetpotato cooked tuber (roots) and vine; SPwou = sweetpotato roots and vine silage made without urea (Dom and Ayalew 2009a); 50CMR = cassava root meal replacing 50% of maize (Tzudir et al. 2012); SPM50 = sweetpotato root meal replacing 50% of maize (Giang et al. 2004).
DM = dry matter; OM = organic matter; NFE = nitrogen-free extract (estimate of carbohydrates); Ash = mineral content estimate; CP = crude protein; EE = ether extract for fats; CF = crude fibre; NDF = neutral detergent fibre.

Table 4. Growth rate and feed conversion in grower pigs on sweetpotato- and cassava-based diets in on-station and on-farm feeding trials.

Diets	Start weight (kg)	Finish weight (kg)	ADI (g/day)	ADG (g/day)	FCR
STDPG	27.1	68	1,694	730	2.33
SPctfv	22.9	51	1,553	502	3.09
SPS50%	28.8	59	1,190	540	2.21
SPS75%	23.8	55	1,800	634	2.84
SPS(ad lib)	18.3	55.3	1,329	398	3.33
HESPS	19.9	55	2,545	615	4.28
LESPS	21.3	57.3	2,513	635	3.99
SPS40	15.8	53	–	423	2.67
SPM40	15.5	52.1	–	416	2.70
50CRM	–	–	–	424	–

STDPG = standard pig grower; SPctfv = sweetpotato cooked tuber (roots) and vine; SPS50% = 50% sweetpotato root and vine (1:1) silage with 50% pig grower (Dom and Ayalew 2010a); SPS75% = 25% sweetpotato root and vine (1:1) silage blended with 75% pig grower (Dom et al. 2011); SPS(ad lib) = fed to satisfaction (Dom et al. 2010); HESPS = high-energy broiler concentrate + sweetpotato silage; LESPS = low-energy broiler concentrate + sweetpotato silage (Dom et al. 2014a); 50CMR = cassava root meal replacing 50% of maize (Tzudir et al. 2012); SPM40 = sweetpotato root meal replacing 40% of maize (Giang et al. 2004).
ADI = average daily intake; ADG = average daily gain; FCR = feed conversion ratio

the resulting diets, as the commercial feed is designed to be a stand-alone feed, providing all the nutrient requirements for growing animals. More recent research using the specifically formulated concentrate Pig Conc.1 blended with sweetpotato and cassava has shown improvements in the feed value of blended diets (Dom et al. 2014a). The reported growth rates and feed conversion efficiency are advantageous for village and small-scale piggeries fed the blended diets. Village pigs under the current simple feeding strategies would otherwise take longer to reach finish weight or maintain productivity, particularly when farmers are unable to maintain even nutrition levels due to feed shortages and rising feed costs.

FEED VALUE OF SWEETPOTATO AND CASSAVA FOR INLAND FISHERIES

Growth, feed conversion and pond yield

Nutrition plays a critical role in fish production and has a direct influence on fish growth and health (Delbert and Gatlin 2010). Like all livestock, fish require a balanced diet, and farming fish requires an understanding of their requirements and formulating balanced diets of energy, protein, vitamins and minerals to satisfy their metabolic needs. Feed requirements vary in quantity and quality according to species feeding habits and digestive anatomy, as well as their size and reproductive state (Gonzales and Allen 2006). Fish can source their feed directly from the pond, from supplied feed, or from a combination of the two.

In PNG, there is an opportunity to use local ingredients such as sweetpotato and cassava to supply energy in fish diets. Sweetpotato and cassava diets formulated with poultry concentrates have resulted in promising growth in fish.

Growth of juvenile genetically improved farmed tilapia (GIFT) was evaluated on two test diets made by combining a high-energy poultry concentrate with cooked cassava meal (HEC) and a low-energy concentrate with cooked sweetpotato (LESP) (Sine et al. 2012). Poultry concentrate and cassava or sweetpotato were combined at 75% and 20% respectively, and 5% palm oil was used to balance each diet (Table 5). Fish were reared in rainwater and the feeds were provided twice daily at a rate of 7% of the body weight of the fish, adjusted by weekly weighing. There was no significant difference ($P > 0.05$) between the harvest weights, feed intake or feed conversion ratios of the different dietary treatments. Growth performance of fish fed on the HEC and LESP diets over 12 weeks was comparable to a standard fish feed (FISHSTD) sourced from Goroka Provincial Department of Agriculture and Livestock (Table 6).

Under good growth conditions and fish care, cultured tilapia in nursery ponds can grow from about 1 g to 20 g and 40 g in five and eight weeks (Thomas and Masser 1999). The body weight of the tilapia fed the HEC and LESP diets in this trial reached approximately 30 g after eight weeks and 46 g by week 12, well above the standard fish feed (Figure 1). This value is within the lower range and may be indicative of the fact that the fish were reared in tanks rather than ponds where other feed organisms are also available. The stocking density in the tanks, 20 fish/m^3, was low. Higher stocking densities may affect feed intake but not feed conversion ratio because fish under stress may not use energy for growth (Al-Harbi and Siddiqui 2000). Stocking tanks with 50 fish/m^3 or more required higher water exchange rates to maintain water quality and minimise the adverse effects of crowding (Yousif 2002). Even for pond-raised tilapia, stocking above 50 fish/m^3 resulted in reduced feed intake, growth and feed efficiency (Yi et al. 1996). On the other hand, stocking tilapia at 50 to 200 fish/m^3 in freshwater ponds had no effect on growth rates and feed conversion when fed twice daily at 3–5% of body weight (Osofero et al. 2009). Better production at the second highest stocking density (150 fish/m^3) was attributed to high crude protein content of the feed, the favourable physicochemical conditions of the reservoir, and the fact that the cage design allowed for high feed intake (Osofero et al. 2009). Open ponds and cage culture fish farming using improved locally made feeds are yet to be trialled in PNG.

Table 5. Ingredients and nutritional composition of experimental diets fed to tilapia.

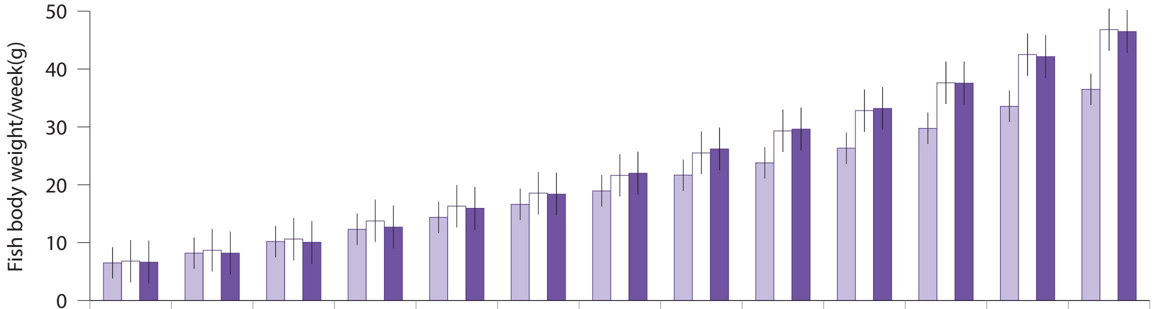
Treatment	Ingredient	Content (%)	Dry matter (%)	Crude protein (%)	Gross energy (MJ/kg)
HEC	HE concentrate	75.0	90.0	42.0	15.1
	Cassava	20.0	86.5	2.1	14.7
	Palm oil	5.0	90.3	0	16.4
LESP	LE concentrate	75.0	90.0	41.5	13.0
	Sweetpotato	20.0	88.0	4.2	14.9
	Palm oil	5.0	90.3	0	16.4

HEC = high-energy poultry concentrate with cooked cassava meal; LESP = low-energy concentrate with cooked sweetpotato.
Source: Sine et al (2012).

Table 6. Nutritional composition of the dietary treatments, and feeding and growth data for tilapia.

Treatment	Nutritional composition			Feeding and growth			
	DM (%)	CP (%)	GE (MJ/kg)	No. of fish	DMI (g/day)	Increase in biomass (g)	FCR
FISHSTD	92.4	36.8	17.6	4	110.9	30.0	3.27
HEC	89.3	35.5	16.9	4	129.1	40.0	2.97
LESP	89.6	35.5	15.1	4	129.3	39.9	2.86
Mean	–	–	–	–	123.4	36.6	3.04
SEM	–	–	–	–	0.83	1.79	0.158
$F_{pr.}$ (0.05)	–	–	–	–	0.360	0.191	0.167
CV (%)	–	–	–	–	55.9	56.3	36.2

FISHSTD = standard fish feed; HEC = high-energy poultry concentrate with cooked cassava meal; LESP = low-energy concentrate with cooked sweetpotato.
DM = dry matter; CP = crude protein; GE = gross energy; DMI = dry matter intake; FCR = feed conversion ratio.
Source: adapted from Sine et al. (2012).



	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10	Wk11	Wk12
FISHSTD	6.50	8.19	10.19	12.31	14.38	16.62	18.94	21.67	23.79	26.33	29.75	33.56	36.50
HEC	6.81	8.69	10.63	13.75	16.31	18.56	21.62	25.50	29.31	32.81	37.62	42.50	46.81
LESP	6.62	8.19	10.06	12.69	15.94	18.38	22.00	26.19	29.62	33.19	37.56	42.15	46.48

Figure 1. Mean weekly body weights of tilapia juveniles fed with three test diets over 12 weeks (FISHSTD = standard fish feed; HEC = high energy concentrate+cassava; LESP = low energy concentrate+sweetpotato) (bars indicate standard error) (Sine et al. 2012).

PRACTICAL IMPLICATIONS: SWEETPOTATO FOOD SUPPLY CHAINS AND FEED PROCESSING

Sweetpotato supply chain logistics

It is estimated that three million tonnes of sweetpotato is produced annually in PNG, three quarters of which is from the highlands provinces. About 50–75% of this is utilised for human consumption, while 25–50% is fed to animals (Bourke and Vlassak 2004). Sweetpotato production in the highlands provinces, such as Eastern and Western Highlands, is a major economic activity as well as providing for household consumption.

A collaborative project between ACIAR, NARI, the Fresh Produce Development Agency (FPDA) and the University of New England (UNE), aimed at understanding postharvest losses, tracked 10 consignments of sweetpotato from the highlands to the two major coastal markets of Lae and Port Moresby (Chang and Irving 2013). Disease incidence and severity were evaluated and distances and times from one point of the supply chain to the next were measured in three case studies (Figure 2).

Sweetpotato crop harvesting days are determined by the shipping schedules of two major companies (Bismark and Consort), the scale of shipment and the availability of road transport. Sweetpotato roots are packed into bags weighing 80–100 kg in the field before being transported to convenient roadside locations. The bags are usually over-packed due to the high charge per bag along the supply chain. There are no formal networks for transporting bags of sweetpotato and farmers use informal arrangements, often paying for space on empty containers hauled by semi-trailers or on open-backed trucks. In addition, there are no proper storage facilities along the supply chain, and bags aim to reach the wharf on the day of shipping. On many occasions, delays in shipping mean three to four days waiting in the open. There have also been instances where delays in opening containers at the port of arrival led to spoilage of the entire bulk produce (most containers are not temperature controlled or ventilated). However, recently shipping containers have been modified by cutting vents for aeration; the benefits of this container ventilation method are yet to be determined.

Damage from harvest to packing

Sorting is carried out in the field to remove insect-infested roots, smaller roots (to feed to pigs), roots damaged by digging stick stab wounds and broken roots, which may be used for household consumption. It was found that skinning damage often occurred at harvest and during transport to the market but most damage took place during packing. As much as

Figure 2. Flow chart of the sweetpotato supply chain from harvest to market, with transit delays and internal temperature of packed bags (80–100 kg).

45–83% of roots were severely skinned during packing (Newman et al. 2011). Skinning can be reduced by curing. Recommendations have been made on improved packaging methods and materials but these are yet to be adopted (Chang and Irving 2013).

Damage during transport and handling

Generally, poor bag handling by hired carriers caused considerable breakages to roots. The size and weight of sweetpotato bags made manual handling difficult. Poor packaging materials combined with bad roads contributed to skinning of roots during transportation. Different packaging materials and sizes, such as cardboard boxes and plastic crates (20–60 kg), have been trialled but were found to be either less durable or more costly than the polyethylene sacks currently used (Chang and Irving 2013).

In consignments where root breakages were high (8–54%), disease incidences were recorded. Long delays between each transit point and lack of storage facilities allows rotting of damaged material and microbial growth. Physiological damage incidence, such as rots and diseases, amounted to 10–14% at the Lae market and 57–78% at the long-distance Port Moresby market (Lazar-Baker et al. 2011). Damage was visible on the skin, impairing the appearance of the roots and hence perceived quality (Irving et al. 2011), however the disease severity was moderate to low, 10–25% (Lazar-Baker et al. 2011). The predominant fungal diseases were soft rot caused by *Rhizopus* spp., dry rot caused by *Fusarium* spp., Java black rot caused by *Lasiodiplodia theobromae* and scurf caused by *Monilochaetes infuscans*. *Penicillium* spp. was also often present as a secondary infection. The main bacterial disease was soft rot caused by *Erwinia* (now *Pectobacterium*) spp. (Lazar-Baker et al. 2011). There was a recognised need to develop quality descriptors to define locally appropriate grades for field and market locations (ACIAR 2011).

Animal feed requirements are not as stringent as for sweetpotato for human consumption. For example, broken roots and partially diseased roots may be recovered during sorting for feed processing (Figure 3). Selling sweetpotato for animal feed may provide an alternative market for offloading bulk produce before spoilage leads to an economic loss. This advantageous use of sweetpotato should not be confused with local production specifically for animal feed.

Sweetpotato food markets

It is estimated that only 1% of the total sweetpotato production or 30,000 tonnes/year is sold at markets around the country (Chang and Spriggs 2007), of which 20,000 tonnes comes from the highlands provinces. The volume of sweetpotato arriving in Port Moresby is estimated to have increased from 800–1,000 bags to 2,000–2,400 bags per week during the 2006–07 period, with each bag weighing an average of 90–95 kg (Chang and Irving 2013; ACIAR 2006). Market survey data (FPDA 2009) showed no particular seasonality of sweetpotato supply, however a general rise in price was seen, with different trends at different markets. From anecdotal reports, prices may fluctuate widely within a market; for example, at Lae main market the price per sweetpotato bag ranged from 25 to 140 kina (0.28 to 1.50 kina per kg) and appeared to be influenced by delays in delivery time. Livestock farmers would not normally source sweetpotato feed directly from food markets, although this would provide an alternative market for damaged and excess stock and a means of stabilising lower prices from the consistent demand. However, village-based sweetpotato growers may consider this a disadvantage for marketing smaller bulk produce and they expect to receive the same price for feed and food grade roots. Such marketing economics are yet to be addressed by value chain analysis of the local sweetpotato and cassava food–feed production systems.

Alternative value-added products of sweetpotato and cassava include dried chips, milled flour and starch, and noodles. Processing methods are currently being evaluated for household production of flour and its derived products, such as biscuits, cakes, buns and fried snacks (EUARD 2012; ACIAR 2014). A cassava-processing pilot project was implemented at a community-run mini-mill. Cassava flour was successfully milled and packaged for sale but the business was discontinued (AIGS 2012). The mill also produced and sold pelletised poultry feed, which eventually became its major business (see 'the Domil experience' below). Cassava was supplied to the mini-mill by local farmers who then obtained processed feed for broiler-raising enterprises (Figure 3). It may be necessary to link flour processing and animal feed production at community-run mini-mills for the activity to be economically feasible.

Sweetpotato feed markets

As much as 750,000 to 1.5 million tonnes of sweetpotato roots may be fed to pigs every year in PNG (Bourke and Vlassak 2004). Presumably most of this sweetpotato feed is grown and used on-farm under traditional village livestock production, particularly of pigs. Roadside markets for sweetpotato feed are seen in the highlands provinces but these are less studied. In the Western Highlands province in particular, local pig farmers are known to purchase sweetpotato feed from village growers, sometimes on a regular and prearranged basis. This demand for sweetpotato as animal feed provides an opportunity for village farmers to earn additional income from selling to livestock enterprises. Furthermore, feed buyers require a larger portion of the crop, including the sweetpotato vines. A number of feed cost assessments from pig feeding trials have indicated that purchasing sweetpotato roots at 0.50–1 kina per kg would allow reasonable profit margins from the sale of grown-out pigs at 60 kg finished weights (Dom et al. 2010; Dom and Ayalew 2009b). These unit costs for sweetpotato roots are within the observed range for food-grade sweetpotato roots. This sweetpotato feed price would be payable at the farm gate rather than at markets either near to or distant from the growing field. There is demand for sweetpotato feed for local small-scale poultry, pig and inland fish farming. Further investigation of this untapped sweetpotato feed supply chain is recommended.

LOCAL FEED MILLING

Feed milling equipment is being adapted and tested under a collaborative ACIAR project (ASEM 2010/053; ACIAR 2010). This project is determining the requirements for storing raw ingredients, appropriate equipment to process ingredients, and power requirements of the equipment. It is also investigating how to operate and maintain the equipment, and user briefs are being developed on the feed mill setup and operation. A storage facility for the sweetpotato and cassava roots is required at the mill site, with capacity depending on the amount of feed being processed. The storage area must be waterproof, well ventilated and protected against infestation by insects, birds, rats and mice (high levels of moisture can result in insect infestations and fungal growth).

Mill flow plan

In the mill an ordered set of procedures is implemented (Figure 3). These include: obtaining feed ingredients and premixes, storing the feed ingredients, weighing them, washing, cutting, drying, grinding, mixing, adding premixes, pelletising if required, bagging prepared feed, labelling feed bags, storing feed on site, selling feed to customers and transporting feed to farmers where required. The equipment used depends on the amount of feed being processed and whether the mill is involved in blending commercial concentrates with local ingredients, such as sweetpotato or cassava. In PNG, 100–200 kg of feed is usually mixed per hour, though larger volumes might be required around regional centres—up to 1–3 tonnes/hour.

Processing sweetpotato and cassava

The first step in the processing of sweetpotato and cassava roots in the feed mill is to wash the roots, either by hand or using an inline washing machine (Figure 3). A flake mill is then used to chip the roots into a suitable size (length 2 cm, width 0.3 cm), and the chips are dried in the sun or using a drum dryer. After drying, the chips can be hammer milled into flour and stored for later adding to a pig or poultry diet. The capacity of the inline washers, flake mill and drying equipment depends on the volume of material to be processed and should be discussed with the equipment manufacturers.

Ensiling sweetpotato and cassava

A separate shed attached to the feed mill can be used to prepare sweetpotato and cassava silage, which offers an alternative way to store and use the roots and forage for feeding to livestock, particularly pigs. When the forage components of the crops have reached maturity, they are wilted to about 40% moisture before being placed through a chaff cutter and cut to 3 cm lengths. Whole roots and tubers can be added to the tuber chaff, salt is added, and the silage is then mixed using a horizontal mixer. The final step is to pack the mixture into an airtight plastic bag and store for up to seven months in a secure area. The ensiling technique has been tested and found to store sweetpotato and cassava silage very effectively, with pH remaining at around 4 even after the bags have been opened provided that they are carefully resealed. When required, the silage can be sent to pig farms for blending with a concentrate mix. The capacity of the chaff cutter, horizontal mixer and the size of storage bags depends on the volume of material being processed and should be discussed with the equipment manufacturers.

The Domil experience

A study conducted among 50 farmers to identify their attitudes to and knowledge about the use of mini-mills to produce feeds indicated favourable (88%) and highly favourable (12%) attitudes towards the idea of using local ingredients to formulate feeds for poultry, pigs and fish. Although only 50% of farmers had knowledge of how the mill operated and how inputs were provided, social learning and networking among Domil farmers was very strong, and this bridged the gap between farmers knowledgeable about the operation of the mini-mill those with less knowledge. This increased awareness on what was happening with the mini-mill and the new development had a positive effect on farmers' attitude.

The recognised benefits of the mill included: being able to secure a bank loan using the mini-mill as collateral; employment; community policing and security; unity/cooperation among villagers; positive attitude, purpose and direction; the introduction of an alternative cash crop (cassava); and the community becoming a model where farmers maximised the use of their time and efforts. The women were able to sell cassava as an alternative cash crop, as men dominated coffee production. The feed was sold to local farmers who raised broiler birds for live market sale. As a result of the broiler bird farming enterprise, poultry manure was available to improve soil fertility. This resulted in an increased quantity of green and leafy vegetables

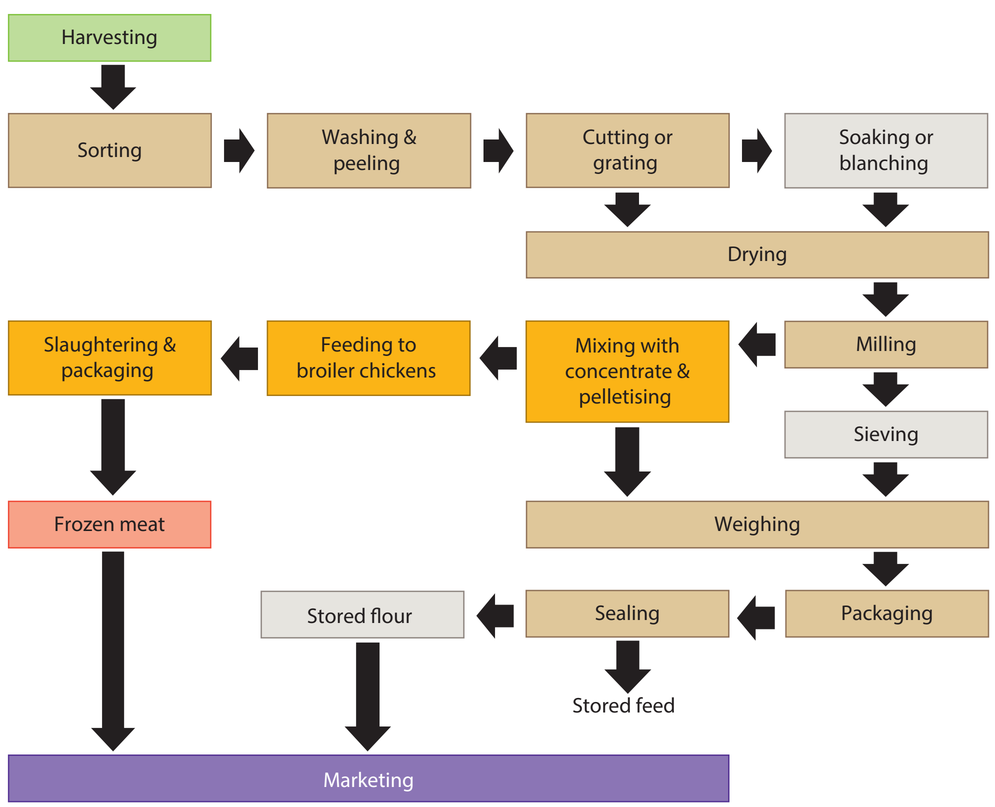


Figure 3. Flow chart for a small-scale milling operation for root crops, from harvest to market, as stored flour and dry feed, and broiler chicken farming for frozen meat (based on the Domil Community Mill).

being produced. Nutrition was also improved from chicken offal products providing a protein supplement for families. The change in farming systems led to higher income earning opportunities for higher value processed feed products and from live bird sales.

The success of the Domil mini-mill was also a result of the quality of leadership provided by the management of the cooperative and their focused approach.

Challenges faced by the Domil community included: the need to train farmers in diet and nutrition, marketing, and postharvest handling skills; maintaining a consistent supply of feed ingredients to the mill; the lack of appropriate processing equipment for feed formulation and postharvest processing of birds; the need for improved postharvest handling of meat products and storage; poor infrastructure for storage and marketing; lack of knowledge and skills to negotiate markets and link up with customers; and an inconsistent supply of frozen meat birds to the market. To make the industry sustainable, farmers require strong income earning opportunities wherever they are. Findings indicated that farmers were willing to spend their money to buy formulated feed within their community. However, there were unrealistic profit expectations and expenditures during the operations which discouraged some farmers.

The issues in piggery, poultry and inland fish farming sectors seemed similar, however the stages of growth, performance and support for each sector were not all the same. The needs of poultry-producing groups were totally different from those of communities with aquaculture projects, and likewise for piggery projects. This calls for specific enterprise strategies in order to fully appreciate and develop each sector.

SWEETPOTATO AND CASSAVA AS POULTRY FEED

Small-scale broiler raising

A series of on-station broiler grow-out trials led to the identification of the following best-bet diet formulations: 50% sweetpotato plus 50% low-energy concentrate, and 50% cassava plus 50% high-energy concentrate (Glatz 2007). It is proposed that when broiler farmers provide their own sweetpotato or cassava tubers, using the energy concentrates affords a major cost saving amounting to a 30% reduction in feed costs, particularly for small-scale broiler farmers in both the lowlands and highland region of PNG. Importantly, the improved poultry feeding systems research now has the participation of Niugini Tablebirds and Lae Feed Mills in manufacturing two concentrate mixtures for blending with either sweetpotato or cassava to provide an energy and nutritionally effective finisher ration (ACIAR 2010).

Small-scale layer farming

Small-scale poultry farming in PNG is characterised by medium-scale commercial, small-scale commercial and small-scale semi-scavenging systems of indigenous chicken and duck production on smallholder and peri-urban farms (Glatz and Pym 2008). These systems are regarded as low input–low output as birds are maintained mainly for savings, ornamental purposes, as a hobby and for cultural reasons. There is no commercial poultry-keeping in rural villages and village poultry production is primarily for household consumption (Quartermain 2000). The main constraints faced by smallholder farms are the rising cost of commercial stock feeds and the high cost of commercial day-old hybrid chicks. Unlike semi-commercial and commercial production, most smallholder farmers lack specific management and husbandry skills as well as skills to improve the nutritional status of stock feed to achieve optimum production and reasonable returns.

Commercial layer birds have a drop in egg production when nutritional requirements are not met by local diet mixtures. In addition, the cost of layer production must be carried for up to 20 weeks (while birds are being reared) before revenue from eggs is realised. This is a financial barrier for raising commercial hybrid layers in small-scale farming. The production of village chickens and their crossbreeds can be improved with commercial diets. However, the return from feed cost tends not to be worthwhile, predominantly because of the smaller body size and egg size of village chickens. Village chickens are not efficient converters of commercial feeds and their feral characteristics mean that they move around and scavenge to find other food.

Under improved management and feeding of village chickens, layer hens were fed 40% sweetpotato or cassava as a basal diet, supplemented with 60% high- or low-energy concentrate, respectively. Sweetpotato was washed and boiled while the cassava was peeled before boiling. After boiling, the hot water was removed leaving tubers to desiccate. The boiled tubers were then mashed and blended with respective concentrates to balance the nutrient composition in line with the commercial mash (Table 7). Egg production of 28-week-old village hens improved when fed on the sweetpotato-based diet (41%) and the cassava-based diet (47%) and was found to be statistically similar ($P > 0.05$) to hens fed on the commercial diet (37%) (Besari et al. 2017a). Egg weights from birds fed on the sweetpotato-based diet (51 g) were the same as the egg weights from birds fed the commercial mash diet.

Farmers in Madang Province engaged in a layer bird farming project using the cassava-based diets. The trial showed there was potential for good egg production in village chickens (E. Solomon pers. comm. on EUARD 2012). Farm income was improved from the sale of eggs and the eggs also provided a good protein source for the family. However, this was only possible if good management techniques were applied, adequate feed was provided and the cassava-based feeding method was carried out correctly.

Village chickens and dual-purpose crossbred poultry

Dual-purpose crossbred poultry are an important part of smallholder and semi-commercial poultry production. In the past, Department of Agriculture programs distributed Rhode Island Red and Australorp chickens to smallholder farms, and they were then maintained by farmers. However, the stocks are now no longer pure breeds but various crosses with village chickens. Improved crosses include F1 crosses of Australorp × Hy-Line Brown, Australorp, F1 crosses of Shaver Brown × Hy-Line Brown and Rhode Island Red.

In the current production system for dual-purpose birds, males are raised for breeding and meat while females are raised for eggs and meat. Layer hens are culled and used for meat after the first production cycle. In the second production cycle, between 70 and 80 weeks, culling is again necessary to maintain productivity in the flock where some birds produce less eggs. In other circumstances the entire layer flock may be culled and used for meat after only one production, without exploiting their full inherent potential by allowing birds to produce eggs in a second production cycle (North and Bell 1990).

A feed using 98% of local ingredients was tested on F1 crosses of Australorp × Hy-Line Brown spent layers (aged 77 weeks) and resulted in optimum production performance (Besari et al. 2017b). The use of local feed in the second and last production cycle maintained profitability even though egg production declined.

Boiled mashed sweetpotato and cassava blended with high-energy and low-energy layer concentrate respectively are feasible for egg production using F1 crossbred village hens (Ahizo et al. 2017; Besari et al. 2017c). The bulking of boiled mashed cassava tubers with low-energy layer concentrate maintained production at reduced cost in a small-scale table egg enterprise. Similarly, there were no significant differences in egg production performance and egg weights in F1 crosses of Shaver Brown × Australorp aged 26–33 weeks when fed the same cassava-based diet (Pandi et al. 2017). The cost of producing eggs with F1 crosses of Shaver Brown × Australorp birds was significantly reduced on the cassava compared to the sweetpotato and commercial diets.

Table 7. Nutrient values of diets fed to village chickens.

Diet	ME (MJ/kg)	CP (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Available P (%)
HELC + BMSP	12.8[i]	15.4	6.1	2.1	2.7	0.5
LELC + BMC	11.6[i]	14.5	5.7	4.7	2.8	0.5
Commercial mash	11.0	16.0	4.0	3.0	3.0	0.4

[i] Estimates, apparent metabolisable energy.
HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato roots; LELC = low-energy layer concentrate; BMC = boiled mashed cassava roots; ME = metabolisable energy; CP = crude protein.
Source: Besari et al. (2017a).

SWEETPOTATO AND CASSAVA AS PIG FEED

Pigs have a well-known appetite for feed and grower-finisher pigs may perform well on a daily offer of a little over 2 kg of dry feed. When feeding boiled sweetpotato and cassava roots, about 6–8 kg of cooked feed is required to satisfy the pig's appetite; large animals and lactating sows need more. Fermented silage tends to reduce the feed intake of growing pigs to about 3–4 kg of fresh weight per day without reducing pig growth performance (Dom and Ayalew 2009a, 2010a, b). However, for the best performance sweetpotato and cassava must be blended with protein ingredients to satisfy the nutrient requirements of pigs. Milling or ensiling feed and blending daily rations may require mechanisation. The level of processing, either manually or mechanically, is determined by the scale of production.

Village pig farms

Village pig farmers usually keep up to five sows, but some, especially in the highlands provinces, may keep more. Village pigs are usually allowed to graze freely which does not require any input from the owners other than releasing or tethering the pigs at selected locations. For more rapid growing or fattening, pigs can be kept in enclosed housing and given additional feed.

Sweetpotato and cassava are already major crops grown for pig feeding at village level, therefore it seems reasonable that feed conservation would be an advantage where perishable feed materials are continuously produced. However, for many village farmers the additional labour required to process animal feed may be a burden they are not willing to take on. Producing dried, stored feed requires cleaning, chopping, sun-drying and milling into meal. Sun-drying alone may be challenging under the typically wet and humid or cold conditions experienced in PNG, particularly when the material is bulky and difficult to handle.

A number of key advantages were noted with ensiled sweetpotato feed. Ensiling fresh feed requires only minimum or no sun-drying, and the feed material may be processed as chopped or grated material without the need for milling. Processing for ensiling at village level may be done by hand using kitchen graters and knives. Blending feed by hand daily would be as usual. Furthermore, fermented silage removes the need for cooking feed and hence reduces the use of fuelwood. Mixed sweetpotato silage fed at about 4 kg fresh weight (3 kg root + 1 kg vine) may be a feasible feeding regime at village level. This level of feeding is similar to the common diet of boiled roots and fresh forage and requires that approximately the same amount of fresh material be processed and stored as silage. To fatten one pig over six months requires about 720 kg of sweetpotato material. Pathogen-tested sweetpotato crops may produce about 2 kg/m^2 of roots (E. Guaf pers. comm.) and twice that amount of vine forage per planting (mound). A crop of 7.5 mounds per month would be required for each pig. Ensiling this amount of sweetpotato allows the same ration to be fed while reducing the amount of labour and land needed under the usual method of boiling sweetpotato roots and feeding fresh vines daily.

Semi-commercial pig farms

Semi-commercial pig farmers may gain the most advantage from more intensive use of sweetpotato and cassava for pig feed. As they are predominantly rural, the farmers have access to sweetpotato and cassava either from their own land or sourced from nearby gardens and markets. Household labour can be utilised in producing feed. However, the challenge is obtaining and maintaining processing equipment and appropriate storage facilities for bulk feed. Semi-commercial farms usually have between five and twenty sows producing intermittently or, with more skilled farmers, in half-year cycles which maintains a continuous supply of piglets for growing and fattening. Sales of pigs tend to be irregular, but all classes of pigs are sold: piglets, weaned pigs, growers and fatteners, including sows and boars.

Pig feeding trials have demonstrated that ensiled sweetpotato roots and vine, compared to boiled root blended with pig grower and fed with fresh vines, improved feed conversion by as much as 28% (Dom and Ayalew 2010b) and 32% (Dom and Ayalew 2010a) for grower pigs bred at Labu Station. This means less feed is required to maintain growth rates of 400–500 g/day. Grower pigs at approximately 20 kg starting body weight will take 120–150 days (4–5 months) to achieve a finishing weight of 60 kg.

In one on-farm trial where six pigs were fattened to 50 kg in 3 months, they were fed a total of 924 kg of sweetpotato silage and an additional 657 kg of pig grower feed (Dom et al. 2010). Following the rationale above, 154 sweetpotato mounds would have provided the feed. At an estimated 1 m^2 per mound, the sweetpotato needed for fattening six pigs may therefore be cultivated on 154 m^2 of land. By the same rationale, a semi-commercial pig farmer with half a hectare (5,000 m^2) of sweetpotatoes may get up to 30 tonnes of fresh weight or about 5 tonnes as dry weight of sweetpotato mixed root and vine silage for pig feed every 3–4-month growing cycle. This volume of feed requires milling machinery for processing and larger storage capacity. A diesel or electrically powered flake mill with a capacity of 120 kg/hour or about one tonne per day is available for this larger scale processing. Blending of feed components may be done using large mixers similar to concrete mixers, and these are available locally.

Intensive small-scale pig farms

Farmers in this subsector are financially secure, well equipped and relatively savvy in their business. They tend to have a long-term commitment to farming, own land and have small investments in terms of tools, machinery, buildings and other assets. They also employ a number of permanent and occasional labourers and purchase feed from manufacturers and local markets as needed. Intensive small-scale piggeries normally manage 20 or more sows and mainly sell finished stock. Their feed requirements are considerably greater than village or semi-commercial farms, but the same rationale applies that if sufficient land is available, considerable sweetpotato or cassava feed may be produced. For example, one hectare of land may provide up to 10 tonnes of dry feed. When blended with nutritionally appropriate feed concentrate such as Pig Conc. 1 at approximately 1 kg sweetpotato to 1 kg concentrate, this would be sufficient to feed 50 pigs over 200 days (about six months) from weaning through to finishing stage. For this scale of feed production, milling, storage and blending facilities would require scaling up and the authors' research results on small-scale piggeries are yet to be proven at this more intensive level of pig production.

SWEETPOTATO AND CASSAVA FEEDS FOR INLAND FISHERIES

Fish feed is made using dry-milled products which are made into pellets. The processing method involves grating fresh tubers into chips and then dehydrating by sun-drying or using ovens. The dehydrated chipped tubers are then ground or milled into flour. This process does not completely dehydrate the root material, but around 80–90% of moisture is removed. The processed cassava or sweetpotato is then mixed with other finely ground dry ingredients containing proteins and vitamins/minerals to produce a complete diet depending on the type of fish. The milled sweetpotato and cassava and other ingredients should all in be similar sized particles so that they blend together well and all nutrients are equally available. Equipment required is a weighing scale, grating machine, grinder, drier (oven or tarpaulin for sun drying) and storage containers or bags.

The next step is pelletising the mixed ingredients into appropriate size. Commercial feed mill operators have pressurised pelletising machines for this step. For a small farmer wanting to pellet feed using a simple meat mincer, a good binding agent (cassava flour can be used) and the right water temperature (30–50°C) are important for good pellets. The materials required to produce pellets include: mixer, mincer (mincing machine), sieve, warm water, drier, scale and storage container or bag. The steps using a pelletising machine involve adding warm water (40–60°C) slowly to the mixed diet ingredients, about 50:50, and mixing thoroughly to form a dough. A small batch of mixture should be extruded through the mincer to see how easily the mixture passes through the die and how the pellets hold together, and the mixture adjusted if necessary. Pellets can be made using different die sizes (1–4 mm) depending on the size of the fish. The moist pellets are cut into similar lengths to the pellet diameter and carefully oven or sun dried. The dried pellets are then carefully packed into containers or bags and stored in a dry, ventilated storeroom (feed quality is susceptible to environmental conditions, such as moisture, light and oxygen).

ECONOMIC ASPECTS OF PRODUCING AND USING LOCAL FEEDS

Poultry farming

Poultry production in PNG includes chickens, ducks, geese, turkeys and other fowl, although chickens form the largest proportion (by both number of birds and demand for feed). Poultry production in PNG is characterised by the strain of poultry, feeding method, management practices and level of investment. There are four distinct poultry production systems based on level of input/investment: large-scale commercial farms; medium-scale commercial; small-scale commercial; and small-scale semi-scavenging (Glatz and Pym 2008).

Commercial production

The large-scale commercial poultry production system in PNG is dominated by broiler chicken production due to the high demand for poultry meat (Gwaisuek 2001). Medium-scale commercial farms mostly produce layers and eggs. The industry grew from the early 1980s under the protection of an import ban. This has since been replaced with a high import tariff. The commercial broiler chicken industry has a high level of self-sufficiency and is vertically integrated. This is characterised by company ownership of breeding farms, hatcheries, feed companies, contracted out-growers of chickens, and processing plants. An estimate of the annual commercial chicken production in 2002 was 17,500 tonnes of frozen meat (Glatz 2007), while Quartermain (2002) estimated an annual table egg production of around 54 million eggs. This production system depends heavily on manufactured stock feeds made largely from imported ingredients. The estimated amount of feed used in this system is over 300,000 tonnes annually (D. Drummond pers. comm.).

The small-scale commercial and the small-scale semi-scavenging production systems can be collectively termed the village poultry production system. There are an estimated 1.5 million village chickens kept by 220,000 families producing 1,858 tonnes of carcass and 6 million eggs annually (Quartermain 2000). The small-scale broiler chicken farmers number around 50,000 families producing approximately 6 million birds annually to supply the informal live chicken markets (ACIAR 2010). The carcass weight from live bird sales of broiler chickens is estimated at 7,000 tonnes per year (Kohun et al. 2006) giving this subsector a value of 180 million kina, assuming an average sale price of 30 kina per bird.

Small-scale broiler production

Small-scale poultry farmers raise broiler chickens in batches of 50, from day-old chicks over a 42-day period. Day-old chicks are fed broiler starter crumble up to day 21, after which the feed is switched to the broiler finisher pellets. Two alternative feeding options, with cassava and sweetpotato blended with low- and high-energy (LE and HE) poultry concentrates respectively, were tested against the standard broiler bird feeds (Table 8).

Under smallholder broiler farms where labour is shared by family members, it costs 10.91 kina to grow a broiler bird up to 2 kg at 42 days using the standard starter and finisher feeds (data not shown). If external labour input is considered, one bird costs 13.74 kina to be raised to 2 kg at 42 days using standard feeds. Using cassava with LE concentrate, the farmer would spend 11.22 kina to raise a bird up to 2 kg at 42 days, which is 2.50 kina or 20% less than with the standard feed. Similarly, if a farmer uses sweetpotato with HE concentrate it would cost 11.07 kina to raise a bird up to 2 kg at 42 days which is 2.70 kina or approximately 20% less than using the standard broiler feeds. Raising day-old chicks with the same starter feed and switching rations at day 22, the gross margins (946.60 kina) and benefit–cost ratio (BCR) of 2.71 favours sweetpotato with HE concentrate when sold at a flat rate of 30 kina per bird.

Small-scale layer production

The rising cost of stock feed is the main factor leading to a rise in the price of eggs in domestic markets. High input costs limit market growth in developing countries (Conway 2012), and PNG is no exception to this trend as up to 70% of the layer feed ingredients are imported.

This situation is being addressed by NARI through trials of sweetpotato- and cassava-based diets blended with high-energy and low-energy layer concentrates. Recent on-farm trials have shown favourable egg production and reduced feed costs with these diets. In one example, the feed intake of village chickens fed a commercial layer diet was lower, egg production was higher and feed conversion was improved (Besari et al. 2017c) compared to sweetpotato- and cassava-based diets. However, the price of commercial feed (2.65 kina/kg) increased the feed cost/g egg, while birds fed on the low-cost diet (LELC + BMC) had a 40% reduction in feed cost/g egg. This result indicates that small-scale layer farmers could use a sweetpotato- and cassava-based diet to maintain egg production performance of village chickens and improve profitability.

Small-scale farmers could also use sweetpotato- and cassava-based diets to feed commercial Hy-Line Brown hens (Table 9). The feed cost per gram of egg can be reduced by 29% and 43% respectively without adversely affecting egg weight. However, egg production by housed hens was significantly reduced for birds fed the sweetpotato-based diet compared to the cassava diet. The overall production cost of farming Hy-Line Brown hens up to point-of-lay compared to village chickens and F1 crosses indicates that it may not be economically viable for village farmers to use Hy-Line Brown hens in their enterprise; however it is feasible for farmers to use Hy-Line Brown spent layers for a second production period because they are cheap to purchase and can be fed on lower cost sweetpotato- and cassava-based diets and maintain reasonable egg production.

Table 8. Estimated costs and margins raising broiler birds on standard feed compared with blended cassava or sweetpotato with low- and high-energy poultry concentrate (introduced at day 22).

Starter phase (1–21 days)	Standard starter crumble feed		
Average chick weight at 1 day (kg)	0.045	0.045	0.045
Average bird weight at 3 weeks (kg)	0.827	0.827	0.827
Average bird weight gain (21 days) (kg)	0.782	0.782	0.782
Feed eaten per bird (21 days) (kg)	1.40	1.40	1.40
Starter feed cost per bird (21 days) (kina)	3.43	3.43	3.43
Finisher phase (22–42 days)	**Standard broiler feed**	**CAS50% + HEC50%**	**SP50% + LEC50%**
Average bird weight at 42 days (kg)	2.7	2.305	2.36
Average bird weight gain (21–42 days) (kg)	0.716	0.523	0.545
Feed eaten per bird (21–42 days) (kg)	1.448	0.842	0.918
Average bird weight gain (1–42 days) (kg)	1.498	1.305	1.33
Feed eaten per bird (1–42 days) (kg)	2.85	2.24	2.32
Finisher feed cost per bird (22–42 days) (kina)	3.48	0.95	0.80
Starter and finisher feed cost per bird (1–42 days) (kina)	6.91	4.38	4.23
Cost of labour per bird[i] (kina)	2.84	2.84	2.84
Cost of producing one bird to 2 kg[ii] (kina)	13.74	11.22	11.07
Mortality assumption rate[iii] (%)	0	0	0
Number of birds sold (live)	50	50	50
Unit selling price (kina)	30.00	30.00	30.00
Total variable costs[iv] (kina)	687.01	560.94	553.40
Gross income (kina)	1,500.00	1,500.00	1,500.00
Gross margin[v] (kina)	812.99	939.06	946.60
Benefit–cost ratio	2.18	2.67	2.71

[i] Unit cost of labour per bird was estimated for a total of 40.5 hours at 3.50 kina/hour.
[ii] Cost of production included costs of day-old chicks, feed and labour while other variable costs were not included.
[iii] Accounted for expected mortality of two chicks in a box of 52 day-old chicks.
[iv] Total variable costs for labour of three persons for 90 days sweetpotato cropping and piggery work at 3.50 kina/hour.
[v] Gross margin = gross income – total variable costs.
Source: ACIAR project LPS/2005/094 (ACIAR 2013).

Dual-purpose crossbred poultry to improve village production

The level of meat and egg production from village chickens is very low; they take several months to reach mature body weight and annual egg production is as low as 77 eggs (M. Bourke pers. comm.) compared to the expected annual production from highly productive Hy-Line Brown hens of 240–260 eggs. However it should be noted that the latter are specifically bred and managed for maximum egg production and profitability in large commercial farms, whereas village chickens usually have to source their own food.

The potential of dual-purpose village chicken crossbreeds as an important contributor to the domestic egg market is yet to be recognised and utilised. The key to successful rearing of village chickens is proper feeding and housing from an early age. Village chickens are able to feed on local ingredients as well as nutritional supplements. Unlike improved commercial chicken breeds, dual-purpose village chicken crossbreeds can be easily and cheaply acquired. Village chickens are prolific and their numbers can be substantially increased in a short time. Moreover, the interventions required to increase production are expected to be within the financial means of smallholder farmers using locally available resources.

Several experiments conducted at Domil Village in Jiwaka Province and Boana District in Morobe Province compared egg production by village chickens, hybrid layer hens and their crosses. The birds were maintained under village management involving basic improvements in housing and feeding of commercial layer pellets. Based on the 8-week trials, the projected annual production is 146 eggs for village chickens, 226 eggs for commercial hybrids and 277 eggs for their crosses. Therefore, if proper feeding and housing are provided, egg production by village chickens can be doubled.

Table 9. Feed costs for village chickens and Hy-Line Brown layers fed boiled and mashed sweetpotato- or cassava-based diets compared to a commercial layer pellet.

Diet	DM feed intake (g/bird/day)	DM feed cost (kina/kg)	Daily feed cost (kina)	FCR to eggs	Egg weight equivalent of intake	Daily feed cost /egg (kina)	Feed cost/g egg (kina)
Village chicken							
HELC + BMSP	116.7	2.51	0.29	2.28	51.17	0.13	0.14
LELC + BMC	123.0	2.21	0.27	2.64	46.59	0.10	0.10
Commercial diet	79.0	2.65	0.21	1.44	54.86	0.15	0.17
Hy-Line Brown							
HELC + BMSP	94.8	1.92	0.18	1.70	55.81	0.19	0.12
LELC + BMC	101.8	1.79	0.18	1.95	52.14	0.09	0.09
Commercial diet	123.5	2.62	0.32	2.17	56.84	0.15	0.16

HELC + BMSP = high-energy layer concentrate and boiled mashed sweetpotato; LELC + BMC = low-energy concentrate and boiled mashed cassava; DM = dry matter; FCR = feed conversion ratio.
Source: Besari et al (2017b).

Table 10. Nutrient values of test diet with local ingredients[i] for village chickens.

Diet	Moisture (%)	ME (MJ/kg)	CP (%)	Fat (%)	CF (%)	Ca (%)	Available P (%)
Local diet	10.00	11.3	15.9	1.05	4	3.64	0.52
Commercial diet	10.12	11	16	4	3	3	0.41

[i] Cassava flour (40%), maize (16%) fishmeal (13.75%), limestone (7.55%), copra meal (6%), sweetpotato leaves (4.7%), cassava leaves (4%), kikuyu grass leaves (2.3%), peanut meal (2.13%), banana meal (2%), cooking oil (0.9%), low-energy layer concentrate (0.28%), common salt (0.2%), dry sweetpotato tubers (0.13%) and methionine (0.06%).
ME = metabolisable energy; CP = crude protein; CF = crude fibre; Ca = calcium; P = phosphorus.
Source: Besari et al (2017c).

The retail price of commercial layer pellets has more than doubled over the past decade (Ayalew 2011). A layer diet made with local ingredients and formulated with a similar nutrient profile to commercial layer feed was also tested (Table 10). When birds were fed on the local diet, egg production declined for all chicken types—by 56% for crossbred hens, 43% for commercial hybrids and 31% for village chickens. This indicates that village chickens may perform better on locally made layer feeds than other chicken types (Besari et al. 2017c). On the other hand, it has been demonstrated that sweetpotato and cassava may be blended with concentrates produced at commercial feed mills to make complete diets for poultry (Pandi et al. 2017) and pigs (Dom et al. 2014). Dual-purpose crossbred Australorp × Shaver Brown and Hy-Line Brown × Shaver Brown chickens fed cassava and low-energy concentrate diet compared to commercial layer feed maintained egg production at improved profit margins (Table 11).

Pig farming enterprises

Village and semi-commercial piggeries

In a typical village enterprise, assuming an average of two sows maintained and a survival rate of six pigs per farrowing, a piggery may produce about a dozen grower-finishers in a year. Six pigs per 6-month cycle (i.e. 120 days gestation + 60 days natural weaning to 20 kg body weight) may be a reasonable number under the village scenario. Most pigs raised on village farms are sold as fattened animals, but piglets may be sold and occasionally sows. In a typical semi-commercial enterprise, assuming an average of 10 sows maintained and a survival rate of eight pigs per farrowing, a piggery

Table 11. Cost of production and projected profit margin for dual-purpose crossbred chickens fed cassava and low-energy concentrate diet compared to commercial layer feed, based on average selling price of 12.10 kina per dozen eggs in Kokopo, East New Britain Province.

Diet	Total feed intake (kg)	Total feed cost (kina)	Cost/kg (kina)	No. eggs produced	Cost/egg (kina)	Selling price/egg (kina)	Gross revenue (kina)	Profit margin (kina)
LELC + BMC	193.57	567.16	2.93	1,532	0.37	1.01	1, 544.76	977.60
Commercial	182.94	578.09	3.16	1,502	0.38	1.01	1, 514.51	936.42

Source: Jeremiah et al. (2014).

Table 12. Estimated costs of making 400 kg of sweetpotato silage for feeding pigs at village or semi-commercial level on a PNG lowlands station trial.

Item/expense	Cropping and ensiling costs (kina)	Recurrent costs excluding labour (kina)
Planting	215.00	
Harvest and processing	150.00	
Weeding	130.00	
Salt (0.5% w/w additive)	4.00	4.00
Knives (6)	23.76	
Cutting boards (6)	82.37	
Ensiling garbage bags (40)	46.93	46.93
Tarpaulin (1)	82.50	
Scale (100 kg)	221.63	
Bins (20)	720.50	
Total costs	1,676.69	50.93
Estimated incremental costs of producing 400 kg sweetpotato silage (kina/kg)		0.13
Cost of dry feed at 33.2% DM (kina/kg)		0.38

Source: Dom and Ayalew (2009b).

may produce about 80 grower-finishers in a year. Forty pigs per 6-month cycle may be a reasonable number for a semi-commercial piggery at full operation. Profitability in village and semi-commercial piggeries is determined by the sale of grower-finisher stocks.

Intensive small-scale piggeries

The following economic analysis for a small-scale piggery enterprise assumes a starting weight of 20 kg and a 60-day finishing period, and uses feed intake and growth rates from two reported trials on local crossbred pigs (Dom and Ayalew 2009b; Dom et al. 2011a). The costs of making sweetpotato silage for feeding pigs at village or semi-commercial level were estimated (Table 12). At the village level labour for cropping is not costed, while at the semi-commercial scale labour is accrued to overall operational expenditure of the piggery and therefore not directly included in the cost of sweetpotato silage. The comparison was made between feeding grower-finisher pigs on pig grower alone (STDPG) or in mixed rations with farm-grown sweetpotato roots and forage either boiled (SPctfv) or ensiled (SPS50% and SPS75%) (Table 13). The unit price of sweetpotato silage was 0.38 kina/kg (dry weight) (Table 12) and the cost of pig grower was 2 kina/kg (July 2014).

Table 13. Costs and gross margins for 60-day grower-finisher period in a small-scale piggery using pig grower alone or in mixed rations with farm-grown sweetpotato roots and forage (either boiled or ensiled).

	STDPG[i]	SPctfv[i ii]	SPS50%[i]	SPS75%[iii]
Assumed starting pig weight (kg)	20.0	20.0	20.0	20.0
Estimated finishing pig weight (kg)	63.8	50.1	52.4	58.0
Weight gain for 60 days (kg/pig)	43.8	30.1	32.4	38.0
Feed intake for 60 days (kg/pig)	101.6	93.2	71.4	108.00
Feed cost for 60 days (kina/pig)	203.28	93.18	85.09	172.35
Unit cost of feed per kg weight gain (kina/kg)	2.32	3.09	2.20	2.84
Variable feed cost for 6 pigs over 60 days (kina)	1,219.68	559.08	510.55	1,034.13
Variable feed cost[iv] for 40 pigs over 60 days (kina)	8,131.20	3,727.20	3,403.65	6,894.19
Variable cost of labour[v] (kina)	7,560.00	7,560.00	7,560.00	7,560.00
Total variable costs (TVC) (kina)	15,691.20	11,287.20	10,963.65	14,454.19
Gross income (GI) from sale of 40 live pigs valued at 500 kina each (kina)	20,000.00	20,000.00	20,000.00	20,000.00
Gross margin[vi] (kina)	4,308.80	8,712.80	9,036.35	5,545.81
Gross margin per pig (kina)	107.72	217.82	225.91	138.65
Benefit–cost ratio (TVC/GI) at live pig price	1.27	1.77	1.82	1.38
Carcass weight at 75% yield[i] (kg)	47.9	37.6	39.3	43.5
Income per carcass at 7.00 kina/kg (kina)	334.95	263.13	275.10	304.74
Gross income from 40 carcasses (kina)	13,398.00	10,525.20	11,004.00	12,189.66
Gross margin[vi] (kina)	−2293.20	−762.00	40.35	−2264.53
Gross margin per pig (kina)	−57.33	−19.05	1.01	−56.61
Benefit–cost ratio (TVC/GI) at carcass price	0.85	0.93	1.00	0.84

STDPG = 100% standard pig grower ration; SPctfv = sweetpotato cooked tubers (roots) and fresh vine blended with 50% pig grower; SPS50% = 50% sweetpotato root and vine (1:1) silage with 50% pig grower; SPS75% = 25% sweetpotato root and vine (1:1) silage blended with 75% pig grower.

i Based on grower pig performance in Dom and Ayalew (2010a).
ii No costs by cooking farm-grown sweetpotato feeds.
iii Based on grower pig performance in Dom et al. (2011).
iv TVC of feed alone; other variable costs were not included.
v TVC for labour of three persons for 90 days sweetpotato cropping and piggery work at 3.50 kina/hour.
vi Gross margin = gross income – TVC.

The variable costs were for total feed cost of finishing six to 40 pigs and labour for cropping and piggery work. Labour costs were accrued over 90 days. Increasing the pig grower component in mixed rations may improve the finishing weights but does so at twice the feed cost. The benefit–cost ratio (BCR) on sweetpotato-based diets was sensitive when pig grower was increased from 50% (BCR = 1.00–1.82) to 75% (BCR = 0.84–1.38) of the ration, indicating that greater carcass or finish weights on the SPS75% diet were not an advantage because of the higher feed costs accumulated (Table 13). The reductions in feed costs on the sweetpotato-based diets were considerable compared to pig grower as a sole feed (STDPG). Estimated gross margins for a small-scale piggery were very much improved on sweetpotato-based diets (BCR = 1.00–1.82) compared to pig grower (BCR = 0.85–1.27) when the gross income from pigs was estimated either by carcass weight at 7 kina/kg or on a fixed live weight price of 500 kina for the 50–60 kg pigs. Using pig grower with 50% sweetpotato silage made on-farm provided a far better margin when the finished pigs were marketed at fixed live weight prices.

Assuming that over 20 sows are maintained, it may be reasonable to scale up the costs for semi-commercial operation to obtain an estimate for intensive pig production. Commercial piggeries operate under one of the following scenarios: (a) sows are raised and bred on location; (b) gilts are purchased and reared until ready to breed; or (c) weaned piglets are purchased for growing and fattening. The latter scenario removes the burden of maintaining sows. Profitability will depend on the output from the grower-finisher phase of the operation. This level of production has not been investigated, however given the rising consumer demand for pork, intensive small-scale piggeries are potentially a lucrative business option for local farmers.

Inland fish farming enterprises

There is currently no fish feed produced commercially in bulk in PNG. The Provincial Department of Agriculture in Eastern Highlands Province with the help of the National Fisheries Authority manufactures small amounts of fish feed which it provides to local farmers. Also, the Highlands Aquaculture Development Centre based in the Aiyura Valley of Eastern Highlands Province produces limited amounts of fish feed for its own use. Limited quantities of imported fish feed for aquarium species are available in a few high-end supermarkets (e.g. Food Mart in Lae) and from other commercial service providers (e.g. Industrial Waters Ltd). Aside from being expensive, available only in small quantities, and available only in towns and therefore unavailable to the majority of rural inland fish farms, these feeds may be less suited to species such as tilapia and carp.

Small-scale inland fish farming in PNG occurs either in pond systems or cage culture systems. Both systems are used in the highlands and lowlands for cash income and household consumption. Fish pond farming systems are widespread throughout the country while cage culture systems are found at fewer locations, such as Yonki and Sirunum Dam. The start-up costs for commencing inland fish farming enterprises are mostly for labour (other than family) and digging equipment to construct and maintain dams and ponds for the fish farm. Pond production expense items include digging materials, water inlet and outlet pipe materials, harvest and handling materials, pond maintenance materials, breeding stock, labour and feed. Cage culture expense items include floaters, harpa nets, harvest and handling materials, breeding stock, labour and feed. Water dams are recommended because an unmanaged source of water may not provide the volume of water or flow rates needed to properly manage fish ponds. It is worth noting that local fish feeds can be made entirely by hand, without large milling equipment. However, one key item that must be purchased is a meat mincer for extruding feed and making into pellets. Meat mincers cost 200 kina or less (Brian Bell Ltd) depending on the size. More thorough economic evaluations for fish feed manufacture and fish farming using local feeds are underway.

MEAT PRODUCTION VALUE CHAINS

Current information on livestock production in PNG is limited due to outdated surveys and estimates. For example, the PNG Household Food Survey 1996 and Gibson (2001) referenced extrapolations from a mixture of disaggregated census data (National Census 2001), industry reports (e.g. Poultry Industry Association), field observations by researchers and rather insensitive data extrapolations from the Food and Agriculture Organization (FAOSTAT data). This represents a distinct weakness for the livestock development planning process, particularly for determining the needs for specific inputs at identified locations within the wider domestic market for animal products.

The recent withdrawal of trade protection (import tariffs) for frozen chickens has had far reaching implications for the national poultry industry. PNG now imports frozen birds into the country for the first time in history. While importation of frozen birds has the benefit of reducing prices for chicken meat, other meat quality and quarantine issues have been raised. More importantly, the poultry industry, and in particular small-scale (i.e. backyard) broiler production, is the most active local livestock business, generating incomes for farming households and entrepreneurs as well as companies supplying feed and day-old chicks to grow-out units nationwide. This national industry will now have to compete with imports.

The production of pork at the local level may be undervalued despite its importance as a source of protein nationally and the more apparent trade in the densely populated highlands region (Figure 4). In the past 10 years, at least two major piggery operations have established themselves outside Port Moresby (Boroma Piggery and Alstonia) and long-term piggeries in Morobe Province have enhanced their output capacity to meet the perceived demand. However, the importation of cheaper pork products, while not a deterrent to consumers, does pose a severe competitive price restraint on local pork producers that may be able to supply the same market.

The production of inland fish by smallholders has not been assessed in the national production context as it is mainly considered an alternative protein source for households, with less active domestic trade. However, there is an emerging market for inland fish and fish products in general, a trend also seen in many other developing countries. At the time of this work data were not available, but they may be forthcoming from the National Fisheries Authority.

Current livestock research in PNG does not cater to the need for identifying specific points in the meat market for planned interventions. It is generally recognised that infrastructure development, such as road networks, facilitates the supply chains for goods and services; however the demand and supply which determine business growth and the requirements for business ventures, such as local trucking, storage and freezer facilities, have been kept on the periphery of the PNG development agenda. Local meat production is even less supported as there is a lack of small slaughter operators or abattoirs within areas that actively produce poultry and pigs in considerable numbers.

One recommended research intervention is to conduct value chain assessments of the current meat market. A value chain consists of a series of organisations that take a product from inputs, for example genetics, eggs, feeds, chicken, processing and markets, through to a final product that is consumed (Theo Simos pers. comm.). From value chain assessments it is possible to diagnose how effectively the chain is working in delivering the product(s) that consumers want. It would then be possible to identify interventions, which may be for primary services, for example supply logistics and sales and marketing, or support services, for example product and technology development and human resource management, and administrative and financial infrastructure. A broad and far-reaching market analysis should also include a study of the overarching policy needs.

CONCLUSION

There is convincing technical evidence of the nutritional suitability of formulated poultry and pig diets which make use of two major local feed resources, namely sweetpotato and cassava. Feed trials on-station and on-farm have shown cost-efficient growth rates for poultry as meat birds and layer birds and for crossbred grower-finisher pigs. Similar feeding and growth trials on inland fish species have demonstrated that sweetpotato and cassava may be used to provide the major portion of energy to juvenile GIFT tilapia.

While there are several challenges in the supply chain of sweetpotato as fresh produce at major urban markets, there are also options for improved local marketing of the root crops. This enables household farmers and smallholder entrepreneurs to diversify their incomes through markets for high-quality fresh

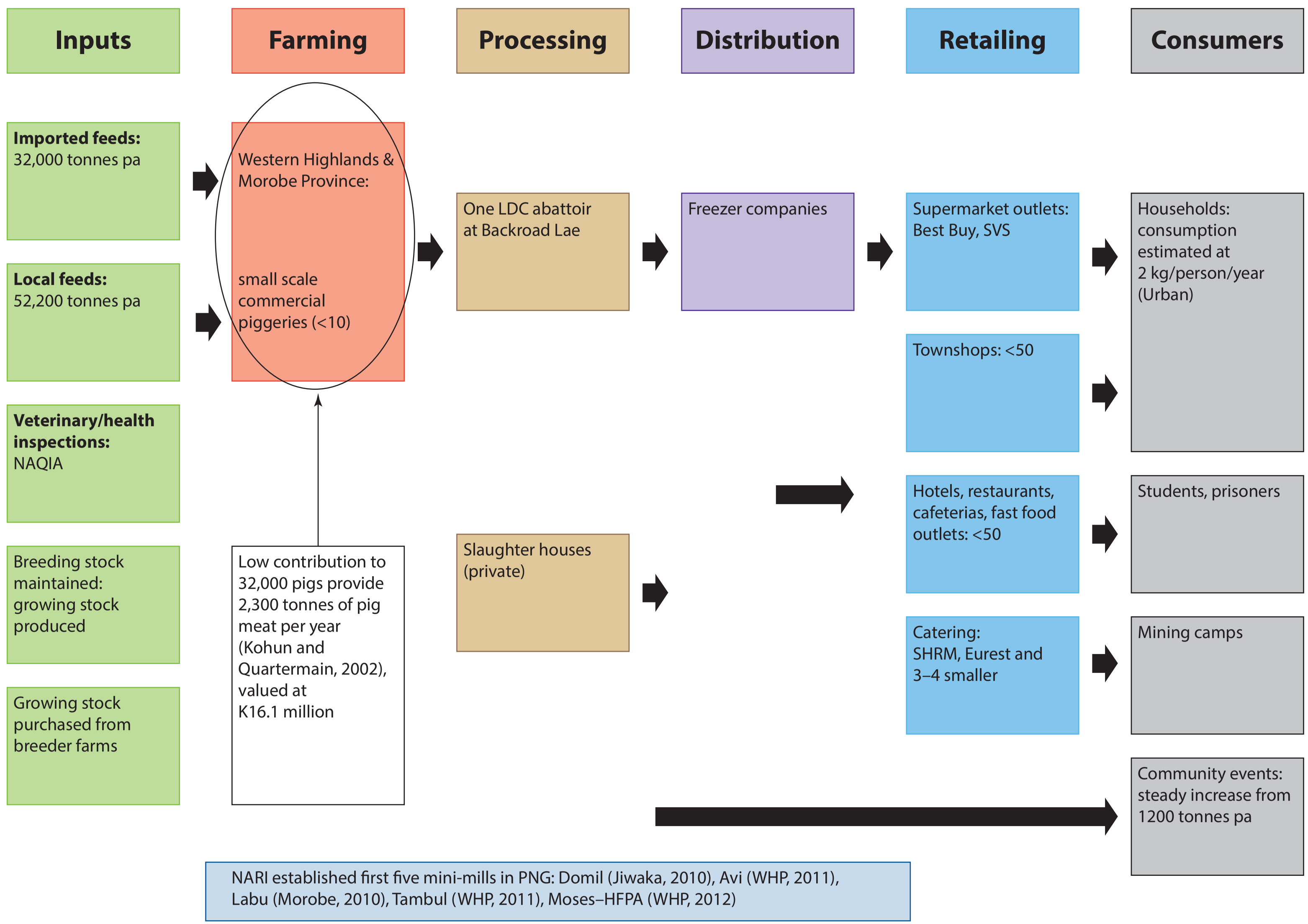


Figure 4. Small-scale pig production value chain in Lae City (Morobe) and Mt Hagen Town (Western Highlands) (ACIAR 2010).

food, processed flour and starch products, and for animal feed.

A mini-mill project provided pilot-scale assessment of mill equipment and mill operation at community level, with potential for mixed crop–livestock farmers and specialist producers to capitalise on the market provided by a central processing facility. The mini-mills concept can encourage small-scale farming at provincial and district level by providing locally milled feeds blended with nutritionally formulated concentrates to supply the growing demand for low-cost feeds for poultry, pigs and fish.

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Use of sweetpotato silage for improved nutrition of pigs in Papua New Guinea

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Abstract

The primary constraint to productivity of piggeries in PNG is the availability of a consistent and nutritious diet, especially for grower-finisher pigs. Imported or manufactured grain-based livestock feeds are generally unaffordable or otherwise unavailable. The majority of village farmers cultivate sweetpotato and cassava as dual-purpose crops for household food and livestock feed year round. This requires continuous family labour to prepare pig feed almost daily. However, there is a simple, low-cost ensiling technique that efficiently conserves nutrients in sweetpotato for over six months before it is fed to pigs. Blending sweetpotato silage in nutritionally balanced rations with protein feeds, such as copra meal, fishmeal, commercial pellet feed and poultry concentrates, resulted in improved growth rates and feed conversion at a competitive benefit-to-cost ratio. Innovative protein concentrate formulations containing mostly local ingredients were also tested and proved to be very highly digestible by grower pigs. Protein concentrates may be produced at local mini-mills, providing farmers easier access to feed at a reduced cost. Pig farming in other Pacific island countries may also benefit from this research.

INTRODUCTION

Farming pigs is an important family activity in many Pacific island countries, including Papua New Guinea (PNG), Solomon Islands, Vanuatu, Tonga, Samoa, and Wallis and Futuna (Morris 2007). In PNG, about 360,000 village farmers maintain an estimated 1.8 million pigs (NSO 2002; Quartermain and Kohun 2002). The pig (*Sus scrofa papuensis*) is native to the island of New Guinea (Pasveer 2003). Many different hybrid pig breeds have also been introduced to PNG, including the Large White, Large Black, Landrace, Hampshire, Berkshire, Tamworth and Duroc (Hide 2003). Uncontrolled crossbreeding has resulted in domesticated village pigs and feral pigs being regarded as a single genetic pool (Spencer et al. 2006; Ayalew et al. 2011).

The nutrition, health and environmental requirements of these mixed-genotype pigs are being re-evaluated. It is recognised that crossbred animals tend to perform better under semi-extensive or low-input management than purebreed parent stock. However, where more intensive management is practised, performance and productivity may be compromised by pig crossbreeding. Targeted research can help to recommend specific management conditions to improve local pig performance and enable breeding of pigs with improved productivity.

Regardless of genotype or pedigree of pigs kept in the village or in small-scale piggery enterprises, most tend to be fed with foods which are conveniently available and affordable to farming families (e.g. Ochetim 1993; Peters et al. 2001b; Dom et al. 2010). Local feed ingredients may include: (1) sweetpotato, cassava, taro and banana, including the stems and foliage; (2) forages such as kangkong (*Ipomoea aquatic*), pueraria, brassicas and mulberry leaves; (3) grasses, such as sugarcane and kikuyu; (4) leguminous shrubs (leucaena); and (5) cash crop waste or excess,

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such as coconuts, cocoa pods and coffee pulp. These ingredients are deficient in protein, but this can be fixed by blending with protein-rich concentrates such as copra meal, palm kernel meal, brewery waste, fishmeal and meat, blood and bone meals. However, increasingly imported grain feeds, such as corn, wheat, sorghum and soybean, as well as by-products such as corn and wheat millrun or rice bran, are popular feeds purchased either as dry meal or as pelleted stock feed.

Sweetpotato and cassava roots may replace corn and wheat as energy feeds in pig rations (Perez 1997; Akinfala and Tewe 2001; Gonzalez et al. 2002). Sweetpotato, cassava and taro are high in starch which provides sufficient digestible energy for pigs, while some protein is available in forage leaves and stems (Nwokolo 1990; Ravindran 1992). However, in addition to being high in dietary fibre, these local feeds contain anti-nutritional agents and are lower in dry matter content. Moreover, since the root crops perish rapidly after harvest, farming families have to cultivate crops continuously in order to maintain a supply of household food and pig feed. Preparing daily pig rations therefore requires considerable labour, including to cultivate and harvest the crops, obtain fuel and water for cooking, and prepare the feed.

Although this mixed crop–livestock farming system has enabled subsistence farming communities to survive successfully in the past, greater demands and challenges are faced by today's producers. An increasing human population, climate change, rising grain feed costs and more demand for pigs and pork meat (for consumer and customary purposes) necessitates more efficient use of locally available feed resources and the capacity to produce affordable feeds either on-farm or closer to farming communities.

Processing methods, such as milling, chipping, drying, cooking and ensiling, can remove the anti-nutrients in root and forage crops.

This paper describes an adapted and tested ensiling technique, and summarises the results of trials using silage to feed local mixed-genotype pigs in PNG. Relevant advances in feed formulation and milling are also discussed. These findings may also be relevant to other Pacific island countries.

THE ENSILING PROCESS

Ensiling (or ensilaging) is the process of producing silage—fermented, high-moisture stored fodder for livestock. Ensiling is commonly used for large-scale storage of dry grain feeds, such as corn, barley and sorghum. Root and tuber crops such as sweetpotato and cassava are high in moisture, bulky, and may need to be peeled, which makes them more difficult to process and manage in large quantities. However, where these crops are readily available and less costly (obtained from gardens, piggery feed crop or at local markets), and where the quantity of feed required is relatively small, it may be within the capacity of village farms to do the processing. In particular, where family or low-cost labour is available, small-scale ensiling may be an economical, resource-efficient means of feed storage for village and smallholder commercial piggeries. Ensiling also conserves feed nutrients for a relatively long time, allowing a more consistent diet to be fed to pigs.

An ensiling technique has been adapted from work in Vietnam (Peters et al. 2001a) and used in pig feed research trials in PNG (M. Dom, unpublished manual). Four critical factors required to achieve good ensiling are: (1) maturity and moisture level of the forage; (2) length of cut; (3) time taken for filling, packing and sealing; and (4) additives (Schroeder 2004). The ensiling technique involved harvesting sweetpotato roots and vines at maturity, washing off dirt and dry material, chopping and grating into small pieces, sun-drying for several hours, mixing with salt, compacting the mixture into plastic garbage bins lined with polyethylene garbage bags, and sealing the bags so that they were air-tight. The materials used were readily available to households and included hand knives, kitchen graters, cutting boards, tarpaulins and soft string.

Ensiling of cassava roots can be done using the same technique (Hang 1998; Dom et al. 2017). However, cassava contains more anti-nutrients than sweetpotato, including cyanogenic glucosides which convert to toxic hydrogen cyanide (HCN), phytates, tannins, oxalates and trypsin inhibitors. Cassava processing for ensiling therefore requires the additional step of peeling the tubers which removes the majority of the cyanogens (Tewe 1991; Teka et al. 2013). Some varieties of sweetpotato contain high levels of trypsin inhibitors, although most cultivars grown in PNG and the other Pacific island countries contain lower amounts of these naturally occurring plant proteins (Bradbury and Holloway 1988). Milling, ensiling, drying, as well as soaking in water and cooking at high temperature, are all effective means for removing hydrogen cyanide and reducing trypsin inhibitors (Tewe 1991).

Ensiling produces an anaerobic environment where natural fermentation of the freshly harvested plant material takes place, facilitated by plant enzymes and lactic acid bacteria. The process causes a lowering of pH from 7 to 4 (Schroeder 2004). During testing, the drop in pH usually occurred within the first four days and was accompanied by release of carbon dioxide, which caused the garbage bags to balloon. Prior to that, on the first day, the plant material exhausted the air within the sealed bag and caused a suction effect on the bag. After 14 days, the carbon dioxide had reduced and the swelling had subsided. The silage remained at pH 4 and a pungent fruity-acidic odour developed in the silo over the 14 days, indicating the presence of organic acids. No microbiological or organic acid testing was conducted.

ADVANTAGES OF ENSILING

Ensiling is a labour-intensive process but it has distinct advantages for preserving and storing feed at the small scale. Even when properly cured, sweetpotato roots may store for only a few weeks after harvest, while ensiled sweetpotato can be stored for much longer periods, and also maintains quality. Ensiling of sweetpotato roots and vines has been shown to conserve feed nutrients for well over six months (Dom and Ayalew 2009a, b; Dom et al. 2010). Ensiling also makes better use of the vine material, which is often discarded as garden waste if it is not fed fresh to pigs. While labour is required for an entire day, after this no further harvesting or processing of feed is needed. This is in contrast to the daily practice of preparing sweetpotato feed by sourcing, cleaning, boiling and blending with other feeds. Stored silage is readily available for blending pig feed at any time. Furthermore, no fuelwood, kerosene, gas or electricity is required for cooking as the fermented silage can be fed directly to pigs of all classes, from piglets to sows. Lastly, ensiling is easily up-scaled if there is a need to produce greater quantities of feed. For example, six women and two men working for three days can ensile (by hand) about 400 kg of sweetpotato root and vine into mixed silage. Alternatively, two men can produce at least 160 kg per day with a manual (foot-pedal powered) mechanical grater. Modified electrical or diesel-powered flake mills have been developed with the capacity to process 40 kg of fresh roots per hour. An ongoing ACIAR project (ASEM/2010/053, 'Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea', http://aciar.gov.au/project/asem/2010/053) is developing local mini-mills for processing local feeds in preparation for blending with specifically formulated protein concentrates for poultry, pigs and fish.

SWEETPOTATO SILAGE TEST DIETS AND NUTRITIONAL VALUES

A number of simple diet formulations were made by blending sweetpotato root and vine silage with locally available protein sources, for use in feeding trials. Nutritional values of the ingredients and the diet formulations were measured (Table 1). Sweetpotato and cassava are commonly available in most village gardens where pigs are kept, and pig grower pellets, copra meal and fishmeal are the most common protein feeds used by village and small-scale farmers. Giant taro is commonly fed to pigs in East New Britain Province as well as rice bran, which is becoming more available from local rice-processing mills.

Growing pigs require more feed and regular feeding because of their high metabolic needs. Feed must contain adequate protein (14–16%). Blended sweetpotato silage is a very palatable feed for grower pigs, is very high in digestible energy (16 MJ/kg DM), and also improves the utilisation of other feed nutrients, including protein (Giang et al. 2004; Dom and Ayalew 2009a, b).

The commercial pig grower pellet feed is formulated to provide 16% protein and 14 MJ/kg digestible energy, which is satisfactory for grower pigs if provided at 2 kg per pig per day. Pig grower pellet was used as a standard reference feed in the feeding trials at a lowland station, at local farms in the highlands and at a coastal island location. Silage stored very well at all locations.

Table 1. Nutritional values of major feed ingredients and test diets used in pig feed trials.

Ingredient/diet	Nutritional value		
	Dry matter (%)	Crude protein (%)	Gross energy (MJ/kg)
Sweetpotato, chopped fresh vines (FV)	9.1	2	5.8
Sweetpotato, grated roots (CR)	35.1	<1	17
Sweetpotato root and vine silage (SPS)	33.2	2	16
Giant taro (TARO)	14.3	2.1	4.5
Rice bran (R)	88.3	8.2	–
Copra meal (C)	90.0	19.9	17.3
Fishmeal (F)	94.1	53.7	17.5
Pig grower (STD)	91.8	16	14
Test diets			
SPS50	60.8	8.0	15
SPCRFV	76.2	8.0	15
SPS75	63.7	14.6	15.2
FCSPS (Morobe Province)	46.9	16.2	16.7
STD+SPS ad lib.	53.8	9.6	–
FCSPS (WH Province)	39.0	8.4	–
RCTARO	60.9	13.3	17.5
FCRICE	91.7	19.0	17.6
FCSPS (ENB Province)	48.8	17.7	17

SPCRFV = sweetpotato cooked roots and fresh vines blended with 50% pig grower; SPS50/75 = sweetpotato silage blended with 50% and 75% pig grower; FCSPS = fishmeal and copra meal blended with sweetpotato silage; RCTARO = rice bran, copra meal blended with giant taro; FCRICE = fishmeal, copra meal and rice bran. FCSPS diet was tested in three different provinces, Morobe, Western Highlands and East New Britain.
Source: Adapted from Dom and Ayalew (2010) and Dom et al. (2010, 2011).

ON-STATION PIG FEEDING TRIALS

We tested the performance of local mixed-genotype grower pigs (25 kg) on two different diets: the traditional ration of cooked sweetpotato roots with fresh vines, and mixed sweetpotato root and vine silage (Table 2) (Dom and Ayalew 2010; Dom et al. 2011). The experiments were carried out at Labu Station in Morobe Province in the lowlands, and were designed to emulate small-scale farming operations. The pigs were bred at Labu Station and housed in an open shed with a high sloping (4 m) corrugated iron roof and concrete pens. Steel pipes provided a constant supply of clean water through nipple drinkers, and feed was provided in concrete feeders. The experiments used 12 grower pigs kept as male and female pairs, which were fed to satisfaction over 8 weeks. Sweetpotato components were blended with either pig grower at 50% (SPS50) or 75% (SPS75) of the feed ration, or a mixture of fishmeal and copra meal (FCSPS). The test diets compared favourably with the 100% commercial pig grower used as a standard reference feed in both trials (STD1 and STD2). Sweetpotato silage blended with 50% pig grower (SPS50) reduced the pig feed intake and improved feed conversion. The carcass yield was 6.3% higher for pigs fed the SPS50, the pork meat was leaner (10.2 mm back fat) and the unit return based on final live weight was marginally improved (by 0.60 kina/kg) compared to the 100% pig grower feed.

Table 2. Performance and carcass yield of local crossbred grower pigs fed cooked or ensiled sweetpotato blended with fishmeal or copra meal concentrates or commercial pig grower in on-station feed trials in Morobe Province, PNG.

Parameter	Treatment means for each test diet					
	STD1*	SPCRFV	SPS50	STD2**	FCSPS	SPS75
Dry matter intake (g/day)	1,694	1,553	1,190	1,866	1,681	1,800
Average daily gain (g/day)	730	502	540	743.4	442.1	634.1
Feed conversion ratio (kg/kg)	2.33	3.09	2.21	2.51	3.8	2.84
Starting weight (kg)	27.1	22.9	28.8	25.2	22.9	23.8
Final live weight[a] (kg)	68	51	59	61.8	45.4	55.0
Carcass weight (kg)	48	37	45	–	–	–
Carcass yield (%)	70.6	72.5	76.3	–	–	–
Sale value (kina)	322	259	315	–	–	–
Return on live weight (kina/kg)	4.74	5.08	5.34	–	–	–
Back-fat depth (mm)	22.28	13.19	10.20	–	–	–

[a] The pork market in PNG is for pigs at 60–70 kg finished weight.
STD1 and STD2 = standard pig grower feed; SPCRFV = sweetpotato cooked roots and fresh vine blended with 50% pig grower; SPS50/75 = sweetpotato silage blended with 50% and 75% pig grower; FCSPS = fishmeal and copra meal blended with sweetpotato silage.
Source: Adapted from *Dom and Ayalew (2010) and **Dom et al. (2011a).

ON-FARM PIG FEEDING TRIALS

Feeding pigs in the PNG highlands is a challenging task. The cooler climate increases feed intake due to higher energy requirements of pigs to maintain their body temperature. Also, the growing season for sweetpotato crops is longer, and there is competition for food production on the limited arable land. Nonetheless, pig keeping is a major activity with great cultural and socio-economic value placed on pigs and pork meat. Small-scale farmers in the PNG highlands tend to be very skilled and knowledgeable about pig keeping, and there are roadside markets where sweetpotato is sold for pig feed. Village pig farmers usually keep between one and ten sows, depending on the availability of grazing and their ability to produce or obtain sufficient feed, and the demand for pigs for local customary obligations. Capable and well-resourced pig farmers may manage 10–20 sows as small-scale enterprises and may produce over 100 piglets in a year, depending on the needs of their customers. These farmers use fishmeal, copra meal and wheat millrun as well as commercial pellet feeds, but regular supply of feed is a problem. Some pig farmers grow small plots of sorghum and oats and use these with vegetable crop residue, especially from brassicas, as sow feed.

In an on-farm trial in the high-altitude highlands of Western Highland Province, a locally made pig feed was tested against sweetpotato silage blended with pig grower and the growth of the farmers' crossbred pigs compared (Dom et al. 2010). Eighteen mixed-pair male and female grower pigs (25 kg) were housed in nine pens with concrete flooring and thatched roofing (2 m slanted, low-profile), with water provided regularly in plastic dish drinkers and feed offered to satisfaction over 12 weeks. The growth rate of the pigs was reduced when fed either a blend of fishmeal and copra meal (FCSPS) or pig grower with sweetpotato silage (STDSPS) compared to the 100% pig grower feed (STD) (Table 3). The 100% standard pig grower feed also produced slower growth at the high-altitude location (592 g/day) than in the lowlands trials (730 and 743.4 g/day; Table 2). It was concluded that increased feed intake was used for generating body heat in the cooler climate (Dom et al. 2010). Feed intake on mixed-diet STDSPS was lower than STD so there may have been nutrient or environmental requirements not met. In addition, the grower pigs in the highlands trial comprised mostly the village pig genotype rather than the hybrid cross. Nevertheless, the socio-economic value placed on pigs finished at around 60 kg brought very high selling prices in the highland market, which resulted in better returns.

At a feed trial conducted on a farm located on the coast of the large island of New Britain, the story was different. Pig keeping here was not traditionally common practice and the farmers were less skilled and less knowledgeable. However, the isolated location created a good demand for pigs and the piggery enterprise had a large capital investment. There was good concrete flooring and walling with sufficient space in the pens, although water was not freely available. The pigs were apparently of good genotypes of some commercial origin, with sows producing at least 10 piglets per litter. Two critical factors noted at this small-scale intensive farm were the lack of a good protein feed and the early weaning of piglets (at less than 28 days old).

The experiment used 18 local crossbred weaned pigs (10 kg) kept in an open shed with low corrugated iron roofing (2 m flat profile) and plastic dish feeders and drinkers, with feed provided to satisfaction and clean hosed water provided regularly (Dom et al. 2011). The main available feed resources used in the island piggery were giant taro, rice bran and copra meal. There was a notable lack of fishmeal and pig grower from local feed suppliers; in fact, fishmeal was flown in at high cost to prepare the test diets. It was notable that the same formulated diet of FCSPS used in previous feed trials was unable to lift the growth performance of the grower pigs to a similar level (Table 3). This was most likely a result of disadvantaged health from a young age considering the very low starting weights of the pigs, despite being maintained on a creep feed mixture of copra meal and corn meal (Dom et al. 2011). Only the high dry matter and high protein diet FCRICE (Table 1) provided an appreciable lift in growth performance (Table 3). Weaned pigs require considerably better nutrition than was provided before grower performances can be markedly improved.

Table 3. Performance and carcass yield of local crossbred grower pigs fed cooked giant taro, sweetpotato silage blended with fishmeal and copra meal, rice bran concentrates or commercial pig grower in on-farm feed trials in Western Highlands (highlands trial) and East New Britain Provinces (coastal trial), PNG.

Parameter	Treatment means for each test diet					
	Highlands trial			Coastal trial		
	STD	FCSPS	STDSPS	FCRICE	FCSPS	RCTARO
Dry matter intake (g/day)	1,886	1,145	1,329	–	–	–
Average daily gain (g/day)	592	368	398	336	196	104
Feed conversion ratio (kg/kg)	3.18	3.10	3.33	–	–	–
Starting weight (kg)	21.1	28.4	24.8	10.3 ± 0.96	9.5 ± 1.58	9.8 ± 2.90
Final live weight (kg)	75	62	61	33.8 ± 4.03	23.3 ± 3.59	17.0 ± 3.72
Carcass weight (kg)	50	48	48	–	–	–
Carcass yield (%)	66.7	77.4	78.7	–	–	–
Sale value (kina)	600	600	600	–	–	–
Return on live weight (kina/kg)	8.00	9.68	9.84	–	–	–
Back-fat depth (mm)	30	24.7	15.7	–	–	–

STD = standard pig grower feed; FCSPS = fishmeal and copra meal blended with sweetpotato silage; STDSPS = pig grower with sweetpotato silage; FCRICE = fishmeal, copra meal and rice bran; RCTARO = rice bran, copra meal blended with giant taro.
Source: Adapted from Dom et al. (2010) (Western Highlands trial) and (2011b) (East New Britain trial).

CURRENT RESEARCH AND PROSPECTS FOR PIG PRODUCTION

Village farmers are seeking advice on how they can utilise local feed resources in pig diets. It is important to develop a more comprehensive range of diet options and demonstrate improved feeding options to pig farmers. Most pigs will grow on a limited diet but pig growth and reproduction levels are usually poor. If the nutrient levels in the feed are not balanced, there is wastage of excess nutrients. Use of a balanced ration, which meets the pig's daily requirement of nutrients and achieves maximum levels of production, will result in minimum wastage of nutrients. However, it is rare for village farmers to have all the local resources available that can be used to make a balanced ration. Use of concentrate, which contains the major portions of protein, vitamins and minerals and can be mixed with local ingredients, has considerable potential in the pig industry as farmers become commercially orientated.

In the search for a convenient protein concentrate for grower pigs, two poultry concentrates were tested on local crossbred pigs and, when blended with sweetpotato silage, provided satisfactory growth rates (average daily gain (ADG) 615–634 g/day), although feed conversion was less efficient (feed conversion ratio (FCR) 4.28–3.99) than the commercial pig grower feed (ADG 722 g/day and FCR 2.89) (Dom et al. 2014). The two poultry concentrates, according to research by the National Agricultural Research Institute (NARI) and ACIAR, may be combined with either sweetpotato or cassava for feeding broiler birds (Pandi et al. 2017). In the case of pigs, a high-energy protein concentrate (containing protein, minerals and vitamins) could be produced by local mills and farmers could supplement this with locally grown feed resources such as cassava, sweetpotato, banana, sago etc. (depending on location). Nutritionists could develop a range of concentrate rations for pigs that can be mixed with carbohydrate resources or even protein resources, such as fishmeal and copra meal. Developing a protein concentrate to blend with sweetpotato and cassava in dry meal, boiled or in ensiled form is the current focus of pig nutrition research at NARI.

Ensiling sweetpotato was promoted to farming communities in the Solomon Islands and Vanuatu as part of a regional research project to demonstrate adaptation of smallholder agriculture to risks associated with climate variability and change, supported by the European Union (NARI EUARD, 2011). NARI worked in collaboration with the Ministry of Agriculture and Livestock of Solomon Islands as well as the Department of Agriculture and Rural Development of the Republic of Vanuatu to demonstrate the use of sweetpotato ensiling technology for feeding pigs in Solomon Islands and Vanuatu. Preliminary results indicate that smallholder pig farmers in both countries find the technology appropriate and effective in improving weight gain of growing pigs. Some farmers at Malafau and Middlebush in Vanuatu even made silage from banana leaves and fruits when these were abundantly available, and successfully fed the silage as a feed supplement to growing pigs.

The current feed mill project funded by ACIAR (ASEM/2010/053; http://aciar.gov.au/project/asem/2010/053) is using the concentrate approach and evaluating the digestibility and production efficiency of concentrate blended with sweetpotato and cassava silage fed to grower pigs. Future work will examine the impact of local feed ingredients in these rations on gut health, nutrient retention and partitioning in pigs. This will enable nutritionists to formulate diets using local feed resources that more effectively meet the nutrient requirements of pigs.

CONCLUSIONS

Effective rations for pigs can be developed from high-protein concentrates blended with local feed resources, such as roots and tubers, fruit, forage, grasses, shrubs and cash crop waste. Perishable succulent and seasonal feed resources can be effectively preserved and stored in the form of silage to provide a more consistent supply of highly digestible and nutritious feed to growing pigs and sows. In promoting smallholder commercial piggeries in rural areas of Pacific islands where root and tuber crops serve both food and feed functions, the silage-making technology can be effectively used to add value to fresh produce, improve storage life of these local feed resources, and create opportunities for local employment. Protein concentrates can be manufactured by regional mini-mills or commercial mills, to complete diets that meet the nutritional requirements of the growing or adult pig.

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Feed ingredient analysis and evaluation for smallholder pig and poultry production in Papua New Guinea

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Abstract

Animal nutrition research at the National Agricultural Research Institute in Papua New Guinea (PNG) is aimed at developing improved feeding systems for livestock so that smallholder farmers can make gains in productivity. Two livestock feeding systems for growing-out pigs and poultry, based on local feed ingredients, provided a wealth of technical information with potential for enhancing production of pork and chicken meat by smallholder farmers. A series of feeding trials revealed that replacing imported grain-based commercial feeds with up to 50% sweetpotato or cassava was effective for both animal performance and economic benefits for growing pigs and poultry under small-scale farming systems, as practised by about 580,000 farmers in PNG. Basic animal nutrition experimental techniques, combined with chemical analysis of innovative feeds, led to the development of new feeding systems that promote extensive use of local feed resources. In addition to adding value to local produce and generating local employment, the technologies can facilitate commercialisation of otherwise subsistence-based smallholder agriculture. These development outcomes contribute directly to PNG Vision 2050's core strategic development area in research and development.

INTRODUCTION

PNG Vision 2050 recognises that subsistence agriculture plays a critical role in enhancing rural livelihoods and the cultural lives of many, and that opportunities exist in food production (i.e. vegetables and fresh meat) for the domestic market. However, realising these opportunities remains a challenge (NSPTF 2009). The use of analytical techniques and chemical testing services has an important role in developing innovative science and technology solutions to overcome some of the challenges which limit development of the rural economy.

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Analytical chemistry provides essential technical tools for evaluating natural resources, such as soil, water, plant and animal materials. Applied in the study of animal nutrition, this can contribute to: (a) relieving dependency on imported grains as energy sources in commercial feeds by enabling effective use of local feed resources as substitutes; (b) creating marketing opportunities in the utilisation of suitable local feed crops; (c) encouraging small-scale feed manufacturing in community-based feed mills; (d) diversifying income-earning opportunities through sale of local feed sources as well as livestock products; and (e) contributing to value-adding through post-harvest food processing. The National Agricultural Research Institute (NARI) addresses these development issues through its strategic plan which focuses on enhancing productivity, efficiency, stability and sustainability of the smallholder agricultural sector (NARI 2011).

According to the PNG nationwide agricultural census of 2000, about one-half of rural households raise pigs for a living (NSO 2002), while in parts of the Southern Highlands, Enga, Western Highlands and Simbu Provinces, up to three-quarters of households keep pigs. Pigs are the most important smallholder livestock in the country (Ayalew 2011) and a conservative estimate of the economic value of the small-scale pork industry is 162 million kina. Gwaiseuk (2001) reported that the PNG commercial livestock sector is dominated by the production of broiler chickens due to a high demand for poultry meat. Quartermain (2001) foresees growth of 5% per annum in the production of meat for household consumption, commensurate with a population growth of 2.0–2.5% per year and increasing affluence. Expansion and sustainability of this subsector depends on encouraging more people to farm broilers by offering support for critical inputs, such as lower feed costs, animal health services and regular extension services, thereby making it attractive and profitable.

Animal production is governed by two main factors: the animal's genetic potential, and the provision of suitable nutritional feed to achieve this potential. Knowing the nutritive content of a feed ingredient is the first step to ensuring proper and cost-efficient ration formulation for maintaining animals, and this entails the use of analytical techniques and testing. Hence, feed evaluation has considerable scientific and practical significance (Nehring and Haenlein 1973).

Animal feeding systems are directed towards economical maintenance of breeding stock and profitable production of animal products (meat, eggs, milk and fibre). Farmers in different places keep different types of livestock and operate under different bio-physical constraints. Formulated feed rations must be suited to nutritional requirements of the species, age or class of the animal, local environmental conditions and resource availability, farmer objectives and economic limitations. In animal nutrition research, feed ingredients and formulated rations must be based on thorough chemical analysis of the nutritive content of different components to enable growth and maintenance of animals within specifically defined performance parameters.

In general, the cost of feeding commercial livestock can account for 60–80% of total production costs, especially in countries like PNG where grain has to be imported (NSO 2002). Grain feeds provide the bulk of protein and energy ingredients used in the locally manufactured feeds, although local ingredients such as copra meal, fishmeal, sweetpotato and cassava are also available and may supplement the grain components in blended feeds. Nutritionally, energy is the major consideration in pig and poultry diets, given that animals eat to satisfy their energy requirement. The relationship between the energy requirement and intake is the cornerstone of practical diet formulation. By combining local and imported feedstuffs to formulate diets with predetermined nutrient and energy ratios, the intake of nutrients can be optimised and the cost of feeding reduced. The effectiveness of this method of diet formulation depends on the accuracy of analytical measurements and precision of estimates describing the energy requirements of animals and the available energy in feeds.

Cereals, such as sorghum, maize or wheat, are the major sources of energy in stock feed, while soybean, a grain legume, is the major source of protein. Because most of these grains are imported, the cost of commercial animal stock feed is a major impediment to the expansion and sustainability of the livestock industry, especially for smallholder producers.

As a response to this challenge, NARI has approved the release of two livestock feeding technology packages based on the use of local feed ingredients (sweetpotato and cassava) to partially replace imported grains used in commercial feeds for growing-out pigs and poultry. The technologies are based on ensiled sweetpotato for pig feed, and broiler concentrates blended with sweetpotato and cassava for poultry. The research is predicted to impact on the livelihoods of about 580,000 small-scale pig and poultry farmers. This paper describes the two feeding system projects conducted at NARI, including description of the analytical chemistry inputs and limitations, key research findings, project outputs, recommendations and their implications with reference to the PNG Vision 2050.

IMPROVED PIG FEEDING SYSTEM

Background

Smallholder farmers predominantly maintain their pigs on supplements of sweetpotato and cassava, both of which are a very suitable source of dietary energy in animal feed provided that the starchy roots are cooked. However, a considerable limitation in rural villages is poor storage of the root crops and green forages used as feed. Ensiled sweetpotato forage was tested as a feed preservation technique that provides nutritious, highly digestible (fermented) feed, maximises the use of tuber and vine, reduces the need for labour in daily pig feeding chores (especially for women) and eliminates the use of cooking fuel (Dom and Ayalew 2009a).

Materials and methods

The technique of ensiling sweetpotato for feeding pigs was adapted from work conducted in Vietnam (Peters et al. 2001), and the fermentation parameters and keeping quality of ensiled sweetpotato tuber and vine were tested at the NARI Livestock Research Station, Labu (latitude 6°40′27″ S, longitude 146°54′33″ E). Analytical techniques were used to evaluate palatability and digestibility in pigs of the sweetpotato tuber and vine ensiled with and without addition of urea. The chemical testing on the silage was done at the National Analytical Laboratory UDC, Lae.

Pig feeding trials were conducted on the use of sweetpotato silage as a major supplement (up to 50%) to commercial grower rations in on-station and on-farm locations in the lowlands and highlands of PNG. The feeding trial had a 4 × 4 Latin square experimental design with four exotic-cross growing pigs and four test diets interchanged over four 10-week periods. Treatment diets were fed as mixed rations with standard feed. More details of the experimental trials are available in the literature (Dom and Ayalew 2009a, b, 2010; Dom et al. 2010).

Palatability and digestibility

Palatability of feeds, or how much of the feed is accepted by the animal and consumed, is determined by voluntary dry matter intake. Digestibility is the absorption of feed nutrients passing through the gastrointestinal tract. The following step-wise equations summarise the information sought from the trials:

1. Feed intake = feed offered – feed refused
2. Nutrient intake =
   nutrient consumed in feed – nutrient in animal waste
3. Nutrient in animal waste =
   nutrient in manure + nutrient in urine
4. Apparent digestibility of nutrient =
   (nutrient intake/nutrient consumed) × 100%

A series of nutrient analyses was conducted in the digestibility trial. Animals were maintained in specially adapted metabolic crates which facilitate the collection of manure and urine for the evaluation of their nutrient contents.

Nitrogen balance

Nitrogen balance testing involves a close examination of the fate of protein supplied to animals in feed. The analysis differentiates protein nitrogen which has been ingested by the animal and the amount that is retained after losses in manure and urine. This analysis is important because protein is needed for normal animal growth and because protein is also a major cost consideration in the balanced feed ration.

Results

Table 1 shows the nutrient composition of the treatment diets. Table 2 shows the apparent digestibility of proximate nutrients as dry matter, ash, fibre, crude protein and nitrogen-free extract. Table 3 shows the nitrogen balance for the diets. The growth performances as body weight gain of the four pigs are given in Table 4. Table 5 includes data from a separate feeding trial conducted with the same diets and provides a comparison of the estimated value of pork meat derived from pigs kept on standard commercial feed and either sweetpotato silage or cooked tubers and fresh vine mixed with standard feed (Dom and Ayalew 2009b).

Table 1. Nutrient contents of the experimental diets (on a dry matter basis).

Nutrient	Overall mean (%)	Treatment means (%)				SEM	*P*
		SPctfv	SPnil	SPwou	SPwu		
DM	64.69	57.69[a]	86.60[b]	57.55[a]	56.90[c]	0.114	<0.001
Ash	2.93	2.38[a]	4.42[b]	2.48[a]	2.43[a]	0.055	<0.001
Fibre	3.12	2.50[a]	4.71[b]	2.61[c]	2.66[c]	0.001	<0.001
CP	7.66	6.09[a]	11.74[b]	6.07[a]	6.72[c]	0.106	<0.001
NFE	50.98	46.72[a]	65.72[b]	46.38[c]	45.09[c]	0.058	<0.001

Treatment means with different superscripts are statistically different at 5% level of significance.
DM = dry matter; CP = crude protein; NFE = nitrogen-free extract; SPctfv = sweetpotato cooked tubers and fresh vine; SPnil = standard ration without sweetpotato; SPwou = sweetpotato silage without urea addition; SPwu = sweetpotato silage with urea addition.
Source: Dom and Ayalew (2009a).

Table 2. Nutrient digestibility of the experimental diets (on a dry matter basis).

Nutrient	Overall mean (%)	Treatment means (%)				SEM	*P*
		SPctfv	SPnil	SPwou	SPwu		
DM	88.02	90.60	86.55	87.53	87.40	1.01	0.111
Ash	69.0	72.4	68.8	68.3	66.6	2.75	0.542
Fibre	71.2	75.3	72.0	67.8	69.7	2.58	0.293
CP[i]	77.52	80.30[a]	80.17[a]	73.97[b]	75.62[a,b]	1.485	0.052
NFE	91.58	93.68[a]	89.95[b]	91.43[a,b]	91.28[a,b]	0.754	0.064

[i] Crude protein in the manure alone.
Means with the same superscript are not significantly different at the 5% level.
Abbreviations are given in Table 1.
Source: Dom and Ayalew (2009a).

Table 3. Digestibility and retention of N for the different diets.

N (g/day)	Overall mean	Treatment means				SEM	*P*
		SPctfv	SPnil	SPwou	SPwu		
Intake	31.50	33.5[b]	45.0[a]	24.0[c]	23.4[c]	3.270	0.002
Faeces	6.85	6.65[ab]	8.90[a]	6.27[b]	5.57[b]	1.272	0.017
Digested	24.6	26.8[b]	36.2[a]	17.7[c]	17.8[c]	20.03	0.002
Urine	7.06	6.52	7.60	5.90	8.22	1.567	0.598
Retention	17.56	20.32[b]	28.57[a]	11.83[c]	9.52[c]	1.530	<0.001
Retention as % of:							
N intake	53.20	60.70	63.40	49.40	39.30	4.960	0.046
N digested	67.8	75.3	78.9	65.8	51.0	5.79	0.053
Digestibility of N[i] (%)	77.51	80.27[a]	80.17[a]	73.99[b]	75.60[ab]	1.488	0.053

[i] Digestibility of N = N digested/total N of diet × 100%.
Treatment means with different superscripts are statistically different at 5% level of significance.
Abbreviations are given in Table 1.
Source: Dom and Ayalew (2009a).

Table 4. Total live weight gain (LWG), average daily gain (ADG), average daily feed intake (ADI) and feed conversion ratio (FCR) on the different diets on a dry matter basis.

Parameter	Overall mean	Treatment means				SEM	*P*
		SPctfv	SPnil	SPwou	SPwu		
LWG (kg)[i]	2.72	3.25	3.37	2.37	1.87	0.461	0.164
ADG (kg)	0.769	0.80	0.85	0.80	0.63	0.196	0.856
ADI (g)	1680	1985[a]	2076[a]	1424[b]	1235[b]	120.4	0.006
FCR	2.01	1.92	2.12	1.85	2.14	0.371	0.924

[i] LWG values were the average of three days of consecutive observation (collection) periods that followed seven days of adaptation as animals switched from one treatment to the next.
Treatment means with different superscripts are statistically different at 5% level of significance.
Treatment abbreviations are given in Table 1.
Source: Dom and Ayalew (2009a).

Table 5. Final live weight, carcass weight, dressing percentage, back fat thickness and sale value of three pigs on different diets.

Diet	Final live weight (kg)	Carcass weight (kg)	Dressing (%)[i]	Sale value (kina)	Unit price (kina/kg)	Back fat thickness (mm)
STD	68.0	48.0	70.6	322.00	4.74	22.28
SPS	59.0	45.0	76.3	315.00	5.34	10.20
SPctfv	51.0	37.0	72.5	259.00	5.08	13.19

[i] Dressing (%) = carcass weight (kg)/final live weight (kg) × 100%.
STD = standard commercial feed; SPS = sweetpotato silage; SPctfv = sweetpotato cooked tubers and fresh vine mixed with standard feed.
Source: Dom and Ayalew (2009b)

IMPROVED POULTRY FEEDING SYSTEM

Background

Sweetpotato and cassava were used as major energy sources for broiler finisher diets. A high-energy concentrate was combined with cassava tubers, while a low-energy concentrate was combined with sweetpotato roots. The experimental technique for studying poultry feeds uses the concept of apparent metabolisable energy (AME), which is similar to digestibility but focuses on energy intake from feed.

Materials and methods

The details of the experimental poultry feeding trials are available in the literature (Glatz 2007) and from J. Pandi (unpublished data).

A total of 192 Ross 308 strain day-old broiler chicks were raised on standard broiler starter rations for 20 days. At 21 days, the 192 experimental birds weighing within ±200 g of the average weight of the flock were randomly allocated to metabolism cages and fed the test diets for 21 days.

Dry matter analysis

Samples for analysis were removed from the refrigerator and allowed to reach room temperature before the analysis was conducted. Crucibles were weighed then approximately 2 g of the test diet or ingredient was placed into the empty crucible and the total weight taken. After weighing, the crucibles containing the samples were placed overnight in an oven at 105°C, and they were weighed again the next day. All dry matter analyses were done in duplicate. Dry matter (DM) was calculated as follows:

$$DM = (W1 - W2)/(W3 - W2)$$

where W1 is the dry weight of crucible and sample; W2 is the weight of crucible; and W3 is the wet weight of crucible and sample.

Gross energy analysis

Pooled samples of each experimental diet and manure were pelleted and used for gross energy measurements using a Parr Isoperibol Bomb Calorimeter (Parr 1266 model). Gross energy (MJ/kg) is defined as the heat of combustion that is given off when a sample is completely oxidised in the bomb calorimeter. All bomb calorimeters were standardised using benzoic acid according to the manufacturer's specifications before analysis of any samples. The apparent metabolisable energy (AME) and corrected AME (n) of an experimental diet on a dry matter basis was calculated as follows:

AME of test diet =
$(GED \times FI) - (GEE \times DE)/FI/DMP$

AME (n) of test diet =
$\{[(GED \times FI) - (GEE \times DE)/FI/DMP] - NR\} \times K$

where GED is the gross energy of the diet, GEE is the gross energy of excreta, FI is the feed intake over the trial period, DE is the total dry excreta collected, DMP is dry matter of pellet diet, NR is a correction factor for 20% body weight gain, and K is the constant 36.52 kJ/g or 0.03652 MJ/kg.

Results

Table 6 provides a summary of the AME values of the local ingredients tested. Table 7 shows the growth performances of broiler finisher birds fed on mixed rations of the local ingredients and a formulated concentrate feed.

Table 6. AME values of local feed ingredients.

Feed ingredient	AME of feed (MJ/kg)	AME (n) of feed (MJ/kg)
Sweetpotato tuber	15.39	15.08
Cassava root	15.87	15.53
Sago	15.02	14.74
Wheat	12.63	12.20
Millrun	11.94	11.57
Palm kernel cake	11.34	10.96
Rice bran	11.63	11.27
Sorghum	12.76	12.37
Soybean	10.82	10.38
Copra meal	15.01	14.71
Pyrethrum marc	13.63	13.34
Flame broiler starter	11.06	10.74
Flame broiler finisher	11.30	10.94

Source: Glatz (2007).

Table 7. Summary of the production performance of broilers from day 21 to day 28, collated from three AME bioassays in 2003.

Feed sources	Weight gain/bird/day (g)	Daily intake/bird (g)	Feed conversion ratio (FCR)
Sweetpotato tuber	38.1^{d}	82.4^{bc}	2.2^{c}
Cassava root	41.4^{cd}	79.5^{c}	2.0^{cd}
Sago	34.1^{d}	76.1^{c}	2.3^{c}
Wheat	53.0^{bc}	87.6^{b}	1.7^{d}
Sorghum	48.0^{c}	85.0^{b}	1.8^{d}
Soybean	54.0^{bc}	83.3^{bc}	1.5^{dc}
Copra meal	36.5^{d}	76.6^{c}	2.2^{c}
Pyrethrum marc	35.5^{d}	75.4^{c}	2.2^{c}
Flame broiler starter	39.0^{d}	92.6^{b}	2.0^{cd}
Flame broiler finisher	44.3^{cd}	85.4^{b}	1.7^{d}

Means with the same superscript within a column are not significantly different ($P > 0.05$) from each other.
Source: Glatz (2007).

DISCUSSION

Agricultural research into improved livestock feeding systems, using analytical techniques and chemical testing, has produced valuable scientific evidence that may lead to a reduced dependence on commercial grain-based feeds for growing pigs and poultry in PNG. Supplementing imported commercial feeds with locally available sweetpotato and cassava by up to 50% in nutritionally balanced diets for pigs and poultry resulted in animal production performances that were effective and efficient for both growth and return on costs. The research findings contribute directly to addressing PNG Vision 2050's second development pillar of wealth creation through enabling effective use of natural resources and greater participation of indigenous people in the rural economy.

Benefits of the improved pig feeding system

Pigs fed with a sweetpotato silage mixed with a commercial grower pig ration at 50% of the total daily feed offer had a lower dry matter intake (Table 4), similar average daily weight gain (ADG) and a more efficient feed conversion ratio (FCR) compared to the commercial feed alone. The improved FCR was due to an overall improved digestibility of all dietary nutrients (Tables 2 and 3). The experimental results of Dom and Ayalew (2009a, b) were then verified in further testing on-station in the lowlands of Morobe Province and on-farm in the high attitude highlands of Western Highlands Province (Dom and Ayalew 2010; Dom et al. 2010). Moreover, there was an indication that not only was the economic return competitive in terms of unit price or kina per kg of carcass, but also in terms of the commercially important qualitative assessments of dressing percentage and back fat thickness (Table 5). The same results have been found in later trials.

The natural silage fermentation process results in a very palatable and highly digestible feed that can be stored for up to seven months. There are many benefits of ensiling sweetpotato on-farm. First, the production of sweetpotato silage makes efficient use of unwanted or unmarketable tubers as well as fresh green vine and leaves. Labour is reduced—there is no longer a need to gather fuelwood or fetch water for cooking the tubers, and daily trips to gardens are not necessary with a feed store on hand. Ensiling creates a demand for fresh sweetpotato, and adds value to the whole forage crop as a possible feed ingredient for sale by non-commercially oriented subsistence farmers.

In the pig feeding trials described, sweetpotato tubers were regularly sourced from local markets in Lae and Mt Hagen, and paid for at fresh food produce prices. This demonstrates the prospect of developing local feed marketing as an alternative for sweetpotato grower-sellers to offload perishable stock, since they are often at the mercy of very wide price fluctuations related to uncontrolled surfeit and deficit. Bags of sweetpotatoes, weighing on average 80 kg, sold at a mere 20 kina or 0.25 kina per kg at Mt Hagen market during a seasonal high, while during a seasonal low, prices climbed to 180 kina or 2.25 kina per kg at the Lae main market.

It is expected that village or small-scale pig farmers, making use of their own home-grown crops and ensiling sweetpotato at household or farm level, would add a negligible cost component to their pig farming ventures. More capable semi-commercial smallholder pig farmers, using the ensiling technology, may need to source additional fresh forage from nearby farms, providing a mutually beneficial add-on effect within the rural community.

Benefits of the improved poultry feeding system

The use of sweetpotato and cassava in poultry feeding systems indicates similar benefits for smallholder farmers, and development options that benefit PNG's rural economy. Based on the results in Table 6, diets made from sweetpotato and cassava have metabolisable energy values of 15.39 and 15.87 MJ/kg respectively, which are higher than that of the standard commercial finisher diet, in this case 11.30 MJ/kg. The nutritional specification for finishing broilers of the Ross 308 strain, as given in the breeders' guideline, is 13.40 MJ/kg which makes these two local ingredients very promising as alternative energy sources to replace cereal grains for finishing broilers. The broilers fed sweetpotato and cassava diets showed daily weight gains of 38.1 g and 41.4 g respectively (Table 7), which were not significantly different to birds fed on the standard finisher ration (which had a daily weight gain of 44.3 g).

Farmer evaluation trials showed that overall performance of broilers fed the cassava + high-energy concentrate diet and the sweetpotato + low-energy concentrate diet was very good; the birds attained a target market weight of 2 kg from week five (Glatz 2007). The sweetpotato + low-energy concentrate diet compared very well with the commercial finisher pellet produced by Nuigini Tablebirds Ltd. The finding that daily weight gain per bird and feed conversion ratio were comparable to a locally manufactured commercial grain-based feed has led to the promotion of two new broiler finisher diets.

A series of on-station broiler grow-out trials led to the identification of the following best-bet diet formulations: 50% sweetpotato + 50% low-energy concentrate and 50% cassava + 50% high-energy protein concentrate (Glatz 2007). When broiler farmers provide their own sweetpotato or cassava tubers and mix them with the protein concentrates, there is a 30% reduction in input costs, particularly for small-scale broiler farmers in both the lowlands and highlands region of PNG. Importantly, the improved poultry feeding systems research now includes the participation of commercial feed mills and they have manufactured two protein concentrate mixtures for blending with either sweetpotato or cassava to provide an energetically and nutritionally effective broiler finisher ration.

Future application of analytical chemistry in agricultural research for development

This paper has demonstrated the successful application of analytical chemistry techniques in agricultural research and development, with results that are directly contributing to the PNG Vision 2050.

The Vision declares a 5% financial commitment to research and development in its public investment budget strategy. Research must expand to include studies of natural resources, the processing and downstream treatment of agricultural and natural resource products, and new areas such as medicinal biota research, including a range of applied research that may yield attractive returns to PNG (NSPTF 2009).

In support of this, and to further develop the use of analytical chemistry within the agriculture sector, the following are recommended for investment.

First, there is a need for strategic investment in the advancement and application of analytical chemistry for educational as well as research needs. The two examples of animal feeding systems research provided here overcame technical barriers during their implementation. These related to analytical testing, where finance was sourced from collaborating research agencies; challenges in sourcing equipment; and training, which was obtained from overseas. On the other hand, the achievements proved that with a minimum of capital input and key personnel and technical services from in-country agencies, crucial agricultural technologies can be adapted and tested for the direct benefit of PNG's farmers.

Second, more collaboration is needed between the relevant agencies in addressing agricultural and natural resource challenges that require scientific research and technology interventions. A very relevant emerging issue is climate change and its implications for all sectors, including agriculture, where sustainable natural resource management becomes a critical concern.

Third, support to organisations and companies that provide analytical services in PNG should be maintained and improved. This may include support for accreditation, standards, auditing and establishing linkages with sister organisations. Two key organisations in this capacity are the PNG University of Technology's National Analytical Laboratory and the NARI Chemistry Laboratory, where the proximate nutrient analyses of samples from the research trials were conducted. There is a need for a PNG food and feed ingredient database and this may be achieved as a project for the analytical chemistry services. Such a project would have a nationwide scope and could involve the chemistry department of the University of Papua New Guinea, the agriculture department of the PNG University of Technology and the NARI Chemistry Laboratory.

The research work reviewed here has shown that science and technology innovations for improving agricultural systems in PNG, developed using analytical chemistry techniques in research, need to be streamlined as essential stepping stones for rural prosperity and enhanced contribution of the agriculture sector to the national economy.

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Current and future research to support smallholder pig production in Papua New Guinea

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Abstract

The village pig in Papua New Guinea (PNG) has been crossbred with commercial breeds resulting in mixed-genotype pigs that are ubiquitous in today's small-scale production systems. There has not been a thorough assessment of the nutritional requirements of mixed-genotype pigs, although growth has improved, despite wide variation in housing, environment and health. In addition, there has been little focus on integrating nutritionally balanced rations into the pig production system to improve overall productivity for small-scale farmers growing their own feed. Research collaboration between PNG's National Agriculture Research Institute, the Australian Centre for International Agricultural Research, the South Australian Research and Development Institute and the University of Adelaide is now focused on providing nutritionally balanced diets of sweetpotato or cassava blended with a formulated concentrate using local protein ingredients with synthetic amino acids and minerals. The research will assess the effects of different root starch sources and processing methods and compare commercial breeds (e.g. Large White-Landrace × Duroc) with mixed-genotype pigs. This paper provides a summary of the research outputs to date and an outline of the next steps to improve pig productivity and sustainable farming in PNG.

INTRODUCTION

The pig (*Sus scrofa papuensis*) has played an indispensable role in village subsistence living and cultural interaction in Papua New Guinea (PNG) since its arrival 6,000 years ago and subsequent domestication (Hide 2003). Through the years, widespread crossbreeding with introduced genotypes, and transfers from one area to another for trade, has resulted in a mixed-genotype animal which is well suited to low-input farming systems (Hide 2003).

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In past decades, pigs provided very little animal protein at the household level. However this has changed dramatically in recent years, and household pork consumption is 11 kg per person per annum (Gibson and Rozelle 1998). PNG is now a net importer of meat (Bourke and Harwood 2009), while pig production in the country has remained stagnant.

There is great potential to boost pig productivity in PNG, and a growing interest by smallholder farmers in commercial pig production. Local production needs to be economically and environmentally sustainable, and locally produced feeds have a major part to play. Sweetpotato and cassava are widely produced starch sources, and opportunities exist for sourcing protein from an increasing number of fish-canning factories. These are the major ingredients required for nutritionally balanced animal feed. There is an inherent logic to maximising the use of such local feed resources. Converting food–feed crops and industrial by-products into high-value feeds, recycling waste from piggeries into crop production and using integrated farming systems are all resource efficient and will contribute to local production which is economically and environmentally sustainable. To achieve this will require focused research, and scientific and technological innovations. This paper summarises past research and development (R&D) efforts, discusses the most recent outputs and sets the future agenda to improve the productivity of small-scale pig production.

AN OVERVIEW OF PIG RESEARCH IN PNG

Government policy and strategic plans (MoAL 2007; NSPTF 2009) recognise the importance of subsistence and smallholder farming in PNG, but agricultural development programs lack consistency and measurable achievements do not accumulate. Productivity of this subsector remains low relative to the yield potential of food crops and production potential of livestock species. There remains much room for improvement in rural farming, particularly with regard to commercialisation.

Indiscriminate and uncontrolled crossbreeding of village pigs has continued for almost two centuries, since the arrival of European settlers and missionaries who brought livestock species with them (Hide 2003). Early government policy supported crossbreeding of native pigs with exotic genotypes with the aim of improving production at the village level (Hide 2003). In the absence of interventions to maintain and promote desirable genotypes of pig, various grades of crossbred pigs are now raised in the villages. It appears that the native genotype is becoming increasingly rare, at least as a domesticated animal. Spencer et al. (2006) found that PNG genotypes were very diverse and Ayalew et al. (2011) noted that village pigs are well adapted to the current village farming practices. These mixed crossbred animals are maintained under variable conditions of housing, feed quality and disease and parasite challenges. Despite this, they appear to perform much better than the parent genotypes. Today, mixed-genotype pigs are the preferred production animals but their nutritional requirements, health status and environmental performances have not been assessed.

Village pigs thrive under low-input subsistence farming. Village pigs kept under grazing systems grew at 190 g/day on a very simple diet of raw sweetpotato and earthworms (Rose and White 1983). Rose and White (1980) also reported high digestive capacity of native pigs for raw sweetpotato diets. The sweetpotato pig feeding system enabled relatively high production, but in the past pig meat provided little nutritional benefit as consumption was confined to festive occasions.

Gibson (2001) reported at the turn of the century that pork meat was the most consumed meat in PNG, at 11 kg per person per annum, a vast increase from the 0.3 to 90 g per person estimated 30 years earlier by Malynicz (1973). However, Gibson (2001) states that his analysis is based on outdated and debatable figures from the 1996 Household Food Survey and that this work needs to be repeated.

The source of household pig meat is often difficult to identify, i.e. whether it is produced in the village, bought from rural/urban markets, or from a commercial fresh meat supply. Moreover, the production and marketing chain of pig meat is undefined. Data on imported meats provide only an aggregate value of animal products. In a mini-survey of Mount Hagen and Lae frozen meat outlets, Dom et al. (2010) found imported cheap pork meat cuts competing with higher quality cuts from local commercial producers.

Of the five key factors for managing and improving pig production, i.e. genetics, nutrition, reproduction, health and environment, the research focus to date has been on nutrition and health. Hide (2003) and Quartermain (2004) provided a bibliography of research on aspects of pig farming in PNG over the last 60 years. Surveillance on health status of pig herds is severely lacking, but a technical document by Watt et al. (1977) and bibliographic summary by Hide (2003) provide a comprehensive list of microbial, parasitic and nutrition-related diseases which can be used as a starting point for further survey. External factors such as climate, temperature and humidity are expected to affect levels of pig production, given the variable conditions and skills with which pigs are managed across lowland and highland areas. Evidence is lacking on the effects of such stressors under PNG farming conditions but it is generally observed that better management at the most basic level of village pig farming allows improvement in sow reproductive performance, piglet survival and growth.

Dom and Ayalew (2009a, b) demonstrated that locally ensiled sweetpotato starch replacing 50% dry matter of a maize–soybean diet gave comparable digestibility and growth performance as sole maize–soybean diet for commercial pigs as well as local mixed-genotype pigs. Additionally, Dom and Ayalew (2010) and Dom et al. (2010) observed pigs of two separate mixed-genotype breeding stocks and found adequate growth rates under improved feeding with commercial pellets when housing and health were well managed at either warm and wet lowland (average daily gain 720 g/day) or cool highland (average daily gain 592 g/day) locations. The same authors also used copra meal and fishmeal with mixed results, where the diets appeared to be lacking in some nutrients. The sweetpotato ensiling technology marks another major advance in pig feeding systems following the introduction of the crop 400 years ago, and the modified Lehman feeding system of protein concentrate supplement with *ad libitum* staple feed 40 years ago. Feeding fresh or dried forage, silage of crops such as sweetpotato, cassava and taro roots, and foliage such as kangkong (*Ipomoea aquatica*) and legume plants (e.g. leucaena and mulberry) is supported by a great deal of evidence in the literature and their use has also been trialled in PNG (Quartermain 2004).

While growth performance on pig feeding trials may be improved, and anecdotally successful in a number of small-scale ventures, this result has not progressed to overall improvements in productivity or profitability. Nutritional imbalance of livestock rations, poor availability of raw feed materials, and high cost of essential ingredients remain major challenges to farm-level productivity for all monogastric animals. Bourke and Harwood (2009) estimate that PNG imports 63,000 tonnes of grain-based feed per annum, while up to 91,000 tonnes of by-product concentrates are produced annually. Despite this apparent abundance of feed resources, unmanageable feed costs continue to limit the development of local pig, poultry and inland fish production.

Through collaborative research projects between the PNG National Agriculture Research Institute (NARI), the National Fisheries Authority (NFA) and the Australian Centre for International Agricultural Research (ACIAR) aimed at introducing feed mills at community level, pig feed production is now linked with poultry and aquaculture feed production to capitalise on the combined demand from all three monogastric animals. It is anticipated that the increase in marine fish canneries in Lae and Madang will lead to greater availability, and hopefully reduced costs, of fishmeal protein. But this is also dependent on sufficiently high and consistent local demand, allowing prices to be more reasonable. The same may be said for local supply of wheat millruns, rice bran, copra meal and palm kernel meal.

Additionally, it is argued that sweetpotato and cassava root crops provide the most readily available local feed resources for small-scale producers, and efforts to improve their nutritional value are the current best option. Improved production performance of pigs, poultry and fish on test diets at NARI Livestock Research Station indicate that the use of root starch from sweetpotato and cassava combined with animal proteins, grains, minerals and synthetic feed micro-ingredients may provide economically attractive options for commercial monogastric animal production in PNG.

CURRENT RESEARCH PROJECTS

There are currently two ACIAR-funded collaborative livestock projects in PNG: one to improve surveillance of animal diseases (AH/2006/157) and another to develop feeding systems to support pig, poultry and fish enterprises (ASEM/2010/53). The first project is led by the PNG National Agriculture Quarantine Inspection Agency (NAQIA) and James Cook University. The second is a collaborative project between NARI, NFA, local NGOs (Christian Leaders Training College, Lutheran Development Services, Ok Tedi Mining Limited), the South Australian Research and Development Institute (SARDI) and ACIAR. It includes postgraduate research through the School of Animal and Veterinary Sciences of the University of Adelaide.

The animal health surveillance project (AH/2006/157) facilitated the collection and reporting of signs of disease in the country's livestock by introducing simple checklists and providing training to livestock owners and animal health auxiliary staff in provincial departments, commercial livestock companies and NGOs. This will expand the reach of government animal health staff, assist with documentation and assessment of PNG's animal health status for endemic animal diseases, and facilitate more rapid reporting of exotic diseases and outbreaks of newly emerging diseases (which may be zoonoses, affecting both animals and humans). Improved information on disease distribution, prevalence and incidence will also greatly assist in disease control programs.

The feeding system project (ASEM/2010/53) is identifying local resources that could be utilised more effectively for feeding fish, pigs and poultry. The aim is to encourage the establishment of small-scale feed mills and develop cheap, balanced diets based mainly on local feed resources rather than imported ingredients. In particular, the project extends the feeding value of sweetpotato and cassava in blended concentrates for poultry, pigs and inland fish production. For improving pig feeding systems, postgraduate research is looking into providing nutritionally balanced diets of sweetpotato or cassava blended with a formulated concentrate using local protein ingredients with synthetic amino acids and minerals. The research is assessing the effects of different root starch sources and processing methods and comparing the performance of commercial breeds (e.g. Large White-Landrace x Duroc) with mixed-genotype pigs. Similar research has been completed for broiler feeding systems and is being advanced for layer birds (J. Pandi, unpublished data); and similar work is planned for fish feeding systems, particularly for tilapia (*Oreochromis niloticus*).

Pig productivity and on-farm profitability using various available feed resources (e.g. sweetpotato, cassava, banana, copra meal and by-products) will be evaluated. Diets based on least-cost feed formulation will be tested at institutions and on-farm to identify those which result in the most profitable pig production.

TRENDS IN PIG PRODUCTION AND CONSUMPTION IN PNG

FAOSTAT (2013) data indicate that, after a rise in 2005–06, meat production in PNG has remained stable over the last five years (Table 1). Demand for poultry is obvious from increased importation when trade tariffs ended. Similarly, increasing demand is predicted for pig meat, although there was a decline in 2009 (data not shown). Game meat, from fishing and hunting, is a major source of protein for rural households, particularly in remote areas and where fishing is convenient; but this may change with rural development.

There has not been an official livestock census in PNG since the early 1970s. According to the PNG census in 2000 (NSO 2002), of the 600,000 livestock farmers 60% are engaged in pig production. Table 2 provides a break-down of the different types of pig production, including figures from Bourke and Harwood (2009) who updated the estimates based on number of sows. The smallholder sector has two broad categories: 360,000 traditional farmers (i.e. individual herd owners) engaged in non-commercial farming, and another 2,000 household farms providing irregular supply to local markets, in addition to 100 commercial farms.

Value chain assessment of pig production is recommended based on the classification provided by Quartermain and Kohun (2002) (T. Simos pers. comm. 2012), and an example value chain map is

Table 1. Meat production in PNG from 2005 to 2011 (tonnes).

Year	Game meat	Pig meat	Cattle meat	Sheep meat	Goat meat	Chicken meat	Duck meat	Cow milk, whole, fresh
2011	355,000	76,000	3,210	27	11.4	5,760	14	180
2010	355,000	74,000	3,210	27	11.4	5,850	14	180
2009	380,000	72,000	3,210	27	12.0	5,940	14	185
2008	375,000	70,000	3,210	27	11.25	5,940	13	180
2007	365,000	70,000	3,210	27	11.25	5,850	13	175
2006	355,000	68,000	3,165	27	11.25	5,850	13	170
2005	330,000	68,000	3,135	30	11.25	5,670	13	165

Source: Available at http://faostat3.fao.org/browse/area/168/E presented in Figure 1. While conducting value chain assessment requires extensive surveys and market research, there are some available data from which estimates can be made.

Tables 3 and 4 give selected data on meat production and consumption from the 1996 National Household Survey. Total (commercial) meat production in 2005 was estimated to be 58,000 tonnes with an additional 30,000 tonnes in imports, giving total meat consumption of 88,000 tonnes (Bourke and Harwood 2009). On that basis, Bourke and Harwood (2009) calculate average meat consumption of about 15 kg per person per year. But Gibson (2001) used the PNG Household Survey data to show that 60,000 tonnes of pork was produced and valued at 243 million kina (Table 3). Originally, Gibson and Rozelle (1998) had estimated the value of meat produced by households at 263 million kina or A$122 million. FAOSTAT 2013 figures extrapolated pork meat production to 68,000 tonnes per annum (Table 1), but given the recent population census figures and an average pig meat consumption of 11 kg per person per annum (Gibson 2001), the total supply falls short by 10,000 tonnes. This indicates that an extra 38 million kina (A$18 million) worth of pig meat is required to satisfy the market demand. At an average carcass weight of 50 kg that means an additional 200,000 pigs, which is beyond the capacity of the large-scale commercial piggeries.

Table 5 shows available feed for livestock, although the list is not exhaustive, for example rice bran and spent brewer's grain are not included. Imports of wheat, soybean meal and sorghum for feed are significant, and more data need to be gathered from PNG and Australian customs, local companies importing feed/food ingredients and local food/feed factories. Estimated volume and retail value of imported and locally manufactured livestock feeds are shown in Table 6. Pigs, poultry and inland fish are the main livestock groups given milled feed. Using the average retail value of pig and poultry feed, Bourke and Harwood (2009) calculate that pigs consume only 20% of stock feeds while the bulk may be assumed to go to feeding poultry. Feed demand for inland fish farms is not yet determined.

Feed supplied is not the actual total available feed in the country, but the off-take that mills in PNG take from the available and imported feed resources.

The estimate by Bourke and Harwood (2009) that only 20% of stock feed in the country is used for pig production is very low considering the number of herds. PNG produces 91,000 tonnes of by-product (protein) concentrate feed (Table 5), 52,200 tonnes of stock feed from local mills and imports 37,000 tonnes of feed (Table 6). Improved feeding practices in the dominant smallholder livestock sector will demand more use of local feed resources and this may be achieved at commercially competitive rates or may

Table 2. PNG pig industry structure and characteristics.

Holding type	Herd size	No. of herds	No. of pigs	Trends	Breeds
Smallholder, traditional	1–20	360,000	1,800,000	Static May be increasing with human population	Native
Smallholder, penned, household	1–3	1,000 (2,000*)	2,000 (4,000*)	Growing slowly	Native, crossbred**
Smallholder commercial	10–100	50 (100*) (including prisons and high schools)	2,000 (6,000*)	Growing slowly	Modern commercial
Medium-scale commercial	100–500	4 (3 institutional)	1,500 (2,000*)	Static	Modern commercial
Large-scale commercial	>500	7	20,000 (2,500 sows*)	Static	Modern commercial

* Updated figures from Bourke and Harwood (2009).
** Authors' observations.
Source: Quartermain and Kohun (2002).

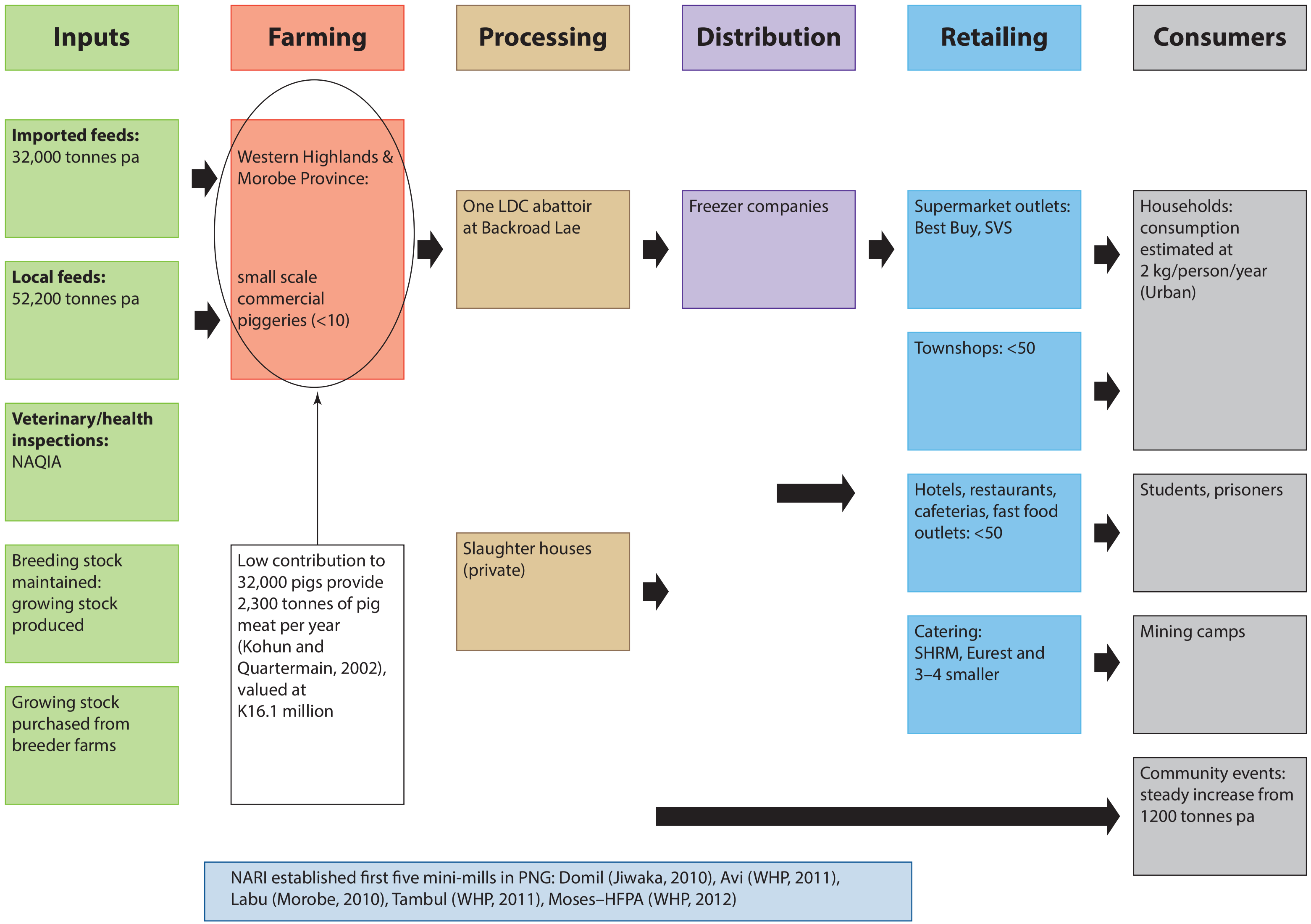

Figure 1. An example of a value chain map for small-scale pig production in Lae (Morobe) and Mount Hagen (Western Highlands). Source: Michael Dom and Theo Simos, for ACIAR project ASEM/2010/053.

Table 3. Selected data for meat production from the 1996 National Household Survey.

Meat	Quantity		Value (million kina ± SE)
	('000 tonne)	(kg/person)	
Pork	60 ± 11	12	243 ± 47
Chicken	4 ± 1	1	20 ± 7
Other meat (incl. bush meat)	16 ± 4	3	26 ± 7
Fish (fresh, dried, shellfish)	50 ± 12	10	60 ± 17

Source: Gibson (2001).

Table 4. Selected data for meat consumption from the 1996 National Household Survey.

Meat	Total value (million kina)			Quantity (kg/person/year)		
	PNG	Rural	Urban	PNG	Rural	Urban
Lamb and mutton	59	36	24	5	4	10
Pork	162	158	5	11	13	2
Chicken	113	72	42	6	5	13
Bush meat and other unspecified meat	33	27	6	5	5	3
Fish (fresh, frozen, dried, incl. shellfish)	60	34	26	10	8	21

Source: Gibson (2001).

Table 5. Available feeds for domestic pigs, poultry and fish.

Feed	Protein content (%)	Volume (tonnes)
PNG millrun	12	33,000
PNG copra meal	21	21,000
PNG oil palm kernel meal	18	31,000
PNG fishmeal	58	6,000
Imported sorghum	Unknown	26,000
Rumion maize	11	5,800
Total available feed material		122,800

Source: Bourke and Harwood (2009).

Table 6. Feed supplied in PNG and estimated retail value using Lae and Mount Hagen pricing.

Source	Volume (tonnes)	Retail value in Mount Hagen ($\times 10^3$ kina)	Retail value in Lae ($\times 10^3$ kina)
Three Lae feed mills local*	52,200	128,542	116,177
Rumion maize local**	5,800	4,060	4,060
Complete feed imported*	37,000	91,112	82,348
Feed supplied	95,000	223,715	202,585
Feed used in pig production (20%)	19,000	44,743	40,517

Note: Estimates of retail values are based on average cost of feeds at *2.46 kina and **0.70 kina per kg.
Source: Bourke and Harwood (2009).

require policy intervention to favour local feed manufacturing. Quartermain and Kohun (2002) emphasised that feed is 80% of the cost of raising livestock and is the number one priority for livestock research. Given that a growing proportion of agro-industrial by-products with good feeding values (copra meal, millrun) are being exported, an analysis of the market value of exported feed resources would be a valuable contribution to better understanding the macroeconomic impact of importing feeds.

At the smallholder level, farmers are able to source the bulk of energy feed from their own crops or from local markets. The two main energy feed crops are sweetpotato and cassava. Annual production of sweetpotato is estimated at 2.8 million tonnes (Bourke and Vlassak 2004), and 30–70% of the roots may be fed to pigs (Hide 2003; Bourke and Vlassak 2004), mainly in traditional unimproved diets on village and small-scale farms. Cassava production is much lower at 271,895 tonnes per annum (Bourke and Vlassak 2004) and is grown mostly in dry areas of the lowlands where it is a valuable drought food and feed crop.

There is good opportunity to make more efficient use of excess and waste/spoiling sweetpotato and cassava tubers and foliage for on-farm feed production or for marketing to smallholder piggeries, if simple processing equipment and storage techniques are accessible at smallholder level. Root and foliage ensiling or drying technology may enhance the feed value of these perishable crops. Hansen et al. (2001) suggest that as much as 1.5 million tonnes of sweetpotato is used as pig feed annually, not including the feed that may be obtained from crop losses to disease damage, unmarketable tubers, damaged tubers and market wastage, and also not including vine yields. By our calculation, converting Bourke and Vlassak's (2004) fresh tuber yield to dry matter feed suggests that as much as 225–630 million kg of sweetpotato is available for pig production annually. At the high level offer of 4 kg dry matter diet component for say 200 days, that is enough starch feed for 315,000–735,000 pigs of 60–70 kg finished weight.

Local sweetpotato cultivars, including 10 promoted by NARI, are capable of producing 13–15 tonnes of roots per year (Bourke and Vlassak 2004), although yields may be below this due to high pathogen levels in the plant. Cleaning of planting material by tissue culture techniques has been shown to overcome this problem (NARI Aiyura 2011; unpublished data). It is notable that leaf and vine from these cultivars may be almost twice the fresh weight yield of tubers (Dom and Ayalew 2009b).

A number of pig feeding trials by the NARI livestock research program have demonstrated the ability of local mixed-genotype pigs to perform well on mixed diets of sweetpotato, giant taro, rice bran, copra meal, wheat millrun and fishmeal. Growth rates improve but vary considerably with nutrient content of the diet. In addition, productivity is markedly improved when better housing is provided and better health status is achieved. Genotype, nutrition and environment are the focus of present research interest, particularly for the local growing pigs produced by commercially oriented smallholder farmers in the highlands and lowlands of PNG.

PORK MEAT MARKETS

The pig meat market has not been thoroughly assessed in the same way as the red meat industry, for instance (Vincent and Low 2000). This would be a major activity under the suggested value chain assessment and a key step for setting strategic targets for smallholder pig producers. As an example of a domestic market, Dom et al.'s (2010) mini-survey data for Mount Hagen are given in Table 7. The data include sources, cuts of meat found in freezer sections and unit prices, but do not include the volume of meat at each outlet. It is quite feasible to carry out similar surveys in other urban centres nationwide.

The main consumer demand is for pork from 60–70 kg finished pigs, i.e. relatively small pigs. Whereas the growing-finisher period is recognised as the most costly in terms of feed requirements, the lower finishing weight mean shorter feeding periods of up to six months. Hence, improving the feed efficiency using cheaper local ingredients partly supplied on-farm may favour small-scale pig farming. If earlier calculations on sweetpotato fresh root total production are extended, the estimated range of potential pork meat production using local feed resources, at an average of 75% carcass yield, is 236,250–551,250 kg.

Smallholder farmers earn income from live pig sales, usually of large (>100 kg) fattened pigs. There

Table 7. Wholesale and retail prices of pork at selected outlets in Mount Hagen town, Western Highlands Province in September 2009.

Supplier	Pork cut	Price (kina)	Quantity	Source
Best Buy	Hock	9.45	Per kg	Imported
	Leg	18.50	Per kg	Lae
	Loin	17.50	Per kg	Lae
	Belly	18.50	Per kg	Lae
	Fillets	26.90	Per kg	Lae
	Tail	10.95	Per kg	Imported
	Jowl	9.75	Per kg	Imported
	Leg ham	31.70	Per kg	Pelgens*
Kera Freezers	Jowl	12.00	Per kg	Imported
Renbo Store	Jowl	9.45	Per kg	Imported
	Tail	9.45	Per kg	Imported
Bintangor	Loin	15.50	Per kg	Imported
	Jowl	11.00	Per kg	Imported
	Head	39.80	Per kg	Imported
	Belly	15.50	Per kg	Imported
Kange Freezers	Jowl	10.00	Per kg	Imported
Main Market Freezers	Jowl	12.00	Per kg	Imported
Plaza Freezers	Jowl	9.80	Per kg	Imported
	Meat cuts	193.00	22.7 kg ctn	Imported
	Jowls (bulk)	115.00	13 kg ctn	Imported

* Pelgens German Smallgoods is the local specialist for bacon and ham products from their own piggery.
Source: Dom et al. (2010).

is a need for economic assessment of informal live pig sales which contribute the bulk of smallholder business. This market tends to be irregular, to be prone to higher pricing which may not be based on costs of production, less likely to ensure quality product, and to be inconvenient for consumers. Experienced farmers reflect that the much higher average unit prices offered to live sales of fattened pigs is discouraging engagement of smallholder piggeries in the formal pork market, since carcass prices are lower. As a result smallholder farmers are reluctant to produce larger pig herds in continuous cycles. This is compounded by a lack of proper slaughter and freezer facilities available to smallholders. These are business and management aspects that could be addressed by collaboration of research and extension agents.

FUTURE R&D AGENDA

The following areas are suggested for further R&D in pig production in PNG. These represent the impression of the authors on the best way forward for improving local pig production.

Genetics

Despite the economic, cultural and historical significance of pigs in PNG, knowledge about genetic attributes, differentiation and production capacity of indigenous pigs is very limited (Ayalew et al. 2011). Recent molecular genetic studies (Nidup 2011) reveal that PNG indigenous pigs retain a reasonably high level of genetic structure and diversity. This is similar to that of feral pigs (Spencer et al. 2006) to the extent that indigenous and feral pigs are considered as a single genetic pool. Decades of well-intended, but poorly designed, government-sponsored programs to promote crossbreeding of indigenous pigs with selected exotic breeds have resulted in a broad admixture of various grades of crossbred pigs in traditional smallholder farms. The rather small average sizes of smallholder pig flocks restricts genetic selection of replacement breeding stock. Regardless of this, the larger body size and faster growth performance of these crosses have attracted strong interest from the rapidly increasing number of smallholder commercial pig growers.

There is a lack of suppliers of breeding stock as well as growing pigs to meet current and immediate future demand. The few major commercial piggeries are opportunistic suppliers of a limited number of breeding boars and gilts at relatively high prices. The establishment of a viable commercial pig breeding enterprise is essential to counteract the continued haphazard spread of exotic and crossbred pig genotypes, not only in market corridors but also in unaffected PNG indigenous pig populations. About 19% of local pigs, even in remote villages, are known through pedigree checks to have an admixture of genotypes with some distant exotic parentage (Ayalew et al. 2011). Long-term indigenous pig genetic evaluation and improvement activities are essential to prevent further genetic erosion of PNG indigenous pigs. This will not only preserve the genetic resource base but also provide parental lines for sustainable crossbreeding programs. Targeted crossing of adapted local genotypes with improved exotic ones is a proven breeding strategy to meet the needs of a rapidly expanding pork markets where commercial piggeries cannot satisfy the demand, as is the case in PNG.

Genetically improved animals need effective nutrition, basic health care and hygiene, and safe housing in order to perform to their full genetic potential. Objectives for improved production performance include improved reproduction, satisfactory growth rate, increased feed efficiency, acceptable back fat depth and greater carcass yield, all of which are influenced by the interplay of genotype and environment.

Nutrition

Local feed resources are available in PNG that could be utilised more effectively for feeding pigs, and include root crops, fruit, forages, bush plants and vines. Farmers could also introduce new crops and use pasture species with higher nutritional value for pigs, for example sorghum, mungbean, pigeonpea, sunflower and amaranth (Cargill 2008; Glatz 2007). Effective rations for village pigs can be devised based on the availability of feeds, and farmers can be educated on feeding management. Three pig feeding strategies could be adopted by smallholders: (1) complete ration formulation using local feed ingredients; (2) development of a concentrated diet that can be blended with local feed ingredients; and (3) dilution of a commercial diet with locally available food products.

In PNG, sweetpotato is the main feed source for pigs. The existing sweetpotato pig feeding systems exhibit several problems, notably low fertility rates and slow animal growth rates. This may be caused by unbalanced and erratic feeding regimes and health problems. Basic diets containing ensiled sweetpotato vines and tubers can be supplemented with a range of locally grown crops and herbage to increase the protein content of the base diet.

Taro (*Colocasia*) foliage is a protein forage option, while giant taro (*Xanthosoma*) is fed in high-rainfall areas where it grows abundantly. ACIAR work in West Papua is investigating local resources for pig diets, for example pasture grasses Sundaleka (*Puerasia cephaloides*), Wurikaka (*Centrosema* sp.) and Jirikpuruk (*Calopogonium* sp.) and fodder trees Dadap (*Erythrina variegata*) and Gamal (*Gliricidia sepium*), plus vegetables in season and chopped banana trunks, and is relevant for PNG. Other ingredients, such as kangkong (*Ipmoea aquatic*), mulberry (*Morus* sp.) and kikuyu grass (*Pennisetum clandestinum*) are used by some farmers and are worth investigating.

Health

There is a paucity of updated animal health and disease surveillance reports and research on modern animal diseases which may impact on livestock and zoonosis with implications for human health in PNG. Brioudes and Gummow (2013) provide a bibliography of domestic animal disease research conducted in Pacific island countries. Hide (2003) provides a comprehensive summary of veterinary work in PNG from 1938 to 2002. A number of technical studies found that confinement tends to exacerbate disease at village and smallholder levels. The effect of health status on productivity of smallholder commercial piggeries has not been assessed, but anecdotal accounts indicate it may be significant. While animal health surveillance will identify disease prevalence, individual smallholder farmers are still unable to afford the cost of most common veterinary drugs, even when they are available from local suppliers. For example, Ivermectin® is sold at up to 452.60 kina (A$216.46) for 200 ml. Also, oral Ivermectin®, which may be more effective, is not available. Some innovative means of supplying veterinary drugs needs to be implemented. In addition, the lack of veterinary staff nationwide and the high cost of veterinary services mean that most farmers are not well assisted to administer drugs or manage stock in more effective ways to prevent disease.

Bacterial pneumonia is common and aggravated by poor nutrition and high parasite burdens. Other diseases, such as anthrax, brucellosis, salmonellosis, *Streptococcus suis*, enteric bacterial infections, swine pox and rotavirus, reportedly occur in isolated cases, linked to poorly managed intensive units. There is notable zoonotic threat from Indonesia's Papuan border for diseases such as rabies and rotavirus. Internal and external parasites are prevalent, and Watt et al. (1977) identified large round worm, kidney worm, stomach worm, nodule worm, lung worm, sarcoptic mange and lice. Infestation by screwworm flies and porcine *Coccidia* are common, whereas *Trypanosoma evansi* is considered to be absent. Watt et al. (1977) also recognised nutrition-related diseases, particularly affecting young piglets, namely deficiencies in calcium, phosphorus, iodine, iron and vitamin A.

Environment

Environmental factors that influence pig performance, including temperature, aeration and space, may be controlled by appropriate housing design. Outputs of gaseous, liquid and solid effluents affect the piggery and surrounding environment, and are an important management consideration when planning to increase the number of stock under commercial production. Integrated farming systems that recycle the nutrients in piggery effluents are potentially very beneficial in small-scale systems and worth investigation. The traditional sweetpotato–pig system has done this for centuries. Intensified farming requires research to better understand the environmental impacts for crop nutrition as well as animal and human health within integrated systems.

Housing material and design are important for managing disease in local pigs because disease vectors become more concentrated within intensive units. Early work by Malynicz and Nad (1973) on different aspects of housing native and crossbred pigs should be revised to improve management standards for the current mixed-genotype pigs. Simple recommendations may be made from the exisiting literature and would be valuable for extension training. In particular, the housing and nutrition needs of sows vary according to their reproductive cycle. Sows and gilts are the basic production units, and it is fundamentally important to evaluate their health status, which indicates that of the piglets and thereby the entire herd (ignoring external disease vectors). Mating boars may be shared or feral pigs, and unless appropriate health standards are set, may introduce other diseases to the domestic herd.

Reproduction

Reproductive performance appears to be neglected at the research level, although skilled local farmers are well aware of the need to provide special care and attention to pregnant and lactating sows. According to reports summarised by Hide (2003), gilts are usually about a year old before their first breeding, gestation is up to 120 days and birth is mostly unassisted. The average litter size is three to six piglets for village pigs, whereas on commercial farms litter sizes can be 10 piglets or more. Field observations show that survival after weaning tends to be lower for smallholders. Weaning age is variable, from four weeks to three or even six months, depending on management. Litter intervals and pregnancy ratios are also variable, where traditional husbandry practices also restrict breeding. Assessment of pig reproductive performance in PNG is a potential research area.

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Challenges in formulating feed for pigs and poultry using local feed sources in Papua New Guinea

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Abstract

Formulating animal feeds in a developing country presents a number of challenges, especially where the aim is to use as many local materials as possible. The task is made more difficult due to the need to consider both smallholder traditional village farming and livestock systems as well as the more advanced livestock and husbandry systems of commercial farms. A project underway in Papua New Guinea is directed towards this aim. Progress has been made using a limited number of local materials under local conditions, and trials have delivered solutions to some of the issues in both research and village farming situations. In order to formulate feeds accurately, it is necessary to fully understand the physical and nutritional qualities of the source materials. The role of the feed formulator is to establish: (a) what materials are locally available; (b) what form they are in; (c) how widespread they are; and (d) what processing has been used to make them safe, usable and mixable. Equally important is a clear understanding of the market requirements of local people. It would be a mistake to assume that local people desire the low-fat pig and poultry products found in mainland commercial markets. Their wish may be for higher fat or leaner pig and poultry. Some research is necessary in this area as such information will influence the feed formulated by nutritionists. There is also a need to understand more about the different genotypes of local pigs and poultry. Nutritionists must incorporate this information into the development of formulations in order to provide satisfactory results under local conditions.

INTRODUCTION

Papua New Guinea (PNG) has a significant number of potential local feed resources (Glatz 2007). Trials so far have concentrated on a limited number of these, mainly cassava and sweetpotato. Banana is also a possible resource, but processing methods need to be developed, while fishmeal and coconut also have promising qualities. All these materials have different parts with quite different physical and nutritional characteristics (Table 1).

Trials using formulated feeds from the resources in Table 1 have so far been directed towards broiler production (village and commercial strains), layer production (Australorps, Australorp crosses and commercial strains) and pig production (indigenous pigs and commercial hybrids). For any of these animals none of the above materials will provide a complete feed, and other non-local materials must be added to make a balanced feed (Ravindran 2013). These additions can be in the form of a concentrate containing protein, pure amino acids, vitamins, minerals, mould inhibitors, antioxidants and any medication that is required.

To provide a complete feed it is necessary to know the physical and nutritional characteristics of the local material. The following questions are among those that need to be addressed.

- What are the nutritional specifications of each material?
- Do the local materials possess any anti-nutritional factors and at what level? How can these be measured? How can the material be processed to reduce toxicity? What level of anti-nutritional factors can be tolerated in a feed mix without affecting production?

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Table 1. PNG local feed resources and components.

Feed resource	Components
Cassava	Roots Stems Leaves Silage—mix of peel, tuber, chips and leaves
Sweetpotato	Roots Stems Leaves Silage—mix of peel, tuber, chips and leaves
Banana	Whole (green) Whole (ripe) Peels and leaves Trunk
Fishmeal	
Copra meal	

Some of these issues are explored below for the main local feed materials in PNG.

ANTI-NUTRITIONAL FACTORS IN LOCAL FEED SOURCES IN PNG

Cassava

Cassava has a long history of being used throughout Africa and Asia as a human food source. Cassava tuber, leaf and vine can all be used in stock feed, and a combination can be used to make silage. Its use, however, demands special treatment as it contains cyanide which is toxic. Some varieties have higher levels than others. There are several methods to reduce cyanide all of which require heat treatment. The product can be boiled and allowed to dry; or mixed with water into gruel and left in the sun for up to eight hours; or chipped and placed in the sun on racks. These treatments reduce the level of cyanide and result in a usable product for humans and animals. Commercial production of cassava involves rapid and advanced techniques to remove the cyanide.

In humans, high levels of cyanide in cassava flour can result in an irreversible paralysis of the legs, known as konzo. Exposed children can also experience reduction in growth. The World Health Organization has set a maximum safe level of residual cyanide in flour of 10 ppm. The average level in untreated cassava is 45 ppm but this can rise to 100 ppm under dry conditions and if the plants are stressed by pest invasion. Egan et al. (1998) developed a test kit for detecting and measuring levels of cyanide in cassava flour. It is not yet known what level of cyanide in pig and poultry feeds will result in reduction in growth performance.

Sweetpotato

Sweetpotato tuber, leaf and vine can be used in stock feed. All parts can be used to make silage. There are many varieties of sweetpotato and there are considerable differences in their fibre levels. High fibre reduces digestibility and this may limit the use of some varieties of sweetpotato in feeds; it would be interesting to compare the performance of different sweetpotato varieties as feed. Some research has been done with pigs on the use of sweetpotato silage by Dom and Ayalew (2009a,b) and this has produced a set of valuable nutrient specifications. This work should now be expanded to commercial production in mini-mill enterprises as well as in traditional feeds.

Banana

The ACIAR project (ASEM/2010/053) has not used banana products in its trials so far, but significant research has been carried out on the use of different parts of the fruit, and at different stages of ripeness, under other projects. Green bananas and peels contain active levels of tannin which makes them unpalatable. Allowing the fruit to ripen and turn yellow inactivates the tannin (Gohl 1981). Machin and Nyvold (1992) reported on a research project that measured the dramatic change in tannin content as banana pulp and peel ripened. Pigs are particularly fond of ripe banana which provides an excellent food supplement. The drying and processing of banana products needs some research as in a wet state it would be difficult to use in mini-mill operations.

Fishmeal

Fishmeal is a valuable high-protein material which can be used in stock feed. Fishmeal is produced from whole fish unsuitable for human consumption as well as the inedible portions of the fish that remain after filleting. These fish trimmings are cooked and the fish oil collected. The remaining cooked component is dried, pressed, ground and treated to form a meal. Fish by-products must be processed when fresh, otherwise there is rapid protein breakdown and the development of biogenic amines, particularly histamine. Use of poor-quality fishmeal will result in poor growth performance. Under tropical conditions fishmeal needs careful storage and for short periods only, as rancidity can occur. Mycotoxin contamination can occur if storage is poor and this, together with high histamine levels and rancidity, makes a dangerous product. When fishmeal is made by small operators, fish by-products (fish cuts and skeletons) are frequently left to stand in the sun until a sufficient quantity has built up for a reasonable batch size, which results in poor quality fishmeal. Antioxidants (e.g. ethoxyquin, oxistat) should be added to fishmeal during processing.

Copra meal

Copra meal (also known as coconut meal or copra cake) is a by-product of the extraction of oil from the dried coconut (copra). Copra meal can be used in limited quantities in pig and poultry feeds. It is high in fibre which limits its use. Unless properly processed and stored, it is quick to develop mycotoxin contamination. Copra meal is more useful in ruminant feeds.

CHALLENGES IN FORMULATING FEEDS WITH LOCAL INGREDIENTS

The materials discussed above are already being researched or used in PNG. Most of the products investigated have been high in moisture and low in crude protein (and therefore amino acids). Supplementation has been necessary to develop broiler, layer and pig feeds that reach satisfactory specifications. This has been done by formulating concentrates containing protein meals, pure amino acids, vitamins, trace minerals, mould inhibitors and antioxidants which have been combined with the local materials. This approach has been difficult however due to the variable moisture levels in the local materials, exacerbated by concern and lack of knowledge about the maximum daily intake of the high-moisture combinations. This situation is the same in both pig and poultry feeding. In order to design the concentrate, and the ratio for combination with high-moisture materials, assumptions had to be made that are not yet supported by evidence. This was particularly difficult with layer feeds, where shortage of adequate nutrient intake results in low egg production, small eggs and poor shell quality. Incorrect assumptions could also lead to reduced growth rate of broilers and pigs.

Results of the research so far have been encouraging, but in the future it will be necessary to process all materials to a lower moisture level and provide more accurate analytical information.

Calcium addition will be required in many feeds so it is important to try and find a reliable local source. Sea shells and crushed reef pieces are worthwhile sources to investigate. These would need to be chemically analysed and processed to be useful in mini-mill enterprises.

CONCLUSIONS AND RECOMMENDATIONS

While formulating feeds has been based on less than complete information, a great deal has been achieved with the research so far. As results of the trials are collated, it will be interesting to see if the assumptions which have been made are correct. Adjustments can be made as the project continues and as more reliable information becomes available.

A clear understanding of the market requirements of local people is also important. It would be a mistake to assume that local people desire the low-fat pig and poultry products found in mainland commercial markets. Their wish may be for higher fat or leaner pig and poultry. Some research is necessary in this area as such information will influence the feed formulated by nutritionists. There is also a need to understand more about the different genotypes of local pigs and poultry. Nutritionists must incorporate this information into the development of formulations in order to provide satisfactory results under local conditions.

The following are recommendations to improve the information shortage and support progress towards easier, more accurate formulations for all species and situations.

- Investigate what end-products local markets require.

- Process local materials to a moisture content of 10–13%. Where high-moisture materials continue to be used, the proportion of concentrate to local materials may need to be changed.
- Establish a database of local materials showing levels of crude protein, fat, fibre, calcium, phosphorus, metabolisable energy (poultry) and digestible energy (pigs).
- Analyse materials for amino acid levels and set up digestibility coefficients.
- Investigate cyanide levels in cassava products and likely effects on production at various levels. This could lead to a safe maximum level being established. Check for cultivar differences. This could lead to recommendation of certain cultivars being promoted in agricultural production.
- Search for reliable sources of calcium and phosphorus.
- Check the benefit of enzyme additives on local materials.
- Investigate and extend the number of locally grown materials that can be used.
- Investigate the use of banana, considering tannin levels and methods of processing.

A final point is that establishing a strong relationship with a commercial mill to manufacture the concentrate is critical to ensure a reliable supply. Without this, all the supplementary materials contained in the concentrate would need to be supplied to each mini-mill site. Costs would increase as smaller quantities attract higher prices and freight charges.

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Production of aquafeed for fish farmers in Papua New Guinea: challenges and opportunities

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Abstract

The development of aquaculture in Papua New Guinea (PNG) faces many challenges, especially the availability and affordability of aquafeeds. As feed remains the single largest input cost in fish farming, it is critical that skills and expertise in fish nutrition and husbandry are developed and fostered in PNG if the enormous potential of this industry is to be realised. Building this capacity in researchers and farmers will lead to increased uptake of fish farming and the establishment of a successful and profitable aquaculture industry. This paper presents an overview of the nutrient requirements of tilapia. It also presents information on the nutrient composition of the major feed commodities available in PNG, and how these data can be used to formulate and make complete feeds or 'feed concentrates' for fish. Use of feed concentrate technology has improved outcomes for farmers of pigs and poultry in PNG and this approach has the potential to improve the uptake of fish farming and production outcomes for farmers of tilapia and carp. This paper also discusses some of the practical issues around small-scale feed manufacturing, feed delivery and assessment of fish performance. It is hoped this information will reinforce the concepts and principles of fish nutrition and demonstrate how flexibility in feed formulation can overcome issues with ingredient quality and availability.

INTRODUCTION

Aquaculture of any scale is still relatively new in Papua New Guinea (PNG). Rural aquaculture began in the late 1950s with the introduction of carp and trout (Smith et al. 2007). In subsequent decades, international groups such as Japan International Cooperation Agency (JICA) and the Food and Agriculture Organization (FAO) of the United Nations conducted various programs attempting to expand aquaculture among PNG's vast population of smallholders. In late 2002, the genetically improved strain, or GIFT tilapia, was bred at the Highlands Aquaculture Development Centre (HAQDEC; Aiyura) and distributed throughout PNG by the Eastern Highlands Province Government (Smith 2007). This was seen as a breakthrough moment for PNG inland aquaculture and new programs were initiated by the Australian Centre for International Agricultural Research (ACIAR) to continue the push. Despite these efforts, the control of broodstock fish, access to fingerlings and supply of good quality feed continues to limit expansion and adoption of aquaculture in both lowland and highland regions of PNG (Allan et al. 2007a; Kolkolo et al. 2007; Sammut and Wani 2015). Many smallholders have ventured into aquaculture but have failed, not because of their lack of endeavour, but because they lacked basic skills in fish biology and husbandry, feed formulation, feed management and feed delivery (Sammut and Wani 2012). Many farmers also have little understanding of the relationship between fish health and nutrition or fish health and water quality. These issues have led to poor growth and survival of stock. With both poor production outcomes and economic returns, farmers have either had to leave the industry or persist at a scale that meets only the immediate needs of the family or village. More successful farmers may produce

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enough fish for sale at roadside or village markets but their supply is often sporadic and unpredictable. Thus, the value chain is constantly broken and potential consumer demand is unmet (Dom et al. 2014). For this and other cultural reasons, the consumption of poultry and pork is still favoured over fish, especially in the highlands.

Irrespective of the constraints mentioned above, access to good quality aquafeeds, or ingredients to make them, remains one of the greatest challenges to the expansion and success of aquaculture in PNG (Booth et al. 2006; Sammut and Wani 2015). At present, there are an estimated 50,000 smallholders in PNG growing fish, however production is low. For this reason, there are no local or international companies making significant quantities of aquafeed in PNG. Importing feed is possible, but the cost of landed goods is beyond the means of most local smallholders. Imported feed ingredients, such as fishmeal, rendered animal meals and soybean meal, are almost exclusively directed towards feeds for the rapidly growing intensive pig and poultry industries. Thus, market forces are limiting the flow of international feed ingredients into the PNG aquaculture sector.

The lack of access to imported commercial aquafeeds, or the production of good quality aquafeeds in PNG, has forced the aquaculture sector to rely on feeds made locally within close proximity to farms. The scale of these enterprises is small, ranging from mini-mills reliant on electricity which might be capable of producing hundreds of kilograms of feed per day (e.g. National Fisheries Agency, Goroka; Highlands Aquaculture Development Centre (HAQDEC), Aiyura; National Agricultural Research Institute (NARI), Labu) to farmers using hand-driven meat mincers capable of making only kilograms of feed per day. Most of the mini-mills are run by government or provincial employees and are rudimentary in terms of equipment and capacity (Booth et al. 2006). These mini-mills were not conceived as small business enterprises in their own right but as a service which might underpin and support the growth of aquaculture until private or cooperative enterprises saw an opportunity to enter the feed industry. Unfortunately, the aquaculture industry in PNG has failed to expand and reliance on mini-mill operations remains.

Major issues with mini-mills include a lack of basic expertise in business management (Lindsay et al. 2015) and lack of expertise in feed formulation principals (Booth et al. 2006). Infrastructure issues include undersized or antiquated equipment, lack of spare parts and lack of expertise in maintaining and servicing equipment. Producing large volumes of feed requires access to suitable driers but at present, mini-mill operators are reliant on air or solar drying of pellets. This can lead to elevated moisture content in pellets, and if stored in this state, aquafeeds can quickly deteriorate and develop toxic moulds (Deng et al. 2010; Fegan and O'Sullivan 2004; Spring and Fegan 2005), There is no real capacity to effectively store large quantities of ingredients or finished feeds ready for sale and distribution. Many mini-mills still make feed on-demand, which means they are idle much of the time. Conversely, when farmers express a demand for feeds, they are not available. Thus, the sporadic output and quality of aquafeeds produced from mini-mills limits expansion and confidence in aquaculture. Access and availability of suitable ingredients still constrains the volume of feed produced from mini-mills, especially in the highlands, where transport of goods from coastal ports such as Lae is still problematic. In the highlands, the cost of feed is often subsidised by government agencies, so the real cost of feed manufacturing is not passed on to the farmer and the consumer. This has the effect of distorting value chains and understating the real cost of production (Dom et al. 2014).

The problems outlined above have been targeted by previous ACIAR programs and projects aimed at developing the smallholder aquaculture sector in PNG and other Pacific countries. Many of these projects involved hands-on training and purchase and installation of equipment (Allan et al. 2007a; Allan et al. 2007b; Booth et al. 2006; Smith 2007). Programs also provided access to useful resources, such as easy-to-read manuals and practical guides on feed making and fish husbandry (Gonzalez and Allan 2007; Sim et al. 2005) and effort has been expended in collating comprehensive feed ingredient databases for the Pacific region (Pirozzi et al. 2011). PNG nationals have also attended master classes in aquafeed nutrition and technology (Allan et al. 2006). However, despite aquaculture training and assistance, there remains a lack of uptake by inland smallholders. This may be in part due to the turnover of trained individuals and breaks in support and extension programs.

The ongoing challenges facing aquaculture in PNG, especially the lack of aquafeeds, is limiting the enormous potential for this industry to expand and offer a third source of highly valuable protein to Papuans. Expansion of aquaculture offers many farmers the chance to diversify from pigs and poultry to potentially create another income stream. Although development has been slow, there are farmers producing fish and presenting them to market. The ongoing development of the aquaculture industry in PNG will require continued support from many organisations at the local, national and international level for some time. Through these collaborations, and capacity building of key agencies and staff, a successful and profitable aquaculture industry can be established in PNG.

This paper presents a brief overview of the nutrient requirements of tilapia, and where appropriate, some comparative data on carp and trout. Much of the information has been taken from recent reviews on tilapia by Davis et al. (2009) and Ng and Romano (2013) as well as important texts on fish nutrition (NRC 2011a; Halver and Hardy 2002). This paper presents useful data on the nutrient composition of the major feed commodities available in PNG and how these data can be used to formulate complete feeds or a feed concentrate ready for blending with carbohydrates, such as cassava and sweetpotato. It will also briefly discuss some of the practical issues around small-scale feed manufacturing using mini-mills, feed delivery and assessment of fish performance. It is hoped this basic information will reinforce the concepts and principles of fish nutrition, and demonstrate how flexibility in feed formulation can overcome issues with ingredient supply and quality. Knowledge of these concepts will improve outcomes for both farmers and researchers growing fish in PNG.

FEED CONCENTRATES: AN ALTERNATIVE WAY FORWARD FOR INLAND AQUACULTURE

Smallholder farmers of pigs and poultry in PNG, with the assistance of ACIAR (Glatz 2012) and NARI, have been exploring the use of feed concentrates to grow their animals (Dom et al. 2014). This concept involves farmers using a concentrated ration formulated for either species and blending it with inexpensive starch-based ingredients, such as cassava or sweetpotato. The concentrate is formulated and made by more skilled individuals at major mini-mills and then sold to farmers to blend or pellet on-farm. Many subsistence farmers produce their own cassava (predominantly in the lowlands) and sweetpotato (predominantly in the highlands) crops, therefore these ingredients are readily available and inexpensive. The concentrate technology removes many of the issues involved in making farm-made feeds for livestock, such as the need to understand feed formulation and problems sourcing protein-rich feed ingredients or supplements, such as vitamin and mineral premixes. Thus, the feed concentrate and starch components can be combined by the farmer in the correct ratio to produce an acceptable feed that provides adequate nutrition for their pigs or poultry during various stages of production. This concept is now being extended to farmers of fish in PNG with the expectation that it may encourage them to make their own feeds and thereby lift aquaculture production and overall interest in the fish farming sector (Kohun 2014). Crafting the feed concentrate and starch components into a quality pellet is more critical for fish than land-based animals, as a high proportion of feed can be wasted if pellets have poor cohesion and durability. This can lead to deterioration of water quality in static ponds and tanks. The concentrate technology has the potential to reduce the cost of feed for fish farmers, as the price of the concentrate is effectively diluted by the quantity of starch used, however these benefits are yet to be tested economically.

The major fish species grown by inland farmers in PNG are tilapia, carp and rainbow trout (*Oncorhynchus mykiss*). There is also interest in farming barramundi (*Lates calcarifer*). Species such as trout and barramundi have higher protein and lipid requirements than tilapia and carp (NRC 2011a), therefore ingredients used to make high-protein aquafeeds for these species generally have a higher content of protein and fat. Examples include fishmeal, rendered animal meals (e.g. poultry meal, blood meal, meat and bone meal), protein concentrates (e.g. soy or corn gluten), fish oil, poultry oil, tallow and vegetable oils (e.g. canola oil). However, trout and barramundi, being predominantly carnivorous species, have lower tolerance to carbohydrates, such as starch and fibre. Therefore, a feed concentrate formulated for these species would almost resemble a complete diet and there would be little scope for farmers to dilute a protein-rich feed concentrate with carbohydrates. For this reason, current research on concentrate technology for fish in PNG has focused on tilapia, as their omnivorous nature means they are more tolerant of dietary carbohydrates (Davis et al. 2009; Ng and Romano 2013; NRC 2011a). Tilapia is not dissimilar to carp in terms of its nutritional requirements, so nutritional recommendations made for tilapia will also be useful in formulating aquafeeds and feed concentrates for carp.

Formulating an aquafeed concentrate for tilapia

Formulating a feed concentrate for tilapia, which can be diluted with cassava or sweetpotato in order to make a complete aquafeed, requires knowledge of tilapia's nutritional requirements and accurate information on the nutrient and energy composition of the feed ingredients available for use. If feeds are to be formulated on a least-cost basis, then the cost of individual feed ingredients, additives and supplements also needs to be known. Least-cost formulation is important in large-scale production of aquafeeds where even small savings can have big economic impacts for companies. It is less important in small-scale research or farm trials which often have different objectives.

Much of the data on nutrient requirements of tilapia can be obtained from literature sources. Globally, tilapia is one of the most widely cultured and studied fish, and researchers have spent decades investigating their nutrient requirements, the digestibility and tolerance to novel feed ingredients (El Sayed and Tacon 1997; Ng and Romano 2013), growth rates and health etc. (Davis et al. 2009; Ng and Romano 2013). Ideally, the nutrient and energy composition of ingredients should be determined analytically. However, where these data are unavailable, reliable literature values are a reasonable compromise but they must be used with caution and common sense.

Feed ingredient composition and quality can vary considerably depending on seasonality, processing, storage conditions and age. Many analytical tests are available to assess the quality of proteins in feed ingredients, such as pepsin digestibility, urease activity, trypsin activity, protein solubility, available lysine, total volatile nitrogen and presence of biogenic amines. Fat quality can be assessed by hydrolytic rancidity and oxidative rancidity (Hardy and Barrows 2002). These tests are expensive and will be generally unavailable in PNG, therefore confidence in the estimated composition and quality of ingredients used to make aquafeeds or feed concentrates will rely on the professional relationships between those selling and those buying commodities. Unfortunately, the naïve use of poor-quality ingredients is often not recognised until weeks or months after feeding has commenced, often manifested as low feed intake, poor growth and survival.

TILAPIA

Tilapia are grouped into two genera: *Tilapia* and *Oreochromis*, but both are commonly referred to as tilapia. About 70 species have been identified but only two species of tilapia (*T. rendalli* and *T. zilli*) and three species of Oreochromis (*O. mossambicus*, *O. niloticus* and *O. aureus*) are widely cultured. *O. niloticus*, otherwise known as Nile tilapia is the most cultured species due to its rapid growth, its ability to utilise natural aquatic foods and the fact that it accepts a wide variety of ingredients. It is also tolerant of a wide range of water quality conditions (Li et al. 2013; Lovell 2002). In many parts of the world, tilapia species are considered a food staple and a cheap source of high-quality protein rather than a luxury food item. They are often referred to as 'aquatic chickens' due to their ability to adapt to a wide variety of conditions and feed sources (Davis et al. 2009). Tilapia are a tropical fish and do not survive at temperatures below 10°C. Feeding activity tends to decline at water temperature below 20°C and stops around 15°C. They are very tolerant of low dissolved oxygen levels and high ammonia levels (Lovell 2002). Most commercial production is based on use of all-male stocks.

Culture of tilapia in developing countries relies on extensive production systems using organic fertilisation and low-cost single feed (e.g. locally available feed, such as rice bran, copra meal, coffee pulp, vegetable scraps etc.) as nutrient sources to supplement the naturally occurring food in pond-based systems. These systems are generally categorised as low-input, low-cost production systems. Many farmers of tilapia and other fish species in PNG are still using these types of systems to grow their fish. It is the use of cost-effective, high-quality aquafeeds that has allowed many Asian countries to move towards intensive production systems that support far higher outputs, leading to increased economic returns for farmers and benefits for consumers (Davis et al. 2009).

GROWTH AND FEED CONVERSION CONCEPTS IN FISH

Fish of different ages reared under different physical or environmental conditions have different rates of growth. Most fish species have a preferred water temperature at which growth rate is optimised, providing nutrition and health are not limiting. Breeding and genetics can also influence growth rate in animals. Growth rate is a simple and useful measure to assess the nutritional adequacy of an aquafeed. This is normally done by measuring or tracking changes in body weight or biomass over time. The efficiency by which feed is converted into useful weight gain is known as feed conversion ratio (FCR). This is a measure of the weight of feed required to promote one unit of weight gain; usually reported as kilograms of feed required to produce 1 kg live weight gain. Metabolic rate is higher in smaller fish so FCR and relative feed intake tend to be lower and higher in smaller and larger fish, respectively.

Knowing the optimal growth rate and FCR of fish allows researchers and farmers to easily assess the performance of fish. Even though a feed may be nutritionally adequate, if feed intake (or input) is restricted, then maximum growth rate will not be achieved. For example, fish receiving a very low level of feed may obtain only enough nutrients and energy to maintain body weight (R_{maint}). Given a ration below this level, they will lose weight. Fish receiving more than the ration that promotes maximum weight gain or growth (R_{max}) will not grow any faster but the feed they eat will be converted less efficiently (i.e. higher FCR value). The ration that optimises or promotes the best FCR (R_{opt}) is slightly lower than the ration that promotes optimal growth rate. An appreciation of the simple relationships between feeding, growth and FCR is critical for evaluating the results of feed research and farm-based production outcomes (see Figure 1).

Growth of tilapia

Many studies have measured the growth rate of tilapia under different culture conditions (Santos et al. 2013; Van Trung et al. 2011). A recent growth model for *O. niloticus* grown at 28°C is presented in Equation1 and is useful for creating simple tables that can be used to benchmark growth of tilapia at similar temperatures in PNG (see Tables 1 and 2).

Equation 1:

$$\text{Fish growth rate (g/day)} = 0.276 \times \left(\text{fish live weight}\right)^{0.458} \qquad (R^2 = 0.73)$$

(Van Trung et al. 2011).

Many growth models are available but not all predict the same weight gain for the same size animals. This is partly related to the model selected and partly due to other factors, such as use of different diets, use of mixed versus mono-sex culture and different rearing conditions (Figure 2). Researchers and farmers of tilapia in PNG should be recording growth and feed intake rates of fish as production occurs (including prevailing water quality conditions) so that a comprehensive dataset of historical information can be accumulated. These data are critical for benchmarking and measuring ongoing improvements in aquafeeds and production efficiency at different locations.

NUTRIENT REQUIREMENTS OF FISH

Fish, like all farm animals, obtain the nutrients they require for maintenance, growth and reproductive functions from four basic components present in most feed ingredients: moisture, protein (amino acids), fats (lipids) and carbohydrates. Fish also require their feeds to supply minerals and vitamins. Many minerals and vitamins can be obtained naturally from ingredients but sometimes they must be added to the formula in the form of premixes. Some ingredients are also deficient in certain amino acids and these can be added where necessary in concentrated form. Fish can also obtain and exchange important minerals such as Na^+, Ca^{2+} and K^+ from the water column to help maintain

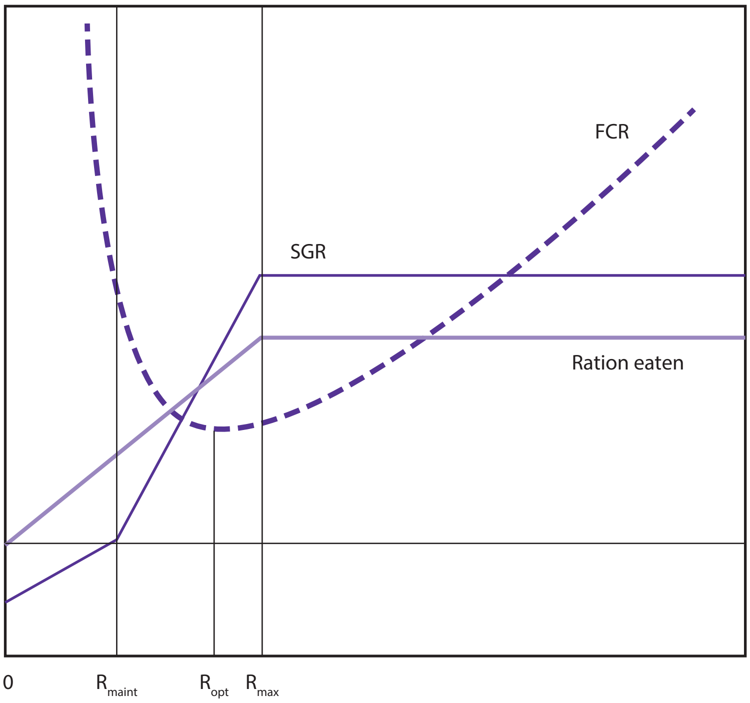

Figure 1. Generalised relationships between feed intake, growth rate and feed conversion ratio in fish.

Table 1. Estimated growth, feed intake and feed conversion ratio (FCR) of tilapia *O. niloticus* grown at 28–30°C. Results based on derivation of a factorial model using diets having 10 MJDE/kg. Data extracted from Van Trung et al. (2011).

Fish live weight (g)	10	50	100	500	1000
Estimated growth (g/day)	0.79	1.66	2.27	4.75	6.53
DE content feed (MJ/kg)	10	10	10	10	10
Estimated feed intake (g/day)	7.7	3.9	2.9	1.5	1.1
DP content feed (g/kg)	327	280	263	227	214
Expected FCR	0.98	1.18	1.28	1.59	1.75
DP:DE ratio	32.7	28.0	23.6	22.7	21.4

DE = digestible energy; DP = digestible protein.

Table 2. Growth of tilapia *O. niloticus* at 28–30°C. Data extracted from Rakocy (1989) cited in Soderberg (2006).

Weight range (g)	Duration (days)	Growth (g/day)	Growth (mm/day)
5–20	30	0.5	1.17
20–50	30	1.0	1.13
50–100	30	1.5	1.12
100–250	50	2.5	1.16
250–450	70	2.9	0.68

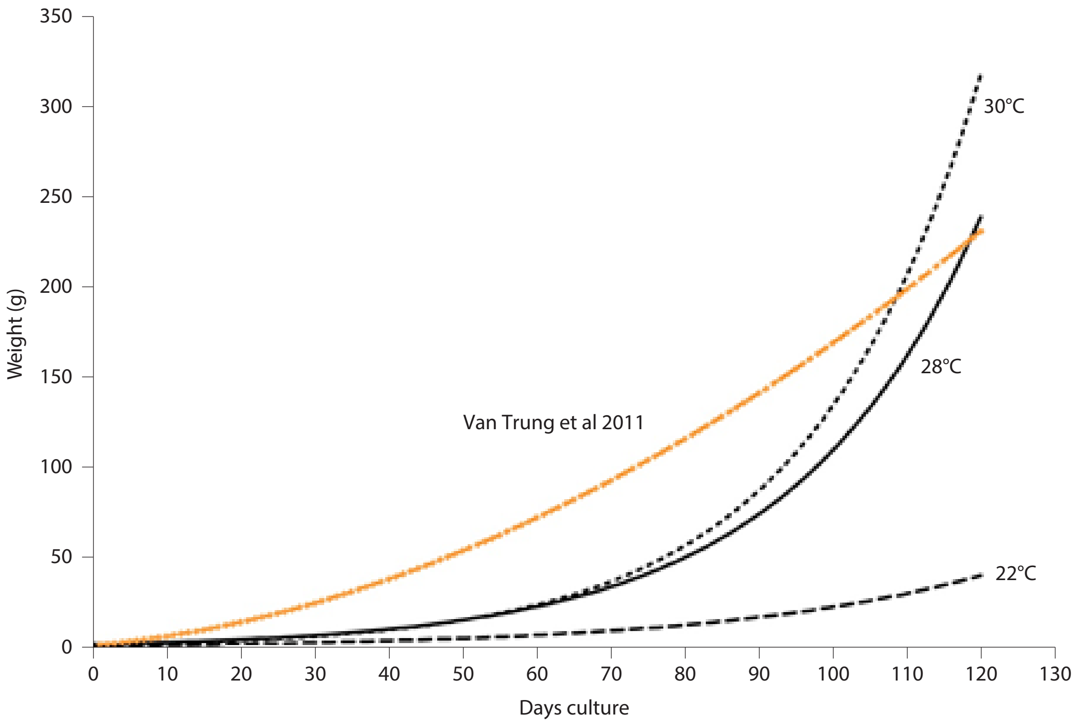

Figure 2. Comparison of several theoretical growth curves for tilapia. (Note the strong effect of water temperature.)

hydro-mineral balance (Moyle and Cech Jr 2000). These ions are usually abundant in most saltwater environments, but when fish are cultured in fresh water, as is the case for inland farmers of tilapia or other freshwater species, it is important to consider or be aware of the concentration of these ions in the feed. Phosphorus is also an extremely important mineral for fish, being essential for growth and bone mineralisation. It can be absorbed from the water but the concentration of phosphorus in water is generally low, so most phosphorus must be obtained from the diet. Phosphorus requirements for GIFT tilapia were recently estimated to be approximately 8.6 g/kg diet using KH_2PO_4 as the source of phosphorus in semi-purified diets (Yao et al. 2014).

This review will assume that the nutrient requirements for tilapia are met only from complete or practical aquafeeds provided by the farmer or researcher. In many cases, omnivorous species, such as tilapias and carps, can obtain additional nutrition from the rearing environment, especially if raised in ponds where free swimming fish can actively forage on plants, small animals and detritus. When fish are reared in cages, this ability to forage is restricted. Therefore, there should be less reliance by the formulator on in-pond nutrient uptake to meet requirements.

Protein and energy requirements

Fish do not have a requirement for protein per se but a requirement for a well-balanced mixture of essential and non-essential amino acids (Wilson 1985). Protein refers to crude protein and is generally calculated by multiplying nitrogen content by 6.25 on the assumption that most proteins contain about 16% nitrogen (NRC 2011a). This is not always the case and true amino acid protein content can be overestimated as many ingredients contain non-protein nitrogen (NPN) compounds, such as nucleic acids, amines, urea, ammonia and nitrates. In some cases, NPN can account for 10–20% of the protein content of feed ingredients. Protein content in aquafeeds for tilapia and other fish will vary depending on many factors, including fish size and growth rate, quality of the protein (e.g. amino acid balance and digestibility), feed intake and amount of non-protein energy in the feed (Davis et al. 2009) (see Tables 3, 4 and 5).

Protein requirement for small tilapia less than 50 g ranges between 30–50% of diet depending on the protein quality, energy level of the diet and feeding rate. Optimum protein level for larger fish ranges from 25–45% of diet. Without access to natural in-pond food sources, most authors suggest small fish should be fed aquafeed with about 36% balanced protein and grow-out fish fed aquafeeds with about 30–32% protein (Davis et al. 2009; Lovell 2002). Some commercial diets for tilapia have been produced with protein levels as low as 17–25% but these type of extreme diets might result in lower conversion efficiency and poorer yields (Li et al. 2013). Digestible energy (DE) content of around 10–12 MJ/kg diet seems appropriate for most tilapia feeds.

The ratio of protein to energy and the form of energy is also important with respect to protein utilisation and fish being able to achieve maximum growth. Protein:energy ratio declines as fish get larger, requiring around 29–25 g protein/MJ gross energy (GE) when fish are small to about 21–19 g protein/MJ GE for growth rations (Li et al. 2013). Modern feeds are formulated using data on the digestibility of individual ingredients. Tilapia appear to digest most ingredients, such as fishmeal, meat meal and soybean meal, very well but obtain less DE from very fibrous ingredients like alfalfa meal and coffee pulp (Lovell 2002).

Table 3. Basic crude protein requirements of different fish species of relevance to PNG (Wilson 2002).

Species	Protein source	Estimated requirement (% of diet)
Asian seabass (*Lates calcarifer*)	casein, gelatin	45
Brown trout (*Salmo trutta*)	casein, fishmeal, fish protein concentrate	53
Rainbow trout (*Oncorhynchus mykiss*)	casein, gelatin	40
Blue tilapia (*O. aureus*)	casein, egg albumin	34
Common carp (*Cyprinus carpio*)	casein	38
Nile tilapia (*O. niloticus*)	casein	30
Zilli's tilapia (*T. zilli*)	casein	35

Amino acid requirement

Tilapia require the same 10 essential amino acids as other fish and land animals (NRC 2011a). Tilapia can meet requirements for methionine and cysteine

Table 4. As-fed (%) crude protein level recommended for fish species of various sizes (Chapter 5, NRC 2011a).

Species	Weight range				
	<20 g	20–200 g	200–600 g	600–1500 g	>1500 g
Nile tilapia (*O. niloticus*)	40	34	30	28	26
Common carp (*C. carpio*)	45	38	32	28	28
Rainbow trout (*O. mykiss*)	48	40	38	38	36

Table 5. General specifications of practical diets for tilapia, carp and catfish (Davis et al. 2009).

Nutrient	Fry	Juvenile	Adult
Protein (%)	45–41	40–36	35–30
DP/DE (g DP/MJ)	26–24	23–21	20–18
Fat (%)	12–11	10–7	6–5
n3 (% min.)	1.0	0.7	0.5
Fibre (% max.)	2.0	2.5	3.5
Ash (%)	9–7	6–8	5–8
Moisture (%)	11–10	11–10	11–10

(sulphur amino acids) by methionine alone or a combination of methionine and cysteine (NRC 2011a). Cysteine and tyrosine are thought to be able to spare about 50% of the methionine and phenylalanine requirements of tilapia (Delmondes et al. 2008; Lovell 2002; NRC 2011a). It should be noted that many studies to determine amino acid requirements of fish have used small rapidly-growing fish. Small, healthy fish likely to have relatively higher requirements for amino acids than larger animals so recommended dietary levels of amino acids should more than satisfy needs of larger fish (Yue et al. 2014). While data on amino acid requirements for tilapia (Table 6) and other species are plentiful, there are fewer data on the availability (i.e. digestibility) of amino acids from individual feed ingredients, especially novel sources available to smallholder farmers. This can make formulating feeds using local ingredient sources, which meet but do not exceed requirements, somewhat difficult. In cases where the formulator suspects low availability of amino acids in some ingredients, it may be prudent to slightly oversupply the level of amino acids in the diet to offset any perceived deficiency.

Lipid and carbohydrate requirements

A true lipid requirement for fish cannot be defined because the level is influenced by a variety of other nutritional factors, not least the presence and amount of energy available from dietary protein and carbohydrate (NRC 2011a). Thus, dietary lipid is primarily a source of energy. A minimum amount of the correct type of lipids must be supplied in order to supply fish with adequate levels of essential fatty acids (EFA) and in some cases cholesterol and phospholipids. Dietary lipids also act as carriers for fat soluble vitamins (Davis et al. 2009). However, the oversupply of lipid leads to unwanted deposition of fat in the peritoneal cavity, digestive organs and tissues, representing wasted energy. Excess deposition of fat may increase weight of fish and improve FCR but it does not improve tissue yield and overly fatty fish can deteriorate quickly once harvested.

Proteins and carbohydrates can be converted into lipids via metabolic processes (i.e. lipogenesis) with amino acids and pyruvate serving as the main energy sources of carbon (NRC 2011a). However, using dietary protein for energy metabolism is undesirable, mostly because dietary protein is expensive and oversupply in the diet is costly. Breaking down or deamination of excess protein also releases nitrogenous wastes into the water column (ammonia), reducing water quality in closed systems. Protein content of aquafeeds can be optimised or even reduced in species that can readily utilise either lipids or carbohydrates as sources of energy. This is commonly known as 'protein sparing'. The ability to use either source of energy

Table 6. Estimate of essential amino acid requirements (% of crude protein) of tilapia (*O. niloticus*), carp (*C. carpio*) and trout (*O. mykiss*). Column at far right indicates the ideal amino acid profile for teleost fish using lysine as a reference.

Essential amino acid	Abbreviation	Tilapia*	Carp*	Trout*	Ideal for teleost fish (% lysine)
Arginine	Arg	4.2	3.8–4.3	3.3–5.9	82
Histidine	His	1.7	1.4–2.4	1.0–1.6	35
Isoleucine	Ile	3.1	2.3–2.5	1.5–2.8	54
Leucine	Leu	2.8–3.6	3.3–4.1	2.3–4.4	70
Lysine	Lys	5.1–5.7	5.3–5.7	3.0–6.1	100
Methionine**	Met	2.1–3.2	1.6–3.1	1.8–2.2	38
Phenylalanine**	Phe	3.8–5.5	3.3–6.5	4.3–5.2	55
Threonine	Thr	3.8–4.7	3.3–3.9	2.6–3.7	56
Tryptophan	Trp	1.0	0.3–0.8	0.4–1.4	14
Valine	Val	2.8	2.9–3.6	1.7–3.4	61

* Data extracted from Ng and Romano (2013), chapter 5 (NRC 2011a) and chapter 3 (Wilson 2002).
** Methionine in presence of cysteine and phenylalanine in presence of tyrosine.

depends greatly on the evolution of the animal, with some species better at using lipids and some better at using carbohydrates (Halver and Hardy 2002). Tilapia, like many omnivorous and herbivorous freshwater fish, evolved on natural diets rich in plant material and low in lipids. For this reason, they do not tolerate high levels of fat in their diet and levels below 10–12% are recommended (Davis et al. 2009; Ng and Romano 2013; NRC 2011a).

Production diets for tilapias, carps and catfish can have total lipid levels as low as 4–8%. Given protein requirements for growing tilapia are around 32% and upper lipid levels are around 12%, this means that about 56% of the diet can be in the form of quality carbohydrates.

In terms of fish nutrition, carbohydrates can be broadly categorised as starches (e.g. simple and complex) and non-starch polysaccharides (NSP). Starches are relatively well digested and include dextrin and glucose. Fish lack the enzymes responsible for digestion of most NSPs, therefore it is poorly digested or not at all (e.g. cellulose) (Ng and Romano 2013). The high level of plant-based ingredients used in tilapia feeds, especially unrefined ingredients, will inevitably increase the level of NSP in aquafeeds for this species and formulators need to be cognisant of the potential impacts this can have on the manufacture of the feed as well as the performance of the animal. The digestibility of NSPs may be increased by pre-treatment with, or addition of, enzymes to aquafeeds (e.g. phytase, cellulase etc.). Other treatment methods, such as heating, acidification or fermentation of ingredients may be useful in degrading NSPs as might be use of pre-biotic and pro-biotic approaches (Davis et al. 2009).

Fatty acid requirement

Like all vertebrates, tilapias, carps and catfish require α-linolenic (18:2n-6) and α-linoleic acid (18:3n-3) in their diet. Tilapia can also chain elongate and desaturate α-linolenic acid to the longer chain polyunsaturated fatty acids (LC-PUFA) eicosapentaenoic (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3) and arachidonic acid (ARA; 20:4n-6) from α-linoleic acid. Even so, it is recommended that at least some LC-PUFA be provided in the diet (Ng and Romano 2013). Use of vegetable oils rich in 18:2n-6, such as soybean oil, has produced better growth performance than marine fish oils rich in 20:5 and 22:6n-3 fatty acids. This is thought to be related to the fact that warm-water fish appear to have a higher requirement for n-6 PUFA than n-3 PUFA (Takeuchi et al. 1983 cited in Lovell 2002; NRC 2011a). There is still much conjecture surrounding the fatty acid requirements of tilapia and the correct ratio of n6:n3 fatty acids. Optimum level of dietary n-6 fatty acid is thought to be around 0.5–1% (Ng and Romano 2013).

Tilapia appear to do well on diets where fish oil is at least partially replaced with alternatives such as soybean oil, coconut oil, linseed oil, grapeseed oil or poultry fat. Palm oil, being one of the most readily available vegetable oils globally, is also likely to be a suitable alternative lipid source for tilapia feeds (Ng and Romano 2013). As always, use of vegetable oils in favour of marine oils in fish diets will change the fatty acid composition of the fillet, reducing the level of beneficial LC-PUFAs EPA and DHA to the consumer. If necessary, this issue can be overcome by introducing finishing diets containing marine oils, at or near the end of the production cycle, to restore LC-PUFA composition.

Vitamin and mineral requirements

Vitamins are organic compounds distinct from amino acids, carbohydrates and lipids, and they are required in very small amounts from an exogenous source, usually the diet. They are classified as water soluble or fat soluble. The mineral requirements of fish are similar to the metabolic requirements of land animals, with the exception of those involved in hydro-mineral balance (NRC 2011a). Estimating the mineral requirements for fish is complicated by their ability to obtain and exchange minerals from the water column. Dietary supplementation of minerals, as opposed to the actual requirements of the fish, are therefore complicated by the prevailing salinity (Moyle and Cech Jr 2000; NRC 2011a). Of the 23 minerals that have been shown to be essential for one or more fish species, practical diet formulations for fish typically contain phosphorus (P), magnesium (Mg), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn) and selenium (Se) (Davis et al. 2009).

Both vitamins and minerals are critical components of any aquafeed, and improper supplementation can have negative consequences on production (Davis et al. 2009). Although the minimum requirements for many vitamins and minerals have been determined for fish (Tables 7 and 8), many nutritionists now acknowledge that these levels may not be adequate for practical production conditions, where differences in the environment and other culture conditions may place additional stresses on the animal (Davis et al. 2009; Ng and Romano 2013). The cost of vitamin and mineral premixes is usually very high; far higher than the cost of normal feed ingredients. Therefore, there is a balance between ensuring that the vitamin and mineral requirements of the fish are met (Tables 9 and 10) and the overall cost of the formulation is not too high.

Fish, especially those such as tilapias, carps and catfish, can obtain some of their vitamins and minerals from natural feeds present in ponds or from individual ingredients within an aquafeed, however most formulators ignore these potential sources and rely on meeting dietary requirements for vitamins and

Table 7. Estimated vitamin requirements for tilapia (data adapted from Ng and Romano 2013).

Vitamin	Vitamin form	Recommended level (mg/kg unless otherwise indicated)
Water-soluble choline	Choline chloride	3000
Choline	Choline chloride	1000
Thiamin (B_1)	Thiamin hydrochloride	3.5
Riboflavin (B_2)	Riboflavin	6
Riboflavin (B_2)	Riboflavin	5 (in seawater)
Niacin (B_3)	NP	26 121
Pantothenic acid (B_5)	Calcium d-pantothenate	10
Pantothenic acid (B_5)		10
Pyridoxine (B_6)	Pyridoxine hydrochloride	1.7–9.5 15.0–16.5
Biotin (B_7)	Biotin	0.06
Folic acid (B_9)	Folic acid	0.82
Folic acid (B_9)	Folic acid concentrate	0.5–1.0
Vitamin B_{12}	Vitamin B_{12}	Not required
Vitamin C	Ascorbic acid	125 mg/100 kg
Vitamin C	C2S CSMP-Mg Ascorbic acid	41–48 37–42 80
Vitamin C	C2MP-Na C2MP-Mg	63.4 40.5
Inositol	*myo*-inositol	100–400 mg/kg
Lipid-soluble inositol	*myo*-inositol	400 mg/kg
Vitamin A	NP	5000 IU/kg
Vitamin A	Retinyl acetate	5850–6970 IU/kg
Vitamin A	Vitamin A acetate	Not required
β-carotene	β-carotene	28.6–44
Vitamin D	Cholecalciferol D_3	374.8 IU/kg
Vitamin E	Tocopherol-acetate	20–100
Vitamin E	α-tocopheryl acetate	63–206

minerals using specialised or proprietary premixes. Tilapia is mostly farmed in fresh water or low saline environments, therefore correct supplementation of minerals is critical to ensure growth and health is optimised (Tables 11 and 12). Increased use of plant proteins increases the level of unavailable phosphorus (phytate) in feeds for tilapia, therefore a good source of available phosphorus, such as dicalcium phosphate, is essential (Ng and Romano 2013).

FORMULATION OF PRACTICAL FEEDS

Diet formulation is an attempt to match the feed specifications to the nutrient requirements of the animal. Diet formulation and manufacture are exercises in compromise between formulating the ideal diet that meets all the animal's requirements and being able to manufacture and distribute an acceptable feed. In this sense, diet formulation and pellet manufacture should

Table 8. Estimated mineral requirements for tilapia (adapted from Ng and Romano 2013).

Mineral	Mineral form	Culture condition	Recommended level
Ca	Ca-sulphate	FW (0 mg/L Ca)	7 mg/kg
Ca	Ca-lactate	FW (27.1–33.3 mg/L CA)	3.5–4.3 mg/kg
Cr	Cr_2O_3	FW	204 mg/kg
Cr	Cr-picolinate	FW	Not required
K	KCl	FW (2.4 mg/L K)	2–3 g/kg
Mg	Mg-acetate ($4H_2O$)	FW (9.12 mg/L Mg)	0.59–0.77 mg/kg
Mg	$MgSO_4$		5 g/kg
Fe	Ferric citrate Ferrous sulphate	FW (59.75 µg/L)	150–160 mg/kg 85 mg/kg
P	Monobasic sodium phosphate	FW (0.52 mg/L P)	5 g/kg
Na	NaCl	FW SW (32–34‰)	1.5 g/kg Not required
NaCl	NaCl	FW	30–3.5 g/kg
Zn	Zinc sulphate ($7H_2O$)	FW	30 mg/kg
Zn	Zinc sulphate monohydrate	FW (7.95 µg/L Zn)	79.5 mg/kg

Table 9. Role of minerals and typical signs of deficiency in tilapia (Ng and Romano 2013).

Mineral	Role	Signs of deficiency
Ca	Essential component in bone and scales for mineralisation	Lower growth
Cr	Improves carbohydrate utilisation	Lower growth
K	Essential for osmoregulation	Lower growth Depressed Na^+/K^+-ATPase activity
Mg	Aids in protein utilisation	None reported
Fe	Essential component in blood	Lower growth Lower haematological values
P	Essential component in phospholipids, ATP and bone	Lower growth Lower P and Ca deposition in bones
Na and Cl	Major ion species in blood Essential for osmoregulation and acid/base balance	Lower growth Depressed Na^+/K^+-ATPase activity
Zn	Essential component in the enzymes carbonic anhydrase, alkaline phosphatase and alcohol dehydrogenase Essential component in cellular membranes Aids in protein and carbohydrate utilisation	Lower growth and protein efficiency ratios Increased liver glycogen Increased moisture in muscle

not be considered independent activities (Hardy and Barrows 2002). Feeds can be formulated for different purposes. Thus, feeds designed for research will often look very different to those designed for broodstock, larvae, fingerlings or grow-out. However, all feeds have a common goal, to bring together a combination of ingredients and additives that deliver the nutrients needed to meet production or research goals in fish husbandry (Hardy and Barrows 2002).

It is now commonplace to use computer software programs to formulate aquafeeds for research and production purposes, although spreadsheet programs such as Microsoft Excel can still be useful when access to such programs is difficult. These programs run linear (Rossi 2004) or stochastic (Roush 2004) programming functions that can calculate the most efficient combination of ingredients that meet the particular set of constraints set by the formulator. In this sense, the program sees the problem only as a

Table 10. Role of vitamins and signs of deficiency in tilapia (Ng and Romano 2013).

Vitamin	Role	Signs of deficiency
Choline	Cellular repair	Lower growth
Thiamin	Coenzyme to thiamine pyrophosphate Essential for various metabolic ways	Anorexia Instability/lethargy Lower haematocrit values Lower feeding efficiency and growth
Riboflavin	Essential for erythrocyte glutathione reductase Essential for liver D-amino acid oxidase	Anorexia and reduced feed intake Nervous symptoms Fin erosion Cataracts Changes in normal body colour Lower liver D-amino acid oxidase No histopathological changes
Niacin	Precursor for coenzymes for carbohydrate metabolism	Skin/fin lesions Haemorrhages Snout deformations
Pantothenic acid	Precursor for coenzyme A for carbohydrate metabolism	Gill lesions Reduced food intake
Pyridoxine	Essential for protein/AA metabolism	Anaemia Lower growth Lower hepatic alanine aminotransferase
Folic acid		Lower growth No change to haematological values
Vitamin C	Important for immunity Important for collagen synthesis Antioxidant properties	Lower growth
Inositol	Structural component in phospholipids of cell membranes Involved in transduction pathways	Lower growth Higher muscle/liver lipid
Vitamin A	Vision Cell growth	Haemorrhages Exophthalmia Oedema Reduced mucous secretion Lower growth and survival
Vitamin D	Possible role and Ca and P bone mineralisation	Lower growth
Vitamin E	Antioxidant properties Important roles in reproduction	Lower growth

Table 11. Example of vitamin and mineral fortification used in commercial tilapia feed (Orachunwong et al. 2001 cited in Ng and Romano 2013).

Vitamin	mg/kg feed	IU/kg feed	Mineral	g/kg feed
Thiamine	20		Calcium	3
Pyridoxine	10		Phosphorus	7
Riboflavin	20		Magnesium	0.4
B_{12}	1		Iron	0.03
Folic acid	5		Zinc	0.2
Choline	500		Copper	0.003
Pantothenic acid	50		Manganese	0.013
Niacin	100		Iodine	0.0025
Ascorbic acid	375			
Biotin	1			
Inositol	100			
K	10			
A		5500		
D_3		2000		
Alpha-tocopherol		50		

Table 12. Recommended vitamin fortification levels for warm water fish (adapted from Roche guidelines, Davis et al. 2009).

Vitamin	Unit/kg feed	Minimum	Maximum
A	IU	4000	8000
D	IU	1000	2000
E	IU	100	300
K	mg	5	10
Thiamine (B_1)	mg	10	20
Riboflavin (B_2)	mg	15	20
Pyroxidine (B_6)	mg	8	12
Vitamin B_{12}	mg	0.02	0.05
Niacin	mg	80	120
Pantothenate	mg	40	50
Folic acid	mg	4.0	7.0
Biotin	mg	0.5	1.0
Vitamin C	mg	50	300
Choline	mg	0	600

Vitamin A: 1 IU is the biological equivalent of 0.3 µg retinol, or of 0.6 µg beta-carotene.
Vitamin D: 1 IU is the biological equivalent of 0.025 µg cholecalciferol/ergocalciferol.
Vitamin E: 1 IU is the biological equivalent of about 0.667 mg d-alpha-tocopherol.
(2/3 mg exactly), or of 0.45 mg of dl-alpha-tocopherol acetate.

mathematical one; to satisfy a series of simultaneous equations. It is therefore imperative that the formulator has knowledge of fish nutrition, ingredient composition and associated issues (e.g. anti-nutrients), ingredient pricing and pellet manufacture in order to assess the potential of successful formulations. When a formulation fails (i.e. cannot be mathematically resolved), this knowledge can allow the formulator to confidently relax certain constraints until a satisfactory solution can be found. Any inaccuracies in inputs to the programs will be reflected in the output. Most formulators are conservative and slightly oversupply critical nutrients to offset the inherent variability in nutrient or energy composition of ingredients. It is now also commonplace to formulate on a digestible or available nutrient and energy basis, where this information is available and reliable.

FORMULATION CONSTRAINTS

Formulation constraints can be nutritional, physical and economic. Nutritional constraints include setting the minimum and maximum protein and energy content of the formula, the level of some or all amino acids, level of fat and possibly some key fatty acids, level of vitamins and minerals or premixes and level of starch. The ratio of different nutrients can also be constrained. Physical constraints are those which limit the upper and lower inclusion limits of an ingredient, and these tend to reflect manufacturing issues (e.g. inability to use more than 20% oil in extruder, the desire to control pellet buoyancy or bulk density, or the need for a certain amount of starch to allow pellet expansion), or the formulators desire to include several protein sources in the recipe. Economic constraints might include the changing price and availability of ingredients (e.g. marginal price changes), total allowable cost of feed and the need to reduce or manage large volumes of warehoused ingredients (see Table 13 for an example of formulation constraints used in production diets for tilapia).

At present, the manufacture of local aquafeeds in PNG is restricted to those made using mini-mills. These mills are extremely rudimentary in nature

Table 13. Example formulation constraints for the least-cost formulation of commercial tilapia feeds (Orachunwong et al. 2001 cited in Ng and Romano 2013).

Constraint	% Restriction	Pre-starter	Starter	Grower	Finisher
Crude protein	Min	40	30	25	20
Crude fat	Min	4	4	4	4
Crude fibre	Max	4	4	6	8
Lysine	Min	2.04	1.53	1.28	1.02
Methionine + Cysteine	Min	1.28	0.96	0.80	0.64
Threonine	Min	1.44	1.08	0.90	0.72
Fatty acid (omega-3)	Min	0.50	0.50	0.50	0.50
Fatty acid (omega 6)	Min	0.50	0.50	0.50	0.50
Calcium	Max	2.50	2.50	2.50	2.50
Phosphorus (total)	Max	1.50	1.50	1.50	1.50
Phosphorus (available)	Min	0.60	0.60	0.60	0.60
Starch	Min	25	25	25	25
Digest. energy (MJ/kg)	Min	11.72	11.72	11.72	11.72
Vit-Min premix	Fixed	2	2	2	2
Fishmeal (60% protein min)	Min	15	12	10	8
Rice bran			No limit		
Wheat bran			No limit		
Rapeseed/Cottonseed	Max	–	10	15	20
Corn/Cassava/Sorghum	Min	10	10	10	10

and not capable of extrusion-cooking or generating significant shear forces on ingredient mixtures. Pellets produced from these mills are therefore cold-pressed and not capable of gelatinising or cooking starches. This constraint however does not preclude mini-mills or farmers cooking carbohydrates such as cassava or sweetpotato, or even feed mixtures before they are pelleted and fed to fish. Cooking has several potential benefits. Firstly, it is very effective at destroying bacteria that may be contaminating the feed or ingredients. It also helps preserve the feed if it is to be stored. Cooking also helps to increase the digestibility of carbohydrate-rich ingredients by gelatinising the starch. Finally, because of the gelatinisation of starch, cooking can increase the binding capacity of starches, resulting in better cohesion of all ingredients and a more durable pellet. Cooking and drying may be particularly important to eliminate cyanogenic glucosides from cassava before it is considered in a formulation for tilapia (Ng and Wee 1989; Oke 1978).

INGREDIENTS AVAILABLE FOR MAKING AQUAFEEDS IN PNG

Fishmeal has long been the protein source of choice for intensive fish culture. This is because it contains an excellent balance of essential amino acids, is a good source of essential fatty acids, vitamins, minerals and energy (NRC 2011a). It is also thought to contain intangible factors that enhance feed intake and immune function. At present, there is a limited supply of quality fishmeal for use in small-scale aquafeed production in PNG. Therefore, alternative protein sources must be considered and the formulator must be able to modify their formula constraints to accommodate changes in availability and cost of ingredients.

Current commercial aquafeeds for tilapias, carps and catfish have low levels of protein, minimal lipid and high levels of carbohydrate (Davis et al. 2009). In many developed countries, practical diets for tilapia are currently based on diets containing 40% soybean meal and other plant proteins. These are combined with low levels of animal proteins to provide the required level of dietary protein (i.e. amino acids) (Davis et al. 2009). Formulators often use a blend of three to four protein sources in aquafeeds to ensure the diet is well balanced. This conservative approach ensures that the 'strength' of the formulation is not overly dependent on one nutrient source. It also guards against the possibility that one or two of the major protein sources are unknowingly deficient in some of the essential amino acids. In a sense, it reduces the risk of the formulation failing.

Diets for tilapias and carps can contain significant amounts of plant-based feed. While these are usually cheaper sources of protein and energy than other higher protein ingredients, they can be problematic depending on whether they contain anti-nutrients that negatively affect palatability or digestion. Some may also have very high levels of fibre (e.g. NSP). A large variety of ingredients have been examined in feeds for tilapia, and while there are advantages to retaining some fishmeal in diets of fry and fingerlings, there is no biological reason to retain it in grower diets as long as the aquafeed is well balanced nutritionally (Davis et al. 2009). Despite this fact, tilapia production diets generally contain some fishmeal (0–20%). Going forward, global production trends predict overall use of fishmeal in aquafeeds for tilapia will be less than3% by 2020 (Ng and Romano 2013).

There are many published resources on the nutrient composition of common and more novel feed ingredients available in PNG and the wider Pacific, and it is not the intention of this paper to repeat this information (Edwards and Allan 2004; Pirozzi et al. 2011). Nonetheless, Table 14 summarises some of the basic feed ingredients that might be encountered in PNG. There are also numerous quality publications on the use of novel feed ingredients by tilapia. These are often valuable sources of information on the chemical composition of new ingredients and generally include recommendations on inclusion level. Many now include important data on ingredient digestibility (Abdel-Fattah 1999; Adewolu 2008; Belal et al. 2015; Edwards et al. 2004; Köprücü and Özdemir 2005; Munguti et al. 2006; NRC 2011b; Santos et al. 2009a; Santos et al. 2009b; Sklan et al. 2004; Zhou and Yue 2012).

Use of any ingredient in a complete aquafeed or feed concentrate is ultimately at the discretion of the formulator. For this reason, they must be aware of the merits and problems each may have with respect to influencing the nutritional adequacy of the feed as well as its manufacturing characteristics. Least-cost

Table 14 Summary of potential feed ingredients for use in formulation of aquafeeds for tilapia. Obtained from various sources including Edwards and Allan (2004) and Pirozzi et al. (2011). Commodity prices are estimates based on data obtained in 2014.

Ingredient	$ Price (kina/ tonne)	Dry (matter %)	Moisture (%)	Crude protein (%)	Fat (%)	Ash (%)	NFE (%)	Crude fibre (%)	Gross energy (MJ/kg)	Digestible protein (%)	Digestible energy (MJ/kg)
Fly herring (dried)	2400	93.8	6.2	52.7	8.4	21.9	10.8	1.00	17.60	45.9	16.03
Fishmeal (FAQ)	2900	91.8	8.2	65.3	7.1	15	4.4	1.00	19.00	58.8	17.86
Fishmeal	2800	86.8	13.2	56.9	7.7	21.7	0.5	0.80	18.00	51.3	16.92
Fishmeal	2600	95.3	4.7	50.3	16.5	21.2	7.3	0.80	18.90	45.3	17.77
Meat meal (rend)	1516	92.6	7.4	49.1	10.3	29.9	3.3	2.30	16.20	31.4	9.40
Meat and bone meal	1516	96.1	3.9	53.8	1.9	2.5	37.9	2.40	19.80	34.4	11.48
Soybean meal	1603	88.4	11.6	44.4	1.2	6.1	36.7	3.90	17.00	40.4	14.79
Soybean meal	1620	90.6	9.4	45.9	1	6.3	37.4	3.90	17.00	41.7	14.79
Peanut meal	5750	90.4	9.6	46.2	9.3	5.2	29.7	6.46	19.10	35.9	15.57
Maize	715	87.8	12.2	8.45	3.66	1.5	74.2	2.60	16.30	6.2	10.98
Corn	715	89.4	10.65	7.21	4.24	1.2	76.7	2.00	16.80	5.3	11.31
Copra meal	1550	94.8	5.2	21.9	9.6	6.2	57.1	12.00	18.70	16.6	6.94
Copra meal	1550	93.5	6.5	23.4	10.4	5.9	53.8	12.00	20.10	17.7	7.46
Copra meal	1550	91.5	8.5	20.8	8	6.2	56.5	12.00	18.30	15.7	6.79
Feed pellets tilapia	5000	90.5	9.5	26	8.6	9.9	46.0	6.00	16.10	22.1	12.88
Feed pellets trout	5500	91.3	8.7	28.1	9.8	11	42.4	6.00	16.50	23.9	13.20
Rice bran (low fat)	450	91.0	9	13	7.4	24.7	45.9	17.90	18.22	8.7	10.49
Rice bran (high fat)	450	91.7	8.26	12.8	16.8	9.81	52.3	12.00	17.14	8.6	9.87
Sweetpotato tubers (dry)	1500	88.7	11.3	4.05	1.3	2.76	80.6	3.00	15.30	2.7	12.70
Tallow	2789	99	1	0	98	1	0.0	0.00	38.00	0.0	34.20
Cassava meal (dry)	900	86.5	13.5	2.1	0.6	3.4	80.4	3.42	12.70	1.7	10.54
Wheat flour (Aust. origin)	900	88.0	12.0	12.0	1.2	0.5	74.6	0.5	16.1	10.8	9.66
Vitamin / mineral premix	15000	97.0	3.0	7.94	9.99	40.84	38.2	0.05	11.35	7.1	10.22
Methionine 50%	6200	99.0	1	57.69	0.25	0.5	40.6	0.05	23.60	51.9	21.24
Cassava leaves	200	93.4	6.64	29	2.37	5.95	56.0	10.21	19.66	12.905	8.68

formulation also requires knowledge of commodity prices, and obtaining up-to-date information about these can prove difficult. Pricing of local PNG commodities and ingredients can be obtained when goods change hands. Pricing of major imported commodities, such as fishmeal, fish oil and animal meals or imported oilseeds and cereals, often remains the intellectual property of the importing feed mill. All prices paid by feed mills for commodities used in agricultural feeds will also regularly vary according to the supply and volume of the ingredient being purchased, the availability of other ingredients as well as a swathe of other economic factors. If necessary, formulators can obtain some idea of spot or long-term commodity prices from reliable sources publishing on the internet (Bacon 2015; www.hammersmithltd.blogspot.com) (Table 15).

PRACTICAL AQUAFEED FORMULATIONS

As an exercise in compromise between satisfying the nutrient requirements of the fish, dealing with variability in the nutrient composition of ingredients and making a good quality pellet, it should be obvious it is impossible to formulate the ideal aquafeed from any set of ingredients. Therefore the art of least-cost formulating lies in getting as close as possible to this ideal for the least possible cost (Rossi 2004). Thus, numerous solutions to a formulation problem are possible depending on the database used and the limitations imposed on it. Even small adjustments in the formula constraints used in linear programming software (e.g. nutrient composition, nutrient requirements, ingredient price, inclusion settings etc.) can result in minor or major changes in the level of ingredients selected and the price of a successful formulation.

Based on the nutrient requirements of tilapia and the ingredient database presented in Table 14, it would be possible to formulate numerous aquafeeds for tilapia and other species using least-cost linear programming. This would be futile because each formulation problem would undoubtedly begin with a unique set of formulation constraints. Rather than present numerous hypothetical formulations, some examples of commercial tilapia feeds are presented in Tables 16 and 17. These commercial formulations are noteworthy for two reasons. Firstly, they demonstrate how little fishmeal is incorporated in well-balanced production diets for tilapia and secondly, how reliant these formulas are on plant proteins and plant starches.

Table 15. Feed ingredient pricing in PNG circa 2014. Source is confidential.

Ingredient	Price (kina/tonne) circa 2014
Wheat 11.5	913.00
Meat meal 50% crude protein	1,954.00
Blood meal 85% crude protein	3,520.00
Fishmeal 56% crude protein (local PNG)	2,125.00
Tallow	2,711.00
Soybean meal 48% crude protein	2,132.00
Millrun 15% crude protein	23.11
Choline chloride 75% active	5,075.00
Liquid(methionine)	8,253.00
Lysine HCl	6,064.00
L-threonine	6,372.00
Copper sulphate	5,412.00

Table 16. Model tilapia formulations adapted from Lovell (2002).

Ingredient	Pond (26%)	Raceway (32%)	Raceway (36%)
Fishmeal	4.0	6.0	12.0
Soybean meal	38.3	48.5	50.8
Wheat middlings	4.0	20.0	18.0
Corn	4.0	22.6	16.5
Dicalcium phosphate	50.8	1.0	0.8
Plant oil	1.5	1.5	1.5
Vitamin mix	0.2	0.2	0.2
Mineral mix	0.2	0.2	0.2

Table 17. Generic production diets for tilapia, carp and catfish taken from Davis et al. (2009)

Ingredient (as-is basis)	36% CP/ 7% fat	32% CP/ 6% fat
Soybean meal 46%	34.00	50.00
Wheat flour 13.2%	19.80	25.00
Fishmeal 64%	13.50	–
DDGS 28.5%	10.00	14.00
Rice bran 13%	8.00	–
Corn gluten meal 60.7%	7.00	3.00
Fish oil (anchovy)	2.70	1.50
Blood meal 90%	2.00	1.50
Ca Phosphate mono 21%	1.30	2.20
Soy oil	0.50	1.70
Vitamin premix	0.50	0.50
Mineral premix	0.25	0.25
Mould inhibitor	0.30	0.30
Choline chloride 60%	0.10	0.10
Vitamin C 35% active	0.03	0.03
Ethoxyquin	0.02	0.02

STRATEGY FOR FORMULATING A CONCENTRATE FOR TILAPIA

As discussed above, the use of an aquafeed concentrate for fish in PNG was advanced because of the success this strategy was having in smallholder production of pigs and poultry (Dom et al. 2014). The premise was that once a concentrate was available, smallholder fish farmers would be able to purchase it and blend it with feed ingredients obtained from their own farms. This would extend the value of the concentrate, reduce the quantity of feed being transported and potentially reduce feeding costs. The preparation and distribution of the concentrate from strategically located mini-mills would also remove the issue of farmers trying to purchase alternative ingredients and formulate their own feeds.

Most staples produced by smallholders in PNG are relatively poor in protein and high in carbohydrate (e.g. cassava and sweetpotato). Essentially, these ingredients are sources of energy. Thus, any feed concentrate formulated for fish will need to be composed of ingredients having relatively high levels of protein (amino acids). The concentrate formula would also need to account for dilution of other important nutrients, such as lipid, vitamins and minerals.

The formulation of aquaculture concentrates in PNG was initially explored with consideration given to two options for tilapia, the species most likely to benefit from the concentrate strategy. The concentrate could be formulated using imported ingredients and mixed with carbohydrate sources. Alternatively, the concentrate could be formulated from local ingredients. This paper focuses on the former option, partly because access to protein sources in PNG is limited, as already discussed. Were they available, the formulation process would be similar. The need for more than one type of feed concentrate was also considered, in view of the fact some farmers were operating at a more intensive level of production than others. Thus, fish being produced intensively in ponds and cages would require nearly all their nutrition from the blended concentrate while fish reared in more extensive systems could be produced on a lower protein concentrate. We will focus on an aquafeed concentrate for growing tilapia in intensive systems, assuming fish must obtain all their nutrition from the feed.

The most important considerations in formulating an aquafeed concentrate are no different to those when formulating complete aquafeeds, namely: composition, cost and availability of ingredients coupled with the nutrient requirements of the animal. As feeds for growing tilapia require approximately 30–32% protein, 5–10% lipid and 10–12 MJ DE/kg, we must ensure the aquafeed concentrate is formulated to contain far higher levels of these nutrients so that when the concentrate is diluted with the chosen carbohydrate, the blended mash still satisfies, as far as possible, the known nutrient requirements of the fish.

It is difficult to manufacture practical aquafeeds with digestible protein levels greater than 50–60% even when using good quality high-protein ingredients, such as fishmeal, blood meal, poultry meal, glutens and protein concentrates. For this reason, a PNG aquafeed concentrate was formulated to have a crude protein base of 50% and a crude lipid level of 12%, meaning dilution of the concentrate with up to 40–50% carbohydrate would only reduce the overall level of protein and lipid to 25–30% and 5–6%, respectively. Ingredients available for use (NARI Labu; circa 2014) were entered into a simple, linear, least-cost formulation program (WinFeed 2004). No chemical analysis of the ingredients in PNG was available so chemical composition was taken from reliable literature sources. Local fishmeal was available (Lae origin) so it was used in lieu of imported fishmeal. Note that the local fishmeal was cheaper at the time of formulation than imported blood meal. Tallow rather than fish oil was used as an exogenous source of lipid and the aquafeed premix was sourced from stocks held in Australia by the NSW Department of Primary Industries. Nutrient requirements for amino acids and some minerals were also linked to protein or dry matter content of the formulation. Minimum constraints were also placed on some ingredients as well as the hypothetical digestible energy (DE) of the formula. An example of a hypothetical aquafeed concentrate based on the aforementioned formulation constraints is presented in Table 18. The ingredient formulation price for this aquafeed concentrate was 2,283 kina per tonne. It is important to understand that this formulation is only one of many possible formulations that could be used as an aquafeed concentrate.

Initial use of an aquafeed concentrate in PNG is being evaluated in farm- and tank-based research trials focusing on the use of cooked, dried and ground cassava tuber meal and cooked, dried and ground sweetpotato meal. Cooking and drying removes cyanide compounds from cassava as well as increases the energy value of the starch and enhances its binding qualities. Adding the aquafeed concentrate to the least-cost formulation database as an ingredient allows quick evaluation of the effect of diluting the aquafeed concentrate by 40% with dried cassava meal before pelleting and re-drying. As can be seen in Table 19, the estimated nutrient analysis is close to that necessary to meet the basic nutrient requirements of tilapia. The overall formulation cost is reduced to 1,370 kina due to the fact that the cost and processing of the dried cassava tuber meal was set at zero, assuming the farmer prepares their own material.

A similar process can be undertaken with dried sweetpotato. In this case, the formula cost remains unchanged as the cost of using dried sweetpotato is also negligible (Table 20).

If larger quantities of dried cassava and sweetpotato meals are purpose-made by mini-mill operators or other cooperatives, then the cost of these ingredients would increase the formulation price of the blended feed. It is important to note that the formula costs presented here do not include costs of transport, labour and operating equipment. Feed companies generate a profit on sale of feeds by adding a profit margin to the cost of making feeds. In Australia, a quality grow-out aquafeed for barramundi and salmon wholesales for approximately A$2,000–2,300 tonne (circa 2014) excluding taxes and logistics; or approximately 4,560 kina.

Notwithstanding the development of aquafeed concentrates, it is also possible to formulate a low-cost, low-fishmeal grower diet for tilapia using a PNG ingredient database (Table 21). Again, the cost of dried cassava meal and dried sweetpotato was set to zero. In this example, ingredient constraints were placed on fishmeal and soybean meal. They were restricted to 10% and 25% inclusion respectively. Cassava meal, sweetpotato, tallow and premix have been 'forced' into the formula by setting minimum

Table 18. Hypothetical aquafeed concentrate formulated for tilapia (NARI feed store; as-fed basis; formula cost 2,283 kina/tonne).

Ingredients	Min (%)	Max (%)	Formula (%)	Nutrients (%)	Min (%)	Analysis (%)
Blood meal 85% CP			5.84	Dry matter %		93.08
Fishmeal (local PNG)	28	40	34.6	Moisture %		6.92
Meat meal 50% CP	20		20	Crude protein %	50	51.20
Soybean meal 48% CP	20		33.52	Digestible protein		41.42
Tallow			3.84	Crude fat %	12	12
Vitamin premix	1	1	1	Ash %		16.17
Methionine 50%	0.8	1.2	1.2	NFE %		16.63
				Crude fibre %		2.16
				Gross energy MJ/kg		18.5
				Digestible energy	10	15.65

inclusion levels of 15%, 10%, 1% and 0.5% respectively. Nutrient constraints were placed on digestible protein (26.3%), crude fat (7%) and digestible energy level (13.97 MJ/kg).

Table 19. Aquafeed concentrate blended with dried cassava meal (NARI feed store; as-fed basis; formula cost 1,370 kina/tonne).

Ingredients	Min (%)	Max (%)	Formula (%)	Nutrients (%)	Analysis (%)
Aquafeed concentrate			60	Dry matter %	90.45
Cassava tuber (dried)	40		40	Moisture %	9.55
				Crude protein %	31.56
				Dig. protein	25.52
				Crude fat %	7.44
				Ash %	11.06
				NFE %	42.14
				Crude fibre %	2.66
				Gross energy MJ/kg	16.18
				Digestible energy	13.61

Table 20. Aquafeed concentrate blended with dried sweetpotato (NARI feed store; as-fed basis; formula cost 1,370 kina/tonne).

Ingredients	Min (%)	Max (%)	Formula (%)	Nutrients (%)	Analysis (%)
Aquafeed concentrate			60	Dry matter %	91.32
Sweetpotato (dried)	40		40	Moisture %	8.67
				Crude protein %	32.34
				Dig. protein	25.93
				Crude fat %	7.72
				Ash %	10.81
				NFE %	42.21
				Crude fibre %	2.50
				Gross energy MJ/kg	17.72
				Digestible energy	14.47

Table 21. Example of a practical aquafeed formulation for tilapia using typical ingredients available in PNG (NARI feed store; as-fed basis; formula cost 1,343 kina/tonne).

Ingredients	Min (%)	Max (%)	Formula (%)	Nutrients (%)	Min (%)	Max (%)	Analysis (%)
Fishmeal (FAQ)		10	10.00	Dry matter %			91.26
Meat and bone meal			24.84	Moisture %			8.73
Soybean meal		25	25.00	Crude protein %			33.42
Rice bran			9.17	Dig. protein	26.3		26.3
Sweetpotato (dried)	10		10.00	Crude fat %		7	7.00
Tallow	1		4.66	Ash %			6.95
Cassava (dried)	15		15.00	NFE %			43.89
Vitamin premix	0.5	0.5	0.5	Crude fibre %			4.13
Methionine 50%			0.83	Gross energy MJ/kg			18.19
				Digestible energy		10	13.97

FEED MANUFACTURING AND STORAGE

Several useful guides on preparing and feeding pelleted aquafeeds using mini-mills or simple farm equipment have been published and disseminated in PNG by ACIAR (Booth et al. 2006; Gonzalez and Allan 2007; Sim et al. 2005). These step-by-step guides are still relevant today. Some of the information contained in these guides is summarised below.

A simple set of equipment is required to make basic aquafeeds, including:

- weighing scales or balance
- mixer (hand mixing, mechanical mixers)
- grinder (hammer or flaking mill)
- particle sieves (various screen sizes)
- pelleting machine (hand or mechanical mincer with different die plates; e.g. 1–5 mm)
- steamer or cooking pans (to cook starchy ingredients or complete mash)
- drying equipment (drying mats, specially constructed air or solar dryers, electric ovens)
- feed containers or storage bags.

Regardless of the scale of the operation, there are essentially five basic steps to preparing quality pelleted aquafeeds from dry ingredients once a formulation has been selected, as follows.

1. Grinding to reduce the particle size of materials to improve mixing and blending.
2. Adding water and other liquids to make a wet mash or dough (cooking mash if required).
3. Forming pellets using a hand or mechanical mincer.
4. Dehydrating, drying and cooling pellets to improve nutritional stability.
5. Packing and storing finished feed in a dry, cool (low humidity), pest-free location.

Proper storage and cycling of ingredients and finished feeds are critical to ensuring the nutritional quality of feed is maintained. Poor storage of finished feeds can reduce shelf life but more importantly, it can result in poor growth, malnutrition, health problems and even mortality in fish (Sim et al. 2005). This is due to loss or oxidation of critical nutrients, such as vitamins, amino acids and essential fatty acids. Feed stored in humid, high-temperature situations is prone to developing certain fungi and moulds which may lead to acute mass mortality of fish. Moulds are also very harmful when inhaled by humans. Commercial feeds contain mould inhibitors (e.g. myocurb) and antioxidants (e.g. ethoxyquin) to help reduce incidence of moulds and potential for rancidity of fats (Gonzalez and Allan 2007). Where possible, these agents should be included at appropriate concentrations in large batches of aquafeed, which may be stored for some time. Rapid turnover and management of ingredients and newly-prepared aquafeed can reduce the risk of contamination by moulds and other pests. In humid conditions, such as those found in the lowlands of PNG, prepared feeds should be used within three to six weeks of manufacture.

FEED MANAGEMENT

The main goal of feeding fish is to adopt a feeding practice that maximises feed intake to achieve the best possible growth rate and production outcomes. Care should be taken to make sure fish are not fed in excess of their appetite as this will result in feed (and money) being wasted and leads to deterioration of water quality. If possible, it is always better to try and feed fish to 'apparent satiety'. This means the farmer or researcher lets the fish feed until they cease feeding actively or the majority of fish lose interest in feeding. This is known as the 'feeding response'. Judging when fish have eaten enough to satisfy their appetite is sometimes difficult because changes in water temperature, photoperiod and other environmental factors (e.g. dissolved oxygen) can reduce feed intake from day to day and week to week. Sometimes the water in ponds is turbid and making judgments about when to stop feeding is difficult because the farmer cannot see the fish. Fish are known to prefer feeding at certain times of the day and feed intake can be optimised by ensuring pelleted feed is offered at these times. Aquafeeds made in mini-mills in PNG will likely be negatively buoyant, meaning they will sink in the water column. Judging feeding response on sinking feeds in turbid water bodies can be extremely difficult. In ponds, the farmer can assume fish will scavenge the pellets from the bottom but if fish are reared in cages, then sinking pellets will pass through the cage if not consumed. Special care is needed when feeding in these situations (e.g. cages in Yonki Dam). Feeding trays can sometimes be used to mitigate the loss of sinking pellets.

Feeding guides

Feeding tables (Table 22) can be used to assist farmers and researchers make decisions about how much feed to give their fish, but tables like these should be used with discretion. They are only ever meant to be a guide and farmers should adjust rations based on regular interactions with, and observation of, their stock. Good farming practices is to record feed intake data, taking note of the time of year, weather conditions and type of feed etc. This builds up an historical account of feeding practices and fish responses. These data can be used by farmers to create specific feeding guides for their own farm. For larger tilapia, feeding twice daily, once in the morning and once at the end of the day, is probably sufficient to promote good growth and FCR when a high quality aquafeed is used.

Table 22. Example of feeding guide for intensively reared tilapia. Data extracted from Creswell (2005).

Feed size (mm)	Fish size (g)	Feeding rate (% BW per day)	Meal frequency (meals per day)
<0.6	<0.5	20	6
0.6–1.0	0.5	15	6
0.6–1.0	1	11	6
0.6–1.0	1	9	5
1.4–2.4	2	6.5	5
2.4	10	6.5	5
2.4	15	4.6	5
2.4	15	4.6	4
3.2	30	3.6	4
3.2	60	3.0	4
4.8	100	2.6	4
4.8–6.0	175	2.2	3
6.0–8.0	300	1.8	3
8.0–10.0	400	1.5	3

When commencing or adjusting feeding rates, an estimate of the amount needed for a certain biomass of fish can be calculated from Equation 2 (adapted from an equation presented by Sim et al. 2005).

Equation 2:

$$\text{Daily feed quantity} = \text{number of fish in pond or cage} \times \text{average body weight of fish} \times \text{\% daily feeding rate}$$

As an example, we will calculate the estimated daily feed amount for a cage of 100 tilapias having an average body weight of 140 g. From Table 22, we can see that the feed rate will lie somewhere between fish weighing 100–175 g, therefore we will use the average of these two values (2.6+2.2/2) = 2.4% BW/day. Therefore, the amount required for this cage is calculated as follows:

$$\begin{aligned}\text{Daily feed quantity} &= 100 \text{ fish} \times 140 \text{ g} \times 2.4/100 \\ &= 336 \text{ g of feed per cage}\end{aligned}$$

To double check, we can divide the biomass by the feed amount (336 g/14,000 g × 100/1) to determine the feeding rate which equals 2.4%.

As mentioned, the calculated amount is only a guide to the actual amount of feed the cage of fish might consume. On any day, they may eat less or more. If the farmer decided to feed the allowance in two meals per day, half the amount (168 g) would be fed in the morning and the other half (168 g) in the afternoon.

ASSESSMENT OF BASIC FISH PERFORMANCE AND PRODUCTIVITY

Biological evaluation of feed ingredients and finished aquafeeds involves feeding fish and analysing some aspect of fish performance. In some cases, it might also be important to determine diet digestibility (Glencross et al. 2007; Hardy and Barrows 2002). The basic measures of assessing fish performance are similar whether conducting aquafeed research or growing fish for food and for profit. All basic measures are easily calculated and provide researchers and farmers with important feedback on the health and productivity of their stock, the indirect quality of their feeds (e.g. a feeding experiment may compare different aquafeeds) and economic potential of their enterprise. Basic morphometric measurements can be taken using simple scales and a rule.

Performance criteria: growth

It is essential that a reliable inventory of fish numbers and fish size is taken at the beginning of every stocking event and again at harvest. This allows calculation of survival (Equation 3).

Equation 3:

$$\text{Survival \%} = \frac{\text{number of fish at stocking} - \text{number of fish at harvest}}{\text{number of fish at stocking}} \times 100$$

For example, a farmer stocks 500 tilapia fingerlings weighing on average 23 g into an earthen pond and grows them for five months at an average temperature of 26°C. At harvest, the farmer counts his fish and finds 23 missing, presumed dead. The average weight of the fish is now 320 g. He also calculates he has used 260 kg of dry pelleted aquafeed over the five months. Therefore survival can be calculated as follows.

Survival % = (500 – 23)/500 × 100
= 95.4%

If fish die during production and they are detected by the farmer (e.g. floating dead at surface or dead at the bottom of ponds) they should be immediately removed and disposed of correctly. A tally of dead fish during production can be used to calculate running mortality. This number should correlate positively with the number of fish finally harvested. If it doesn't, it may indicate fish have escaped from cages, perished and decomposed before detection or been stolen. Sudden spikes or escalation in mortality can be an indication of health problems (infection or disease), problems with water quality or problems with feed. Failure to resolve the problem/s could result in complete loss of stock. It is important to realise that dead fish represent not only the loss of animals but also the loss and waste of feed.

Measures of fish biomass are also important and should be determined at the beginning and end of production. In research trials, these measures are often determined more regularly e.g. every two weeks or monthly.

Using the survival example above, the stocking (Equation 4) and harvest biomass (Equation 5) can be calculated.

Equation 4:

$$\text{Stock biomass} = \text{number of fish at stocking} \times \text{average weight of fish}$$

In this example, stock biomass = 500 × 23 g
= 11.5 kg

Equation 5:

$$\text{Harvest biomass} = \text{number of fish harvested} \times \text{average weight of fish}$$

In this example, harvest biomass = 477 × 320 g
= 152.6 kg

Therefore, the biomass gain of the pond =
152.6 – 11.5 = 141.1 kg

The farming example can also be used to determine the growth rate of the fish. This can simply be the absolute weight gain (Equation 6), daily weight gain (Equation 7) or specific growth rate (SGR) (Equation 8).

Equation 6:

$$\text{Absolute weight gain (g/fish)} = \text{harvest weight of average fish} - \text{stocking weight of average fish}$$

In this example, absolute weight gain = 320 – 23
= 297 g

Equation 7:

$$\text{Daily weight gain} = \frac{\text{harvest weight of average fish} - \text{stocking weight of average fish}}{\text{duration}}$$

In this example:

$$\text{Daily weight gain} = \frac{320 - 23}{5 \text{ months} \times 30 \text{ days}}$$

= 1.98 g/day

Equation 8:

$$\text{Specific growth rate (SGR\%/day)} = \frac{\ln\left(\text{harvest weight}\right) - \ln\left(\text{stock weight}\right)}{\text{duration}} \times 100$$

In this example:

$$\text{Specific growth rate (SGR\%/day)} = \frac{\ln(320) - \ln(23)}{150} \times 100$$

$$= 1.75\%/\text{day}$$

Specific growth rate can be used cautiously to predict the size of fish at some time in the future, if the water temperature and SGR are reasonably stable (Equation 9).

Equation 9:

$$\text{Final body weight (FBW)} = \text{initial body weight} \times e^{(\text{SGR} \times \text{days}/100)}$$

In this example, $\text{FBW} = 23 \times e^{(1.75 \times 150/100)}$

= 317.5 g body weight after 150 days

Another weight-based performance measure being used is the thermal unit growth coefficient (TGC) (Equation 10).

Equation 10:

$$\text{TGC} = \frac{\text{final weight}^{1/3} - \text{initial weight}^{1/3}}{\text{sum of degree days in °C}} \times 1000$$

In this example:

$$\text{TGC} = \frac{320^{1/3} - 23^{1/3}}{150 \text{ days} \times 26\text{°C}} \times 1000$$

$$= 1.024$$

The TGC can also be used to predict the future weight of fish and is considered more robust than SGR, however TGC should be determined for specific farms or research units and under similar environmental conditions. If enough data are collected, both SGR and TGC can be used to construct feeding tables. An example using TGC is presented below (Equation 11).

Equation 11:

$$\text{Final body weight (FBW)} = \left[\left(\text{initial body weight}\right)^{1/3} + \left(\frac{\text{TGC}}{1000} \times \text{Temp} \times \text{days}\right)\right]^3$$

In this example:

$$\text{FBW} = \left[23^{1/3} + \left(\frac{1.024}{1000} \times 26 \times 150\right)\right]^3$$

$$= 319.6 \text{ g}$$

Condition factor

A biological measure that combines the weight and length of the fish is known as Fulton's condition factor (K). This index is related to the general shape and appearance of the fish, the premise being that fish in better condition will be heavier at a given length (Richter et al. 2000). Farmers will sometimes say their fish are poor or in good condition but this is a qualitative expression and will vary from farmer to farmer. Fulton's condition factor is a quantitative measure of fish morphology that is useful for comparing general health of animals between farms and over seasons. It is influenced by age of fish, sex, season, stage of maturation, fullness of gut, fat reserves and state of gonads (Barnham and Baxter 1998). For example, a very fat fish will have a higher K value than a lean animal of the same length. It is important that the length of the animal is measured consistently using either total length (end of tail) or standard length (end of caudal peduncle). Data on condition factor can be collected over time which will improve its usefulness in terms of assessing the performance of tilapia or trout (Equation 12).

Equation 12:

$$\text{Fulton's condition factor } K = \frac{105 \times \text{weight of fish in grams}}{(\text{length of fish in millimetres})^3}$$

A recent study determined the condition factor of mixed-sex *O. niloticus* weighing between 15 g and 430 g and with lengths of between 76 mm and 273 mm to be approximately 1.09. For salmonoid fish, such as rainbow trout, K values of 1.60, 1.40, 1.20, 1.00 and 0.80 describe fish in excellent, good, fair, poor and extremely poor condition, respectively (Barnham and Baxter 1998).

Performance criteria: feed conversion

A simple measure of the efficiency of feeding is known as feed conversion ratio (FCR). This is a measure of the mass of feed that has been used to increase the biomass of fish; i.e. feed intake per unit of gain (Equation 13).

Equation 13:

$$\text{Feed conversion ratio (FCR)} = \frac{\text{total feed consumed}}{\text{total fish weight gain}}$$

Again, using the example above:

$$\text{Feed conversion ratio (FCR)} = \frac{\text{260 kg aquafeed}}{\text{141.1 kg fish biomass gain}} = 1.84$$

This means it takes 1.84 kg of dry pelleted aquafeed to produce 1 kg of fish; the lower the FCR the better. A high FCR with high survival probably means the farmer is either overfeeding (wasting) or underfeeding (starving) his stock (see Figure 1). FCR will also be high if there is a lot of mortality. Care should be exercised when reviewing or presenting FCR data as in some cases it is presented as economic FCR (eFCR) and in some cases biological FCR (bFCR). The former is generally used by farmers as it is a reflection of the actual amount of aquafeed used and the surviving biomass of fish reaching market. It ignores mortality. The latter is often used by researchers as it accounts for mortality and is a more accurate reflection of the nutritional value of the aquafeed. Calculating biological FCR accurately requires data on the number and weight of fish that die. When survival is 100% both eFCR and bFCR are the same.

An alternative to FCR is feed efficiency (FE) which is the reciprocal of FCR. It is often reported in percentage terms; i.e. biomass gained per unit of feed intake.

Rearranging the FCR example above, FE can be calculated as follows (Equation 14).

Equation 14:

$$\text{Feed efficiency (FE)} = \frac{\text{141.1 kg fish biomass gain}}{\text{260 kg aquafeed}} \times 100 = 54.3\%$$

An FCR of 1:1 is equivalent to a FE of 100%. An FCR of 2:1 is equivalent to a FE of 50%.

Another variable to consider when calculating FCR is the moisture content of the aquafeed or indeed the food used to rear the fish. FCR is normally calculated using 'as-fed' feed intake and wet biomass gain of fish. The as-fed moisture content of good aquafeed is generally around 5–6% whereas the moisture content of industrial fish is about 70% (e.g. pilchards, anchovetta etc.). Thus it is prudent to convert feed quantity data to a 'dry-matter' basis before making comparisons between feed types.

Aquafeed pricing will vary based on many external factors that are beyond the control of the farmer. If desired, the farmer or researcher can compare the performance of fish based on the cost of the feed and the resultant or expected FCR. This is known as the feed cost per kilogram of fish produced or feed cost per unit gain. While the actual cost of production should be properly calculated by subtracting all expenses from all revenues, the feed cost per unit gain remains a quick and useful predictor of productivity and profitability, providing it is used sensibly (Zeigler 2015).

For example, a farmer wants to trial a new aquafeed and decides to keep half his production on the old formulation and switches half his production to the new aquafeed. The new aquafeed is slightly more expensive than the old one due to slightly higher protein levels. The manufacturer of the new feed claims that, although it is a little more expensive, it will result in a 10% improvement in FCR (i.e. a lower FCR). If the current FCR is 1.84 then a 10% improvement will reduce FCR to approximately 1.66. The farmer does the calculation and discovers his cost of production will reduce by 0.38 kina per kilogram of fish produced, or around 5.3%. This is providing no other basic inputs change and the claimed improvement in FCR is realised. For a smallholder fish farmer in PNG, this saving may not be of any consequence, however at large production scales, where tonnes of feed are being consumed and tonnes of fish are being produced, the cost-benefit of switching to the higher protein feed would be significant (Table 23).

Table 23. Example comparing feed cost per unit of production using feeds with different costs, FCR and protein content.

Variables	Old feed: lower protein, lower cost	New feed: slightly higher protein, higher cost
FCR	1.84	1.66
Feed cost (kina/kg feed)	4.00	4.20
Feed cost (kina/kg fish produced)	(1.84 × 4.00 kina) = 7.36 kina/kg fish produced	(1.66 × 4.20 kina) = 6.97 kina/kg fish produced

Additional performance metrics

Research on development and testing of new aquafeeds generally involves collection of additional metrics on fish performance. The list of metrics that can be used is extensive but they generally fall into two categories: non-destructive sampling, where samples can be collected without euthanising the fish, and destructive sampling, where fish must be euthanised to determine carcass composition and to investigate changes to internal organs and tissues.

Examples of non-destructive sampling are blood collection, skin scrapings, fin cuttings and skin colour measurement. Examples of destructive sampling include euthanising fish to determine yield (e.g. head on gutted weight (HOG), head on gilled and gutted weight (HOGG) and fillet recovery. Fish must be killed to gain access to organs in order to determine hepatosomatic index (HSI) and viscerosomatic index (VSI), level of peritoneal fat, histology of organs and composition of whole fish and specific fish tissues (e.g. protein and amino acid content and fatty acid content).

Fundamental to development and testing of aquafeeds is determination of the digestibility of ingredients and complete diets. In some fish, this can be done using non-destructive methods (settlement and stripping) and in some fish, dissection of the intestine is necessary, therefore fish must be euthanised. A lengthy review of all techniques involved in assessing feed ingredients and complete feeds is not warranted here and useful research papers and reviews can be found elsewhere (Allan et al. 1999; Glencross et al. 2007; NRC 2011a).

It is important to note that many of these additional measurements and tests are useful in understanding the underlying impacts that changing nutrition has on metabolism. However, the growth rate, feed conversion and health of the animal remain the key feedback mechanisms by which to judge the efficacy of any aquafeed.

CONCLUSION

Suitable aquafeeds and feed concentrates can be formulated for most fish species, providing the nutrient and energy composition of the feed ingredients and the basic nutrient requirements of the species are known. Reliable data from the literature can be used to formulate aquafeeds if the nutrient and energy composition of feed ingredients is unknown, but it should be used cautiously as many factors can negatively affect the nutritional value of feed ingredients. The quality of farm-made feed and mini-mill feed will not be as high as that produced in dedicated feed plants however well-bound, durable pellets can be produced using simple equipment by understanding its limitations and the pelleting qualities of the ingredients being used. Assessment of feed utilisation for research or production purposes can be made by recording simple biological responses, such as growth rate, survival, feed intake and feed conversion ratio (FCR). Collection and recording of data should be encouraged so that farms can benchmark their performance from year to year.

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2

Socio-economics of local feed production

Mini-mill and village enterprise cost and profitability models for Papua New Guinea

Ian Black[1†]

Abstract

Mini-mill and village enterprise models for Papua New Guinea were derived under an ACIAR project. This paper outlines how they were constructed and summarises the results and findings. The models show that the prices of mini-mill concentrates are highly competitive with concentrates offered by the large feed mills for the village broiler and layer industries. When these concentrates are mixed with sweetpotato or cassava to create a village enterprise feed, the combination is also thought to be highly competitive with the complete feed equivalent offered by the large feed mills and by companies that import feed directly from overseas.

INTRODUCTION

The current ACIAR project 'Enhancing role of small scale feed milling in the development of the monogastric industries in PNG' (ASEM/2010/053) and its predecessor 'Improving the profitability of village broiler production in PNG' (ASEM/2005/094) provided feed ingredient technology for mini-mill concentrates based on local and imported ingredients (Glatz et al. 2013). They also provided recommendations for feeding intensively farmed animals in village enterprises using mini-mill concentrates and sweetpotato in the highlands, and with cassava in the lowlands.

Several mini-mill and village enterprise models were derived for Papua New Guinea (PNG) as part of ASEM/2010/053. The titles of the mini-mill models that were generated are shown in Table 1 and those for the village enterprise models in Table 5. This paper outlines how they were constructed, summarises the results, and suggests important findings from the models. It is aimed at non-specialists who are interested in the modelling process and the results.

In principle, the models have separate highland and lowland costings, with some specific directed modelling included. The directed modelling has two components. The first is the suggested use of a 'universal concentrate' provided by commercial mills in PNG to mini-mills as a significant part of the concentrate generated by the mini-mills for broilers and layers. The second is the suggested use of sweetpotato silage as a substitute for sweetpotato tubers in hybrid pig village enterprises in the highlands.

METHODOLOGY

Model format

The models are electronic spreadsheet based. The line items in each spreadsheet are self-explanatory. The detailed assumptions for line items and explanations of the cell calculations for each line item are contained in the electronic versions as notes.

Major sources of information

The sources of information are as follows.

- Fresh Produce Development Agency statistics for sweetpotato and cassava market prices;
- PNG generalised grouping price indices to update initial price estimates;

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- Kaliber, Indonesia for equipment and machinery costs;
- Expert opinion obtained during ASEM/2010/053 project workshops; and
- Commercial in-confidence price data for micronutrient and protein source ingredients.

An important assumption in the modelling was the application of a 30% discount to the market prices of sweetpotato and cassava. This is thought to be justified because time is saved by avoiding selling individual tubers in markets, and because of the use of substandard tubers that are acceptable when used in bulk in mini-mill mixes or in village enterprises. The modelling reflects prices and assumptions made by the author as at August 2015. Such assumptions and prices, and therefore modelling results, may not apply accurately at times later than this.

RESULTS AND DISCUSSION

The mini-mill models

The mini-mill models are made up of three key spreadsheets. The final spreadsheet covers the cost of feed ingredients as well as costs from annual and fixed costs. The second and third spreadsheets cover annual and fixed costs, and the results are fed into the final spreadsheet. The second and third spreadsheets are common to all the mini-mill models; only the final spreadsheet differs. This is because of the different feed ingredients needed for the particular concentrate destined for different village animal industries. Table 1 shows the main results from the mini-mill modelling for prices of concentrate. An arbitrary 30% has been included as a mini-mill margin at the mill gate. An additional arbitrary 30% has been added to the mill gate price as an allowance for transport to the reseller as well as reseller margin.

Table 2 shows an example of the final spreadsheet in a mini-mill model (styled as a table). The example of a mini-mill operating in the highlands producing broiler concentrate has been used.

Tables 3 and 4 show the annualised capital costs and annual operating costs for a lowlands example. The price estimates were obtained in PNG from participants attending workshops for project ASEM/2010/053. The price of universal concentrate includes estimations for margins and running costs. Table 1 shows that the universal concentrate approach produces a result that is no different to the normal mini-mill feed ingredient approach in the highlands and only marginally different in the lowlands.

It is considered that the prices of mini-mill concentrates, shown in Table 1, are highly competitive with concentrates offered by the large feed mills for the village broiler and layer industries (the comparison figures for the large feed mills are 'commercial in confidence'). When these concentrates are mixed with sweetpotato or cassava to create a village enterprise feed, the combination is highly competitive with the complete feed equivalent offered by the large feed mills and by companies that import feed directly from overseas (again, these figures are 'commercial in confidence).

Table 1. Mini-mill model results for prices of concentrate.

Type	Price at mill gate (kina/kg)		Price at reseller (kina/kg)	
	Highlands	Lowlands	Highlands	Lowlands
Broilers	2.4	2.2	3.1	2.8
Broilers, UC	2.4	2.2	3.1	2.8
Layers	2.0	1.7	2.6	2.2
Layers, UC	2.0	1.8	2.6	2.4
Hybrid pigs	1.4	1.1	1.8	1.4
Tilapia	3.2	2.8	4.1	3.7

UC = universal concentrate.

Village enterprise models

Table 5 shows the results from modelling profitability for the different village enterprises, when using local feed mixed with mini-mill concentrate. The results show poor profitability in the tilapia growing enterprise. The relatively expensive high-protein concentrates (see Table 1) fed without dilution, together with a lack of premium for fish protein, is responsible for this poor profitability. Table 5 also shows that broiler farming has lower profitability than egg or pig farming. However, in its favour is the fact that the enterprise is a very simple operation to run.

Taken together, the village enterprises for broilers, eggs and hybrid pigs are highly profitable and represent good business opportunities. However, once family and social obligations are met through the 'wantok' system, whereby produce is given away, bartered or sold at cost, profitability will fall significantly. The farm enterprise models consist of one spreadsheet only. Table 6 shows an example of a broiler growing enterprise in the highlands.

CONCLUSION

The modelling shows that tilapia farming has relatively low profitability due to the high cost of protein ingredients in the diet. Broiler farming is less profitable than egg or pig farming, but running a smallholder broiler enterprise requires less management skills than pig, egg and aquaculture enterprises.

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Table 2. Final spreadsheet for producing concentrate for broilers in a mini-mill operation in the PNG highlands.

Ingredient	kina/ tonne	kg used in a tonne mix	Cost/ revenue (kina)
High protein			
Fishmeal	2,557	200	511
Copra meal	950	200	190
Soybean meal	2,493	250	623
High energy			
Palm oil	2,746	70	192
Low-cost by-product			
Millrun	350	270	95
Premix	15,668	10	156.7
Total		**1,000**	**1,768**
800 tonne/year (20 tonne/week for 40 weeks/year for running mill)			1,414,397
Annualised capital cost			27,642
Operating			44,500
Total			**1,486,539**
Inclusive of profit margin (30%)			**1,932,500**
Price per tonne at the mini-mill gate			2,416
Price per tonne at the retailer (+30%)			3,410

Table 3. Annualised fixed costs for a mini-mill in the PNG lowlands.

	Cost (kina)	Amortisation (years)	Annual cost
Capital			
Land	6,000.00	2	30
Fence	2,500.00	1	25
Sheds	5,000.00	2	25
Roads, compaction, etc.	4,000.00	2	200
Mini-mill[a]			
Hammer mill (including electric or diesel motor)	4774.70	1	47
Discharge screw and electric motor	2,835.56	1	28
Elevator (including electric motor)	4,314.52	1	43
Mixer with gear motor and slide below mixer	5,439.70	1	54
Hopper with frame	3,710.70	1	37
Discharge screw and electic motor	2,835.56	1	28
Pellet mill (including electric motor)	9,738.26	1	97
Panels and cabling	5,846.68	1	58
Shipment to Lae and installation	17,290	1	172
Total	**56,785.63**		
Scales	1,200.00	5	24
Power supply and connection to machinery	9,600.00	5	192
Hand cutting and handling tools	120.00	5	2
Storage and materials movement equipment	360.00	5	7
Office equipment	12,000.00	5	240
Bags, bins etc.	15,000.00	5	300
Vehicle (second hand)	27,000.00	5	540
Less average annual interest on savings banked for replacement of capital			413
Grand total	**139,565.70**	**1**	**1,740**

[a] Higher annualised costs (total 18,730 kina) apply in the highlands because of additional transport and installation costs.

Table 4. Annual costs for running a mini-mill.

Operating costs	Lowlands (kina)	Highlands (kina)
Fuel	16,000	20,000
Municipal rates	0	0
Power	0	0
Phone	500	500
Night security	4,000	4,000
Office supplies	1,000	1,000
Pest control	1,000	1,000
Labour:		
Manager/skilled manual labourer	6,000	6,000
Labourers (2)	6,000	6,000
Repairs, maintenance and replacement	6,000	6,000
Total	**40,500**	**44,500**

Table 5. Profitability (%) of different village enterprises in the highlands and lowlands, using local feeds mixed with mini-mill concentrates.

Type	Batch size	Batches per year	Highlands Sweetpotato	Lowlands Cassava
Broilers	50	4	40	43
Eggs	100 layers	1	57	59
Hybrid pigs, sweetpotato tubers	75 growers	2	57	66
Hybrid pigs, sweetpotato silage	75 growers	2	59	
Tilapia (concentrate only used)	1000	2	18	20

Table 6. Spreadsheet for highlands broiler enterprise using a mini-mill concentrate mixed with sweetpotato.

	Quantity	Unit	Price (kina)	Total cost or revenue
Costs per batch of birds				
Mini-mill concentrate (retail outlet price inclusive of concentrate)	60	kg	3.15	189.00
Sweetpotato fresh (energy source added to fresh concentrate)	120	kg	0.63	75.60
Shed and equipment (5 year shed life, 4 batches a year)			1,000.00	50.00
Labour	50	hour	1.80	90.00
Day old chicks	52	chicks		200.00
Mortality	2	birds		
Age to market	50	days		
Total cost per batch				**604.60**
Revenue per batch				
Live bird sales	50	birds	20.00	1,000.00
Batch operation surplus				**395.40**
Annual turn out (batches/year)	4	batches		
Operation surplus per year				**1,581.60**
Profit (%)				**40**

Modelling the profitability of village hybrid pig farming in Papua New Guinea with silage as a feed source

Ian Black[1†]

Abstract

This paper compares the profitability of village hybrid pig farming using mini-mill concentrate plus silage, both with and without incorporating the opportunity cost of the silage as mineral fertiliser, and with and without accounting for the labour in returning pig manure to sweetpotato gardens. Under a 'worst case scenario', the profitability of pig farming is reduced by approximately 3%, from 62% to 59%, if the cost of the silage as mineral (N, P and K) fertiliser that needs to be replaced in sweetpotato gardens is taken into account. This profitability of the mini-mill concentrate plus silage feeding approach, taking into account the cost of silage as mineral fertiliser, is 2% higher compared to a mini-mill concentrate plus sweetpotato tuber feed approach in the highlands. These results suggest that harvesting sweetpotato tops, roots and reject tubers from fields for silage to be used in pig production has a significant cost attached to it. Given that mineral fertiliser does not form part of the sweetpotato growing system in Papua New Guinea, the most obvious recommendation is that pig manure be returned to sweetpotato fields. It is noted that the pig feed concentrate used in raising hybrid pigs imports nutrients from elsewhere via the concentrate used in the feed. When the labour involved in returning pig manure to sweetpotato gardens is accounted for, the profitability of the enterprise is the same as when plant nutrient return is accounted for by mineral fertiliser.

INTRODUCTION

It has been suggested that silage made from sweetpotato tops, roots and reject tubers could be used as a feed source for village hybrid pig farming in Papua New Guinea (PNG), and a National Agricultural Research Institute (NARI) research program is actively pursuing this approach. Silage removes soil nutrients in a farming system where mulching of crop tops and village waste is used to support sweetpotato cropping, and no additional fertiliser is generally added to the system. This paper examines the effect on profitability of a pig feeding system that incorporates silage in hybrid pig farming, accounting for nutrient return to sweetpotato gardens either as spread nitrogen (N), phosphorus (P) and potassium (K) fertilisers or as pig manure.

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ASSUMPTIONS

1. N, P and K are considered to be the nutrients most likely to limit yields in a cropping system. Assuming that the other soil nutrients are non-limiting in terms of crop yield, an approach to valuing the cost of silage used in a village pig farming system is to put a price on the N, P and K removed as replacement mineral fertiliser. Plant analysis is widely accepted as a methodology for determining the nutrient requirements of crops (Reuter and Robinson 1997; O'Sullivan et al. 1997).

2a. All the N, P and K removed needs to be replaced in order to maximise the yields of sweetpotato tubers. This is termed the 'worst case scenario'.

2b. Some sweetpotato fields in PNG may be so inherently fertile and so rich in organic matter that replacement of these nutrients is unnecessary, at least for the first crop after removal of sweetpotato material. This is termed the 'best case scenario'.

These two scenarios will be used and discussed in the next section.

3. The silage is composed of half sweetpotato tops and half roots and reject tubers.
4. Silage contains 30% moisture by weight.
5. The N, P, K nutrient composition of sweetpotato tops and tubers is the same as that reported by Traynor (2006).

RESULTS AND DISCUSSION

Table 1 shows the costs, revenue and resultant profitability from a hybrid pig farming system model using sweetpotato tubers plus mini-mill concentrate in a highlands village. This example provides a standard model incorporating sweetpotato tuber costs at market prices discounted by 30% for bulk orders.

Table 2 shows the best case silage feed scenario. If it was known that the particular soil that the sweetpotato was grown on was so fertile and high in organic matter that it would not be necessary to replace the N, P and K nutrients, only the cost of making the silage would be accounted for. Table 2, as well as Tables 3 and 5, differ from Table 1 in that the amortised cost of a second shed plus hand-driven flake mill is included as well as the cost of making the silage, in terms of labour.

Table 3 shows the same model when the cost of silage as mineral fertiliser is taken into account. This is a worst case scenario that assumes N, P and K are all rate limiting in terms of sweetpotato tuber yield. The assumption is that all the N, P and K removed needs to be replaced by elemental fertiliser. The cost of spreading fertiliser is entered as a separate line item in Table 3. A labour allowance to spread the fertiliser of two days (16 hours at 2.50 kina an hour) is included.

Table 1. Costs, revenue and profitability of hybrid pig farming in a highlands village using sweetpotato tubers plus mini-mill concentrate.

	Cost (kina)	Amortise (years)	Annual cost (kina)
Shed	10,000	15	667
Labour	4,320	1	4,320
Medication	1,000	1	1,000
Drums buckets scales	600	5	120
5 sows, 1 boar, landrace cross	3,600	2	1,800
Total			**7,907**
Feed			
Sows and boar (6 animals @ 3 kg/day, 30% conc.)	3,942.918	1	3,943
Growers (37 animals @ 800 g/day for 2 weeks, 40% concentrate; assume weaning at 4 weeks)	559.44	1	559
Growers (38 animals @ 2 kg/day for 18 weeks, 40% concentrate; assuming weaning at 4 weeks)	10,514.45	1	10,514
Total			**15,017**
Grand total costs			**22,923**
			Revenue (kina)
37 growers @ 300 kina at 6 weeks			11,100
38 @ 18 weeks @ 1,000 kina			38,000
Sows and boars every second year at 3,000 kina halved for 2 cycles			4,500
Total revenue			**53,600**
Profit			**30,677**
Profit (%)			**57**

Under the N, P and K all yield rate limiting assumption, it can be seen that the profitability of the enterprise is 2% higher than the standard concentrate plus sweetpotato roots model shown in Table 1.

The cost of the N, P and K removed as mineral fertiliser is shown in Table 4.

Table 5 shows a model using mini-mill concentrate plus sweetpotato silage where the pig waste is returned to the sweetpotato gardens, accounting for the labour involved in doing so (three hours a day at 2.50 kina an hour). This is added to labour line item in Table 3 as three hours a day at 2.50 kina an hour. It can be seen that the profitability is the same as Table 4, where the cost is accounted for as spread mineral fertiliser (i.e. 59%).

In a best case scenario, the N, P and K removed in the silage has no effect on the subsequent yield of the next sweetpotato crop. This is equivalent to the Table 1 model; in this case there is no opportunity cost of N, P and K removal. This may be the case in a highly fertile soil that is very high in organic matter. However, if N, P and K continue to be removed in subsequent years as silage, there will surely be a cumulative effect on yields over time. Figure 1 illustrates this point. In a soil that is low organic matter and has low fertility, the first and subsequent harvests could show a drastic reduction in yield (see the low organic matter soil scenario shown in Figure 1).

Table 2. Costs, revenue and profitability of hybrid pig farming in a highlands village using sweetpotato silage plus mini-mill concentrate, not taking into account the opportunity cost of silage (the best case scenario).

	Cost (kina)	Amortise (years)	Annual cost (kina)
Shed 1 pigs	10,000	15	667
Shed 2 silage and machinery	7,500	15	500
Machinery: flake mill	3,524	15	235
Labour	6,000	1	6,000
Medication	1,000	1	1,000
Drums buckets scales	600	5	120
5 sows, 1 boar, landrace cross	3,600	2	1,800
Total			**10,322**
Feed			
Sows and boar (6 animals @ 3 kg/day, 43% conc.)	2,549.556	1	2,550
Growers (37 animals @ 800 g/day for 2 weeks, 43% concentrate; assume weaning at 4 weeks)	320.7456	1	321
Growers (38 animals @ 2 kg/day for 18 weeks, 43% concentrate; assuming weaning at 4 weeks)	7,411.824	1	7,412
Total			**10,282**
Grand total costs			**20,604**
			Revenue (kina)
37 growers @ 300 kina at 6 weeks			11,100
38 @ 18 weeks @ 1,000 kina			38,000
Sows and boars every second year at 3,000 kina halved for 2 cycles/ year			4,500
Total revenue			**53,600**
Profit			**32,996**
Profit (%)			**62**

Table 3. Costs, revenue and profitability of hybrid pig farming in a highlands village using sweetpotato silage plus mini-mill concentrate, taking into account the opportunity cost of silage as mineral fertiliser (the worst case scenario).

	Cost (kina)	Amortise (years)	Annual cost (kina)
Shed 1 pigs	10,000	15	667
Shed 2 silage and machinery	7,500	15	500
Machinery: flake mill	3,524	15	235
Labour	6,000	1	6,000
Medication	1,000	1	1,000
Drums buckets scales	600	5	120
5 sows, 1 boar, landrace cross	3,600	2	1,800
Total			**10,322**
Feed: concentrate costs			
Sows and boars (6 animals @ 3 kg/day, 43% conc.)	2,549.556	1	2,550
Growers (37 animals @ 800 g/day for 2 weeks, 43% concentrate; assume weaning at 4 weeks)	320.7456	1	321
Growers (38 animals @ 2 kg/day for 18 weeks, 43% concentrate; assuming weaning at 4 weeks)	7,411.824	1	7,412
Total			**10,282**
Feed: cost of silage as spread fertiliser			**1,300**
Grand total costs			**21,904**
			Revenue (kina)
37 growers @ 300 kina at 6 weeks			11,100
38 @ 18 weeks @ 1,000 kina			38,000
Sows and boars every second year at 3,000 kina halved for 2 cycles/year			4,500
Total revenue			**53,600**
Profit			**31,696**
Profit (%)			**59**

Table 4. Sweetpotato silage used in the village pig enterprise model, costed as mineral fertiliser.

		N	P	K	Total
Sweetpotato vine silage used in pig enterprise (kg)	9,439				
kg N, P and K in silage		1,746	529	38	
Mineral fertiliser		Urea	Triple super	KCl	
		3,796	2,517	73	
Value highlands (kina)		6,574	5,379	133	12,085
Value lowlands (kina)		5,435	4,623	111	10,169

Formulas for highlands and lowlands valuation
Source of fertiliser prices: Mundi indexes
US$1 = 2.7 kina (conversion rate)
Add US$50/t for transport to a PNG port
Add 250 kina/t for freight to highlands
Add 50 kina/t for freight to lowlands
Add 50% for bagging and reseller margin

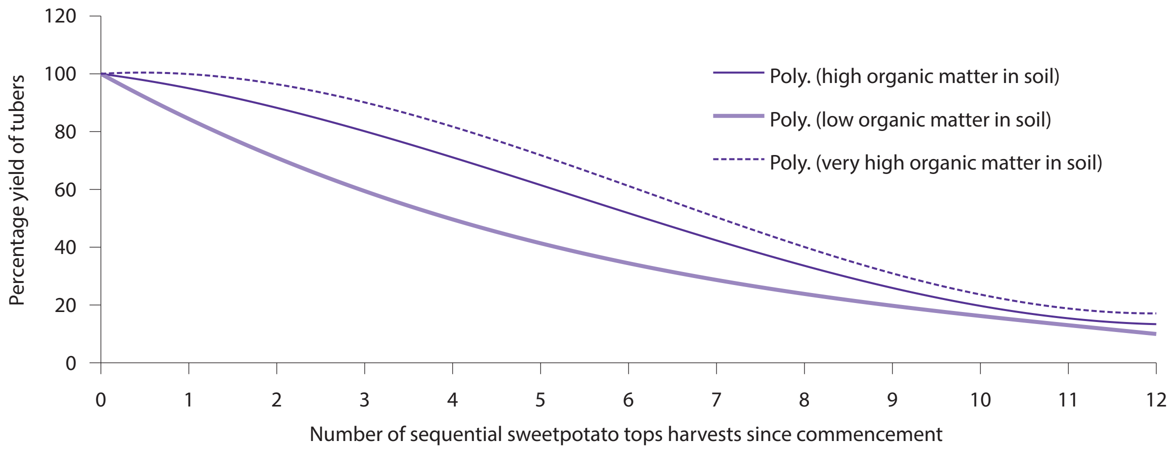

Figure 1. Possible sweetpotato tuber yield scenarios when sweetpotato tops are removed and pig manure not returned. Poly = polynomial function fitted to an artificial data set.

Table 5. Costs, revenue and profitability of hybrid pig farming in a highlands village using sweetpotato silage plus mini-mill concentrate, accounting for the labour in returning the pig waste to the sweetpotato gardens.

	Cost (kina)	Amortise (years)	Annual cost (kina)
Shed 1 pigs	10,000	15	667
Shed 2 silage and machinery	7,500	15	500
Machinery: flake mill	3,524	15	235
Labour	7,365	1	7,365
Medication	1,000	1	1,000
Drums buckets scales	600	5	120
5 sows, 1 boar, landrace cross	3,600	2	1,800
Total			**11,687**
Feed			
Sows and boar (6 animals @ 3 kg/day, 43% conc.)	2,549.556	1	2,550
Growers (37 animals @ 800 g/day for 2 weeks, 43% concentrate; assume weaning at 4 weeks)	320.7456	1	321
Growers (38 animals @ 2 kg/day for 18 weeks, 43% concentrate; assuming weaning at 4 weeks)	7,411.824	1	7,412
Total			**10,282**
Grand total costs			**21,969**
			Revenue (kina)
37 growers @ 300 kina at 6 weeks			11,100
38 @ 18 weeks @ 1,000 kina			38,000
Sows and boars every second year at 3,000 kina halved for 2 cycles			4,500
Total revenue			**53,600**
Profit			**31,631**
Profit (%)			**59**

Table 6. Comparison of profitability of village hybrid pig farming under different scenarios.

Scenario	Profitability (%)
SP tubers plus MM concentrate (Table 1)	57
SP silage plus MM concentrate, no nutrient return (Table 2)	62
SP silage plus MM concentrate, nutrient return to SP gardens via mineral fertiliser (Table 3)	59
SP silage plus MM concentrate, nutrient return via to SP gardens via manure return (Table 5)	59

SP = sweetpotato; MM = mini-mill.
This modelling shows that hybrid pig farming is a highly profitable business, whether the feed regime includes sweetpotato roots or sweetpotato silage.

The sweetpotato farming system in PNG relies on adding village waste to the sweetpotato gardens as a way of returning nutrients to the soil. It is unlikely that such a system will change to using replacement mineral fertiliser, at least not in the near future. If this is the case, the best that can be hoped for is to add pig waste to the sweetpotato gardens in a similar manner. Accounting for the labour involved in doing this reduces the profitability of the silage feed model, as shown in Table 6, but the profitability is still higher than the conventional alternative of feeding the pigs with sweetpotato roots plus concentrate. Another advantage of returning pig manure to sweetpotato gardens is that it includes the plant nutrients contained in the concentrate portion of the pig feed. Under the assumption that adding pig manure to the sweetpotato gardens has the same effect as replacing the plant nutrients via mineral fertiliser, Table 6 also shows that accounting for labour involved reduces the profitability of the silage feeding system by the same amount as returning the nutrients via mineral fertiliser.

CONCLUSION

This paper suggests that nutrient removal from sweetpotato fields may have a significant impact on the profitability of pig farming when using silage as a feed ingredient. In a worst case scenario, where all nutrients have to be returned to the soil as mineral fertiliser in order to maintain tuber yields, the modelling shows that the advantage of the silage approach is significantly reduced in terms of profitability, when compared to a conventional feeding model. If nutrients are returned via adding pig manure, profitability is reduced by the same magnitude.

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Mini-mill concentrate feed models and village enterprise models for broiler, egg, hybrid pig and tilapia production using predominantly local feed ingredients

Ian Black[1†]

Abstract

The derivation of 16 models that show potential costs and profitability of mini-mills producing concentrate feed for sale to village enterprises farming broilers, eggs, hybrid pigs or tilapia is described. In addition, eight models are described that show potential costs and profitability of the corresponding village enterprises. The models have been derived for both highland and lowland enterprises. Before social obligations are met, the results indicate similar high profitability (55–60%) for enterprises that produce broilers, eggs or hybrid pigs. The profitability for enterprises involved in tilapia production is much lower (10% profitability). For broiler and egg production, concentrate made by mini-mills appears competitive with Lae-based commercial mill concentrate.

INTRODUCTION

In 2010, it was estimated that village-produced monogastric animals in Papua New Guinea (PNG) had a market value of A$190.5 million/year and involved about 600,000 small farmers (Glatz 2010). This value does not include the non-market village sector. Black and Yalu (2010) calculated that using predominantly local ingredients in the feed concentrate, together with a local carbohydrate source for the remainder of the diet (termed here 'the new technology'), would reduce village broiler production costs by about 40%. If a price production elasticity of 0.7 is assumed, this suggests that the new technology could increase the production of village-produced broilers by 25% (0.7 × 40% = 28%; conservatively 25%), provided full adoption of the new technology occurs. Hence, the stated objective of the ACIAR project 'Enhancing role of small scale feed milling in the development of the monogastric industries in PNG (ASEM 2010/053), i.e. "this project is planned to result in a 25% increase in profitability of monogastric sector and increase production by 5% per annum" (Glatz 2010) seems feasible, provided that the new technology impacts the other village monogastric industries in a similar manner.

MICROECONOMIC THEORY

A microeconomic argument based on producer and consumer surplus resulting from the impact of new technologies derived from research is presented. A basic model of research benefits resulting from the implementation of new technologies in a closed economy (Alston et al. 1995) is shown in Figure 1. A 'closed economy' is assumed because village-produced animals are not exported to other countries.

Figure 1 illustrates the supply of village broilers, with the x axis representing quantity, *Q*, and the y axis their price, *P*. All curves are defined in terms of annual flows. The demand curve for village-grown

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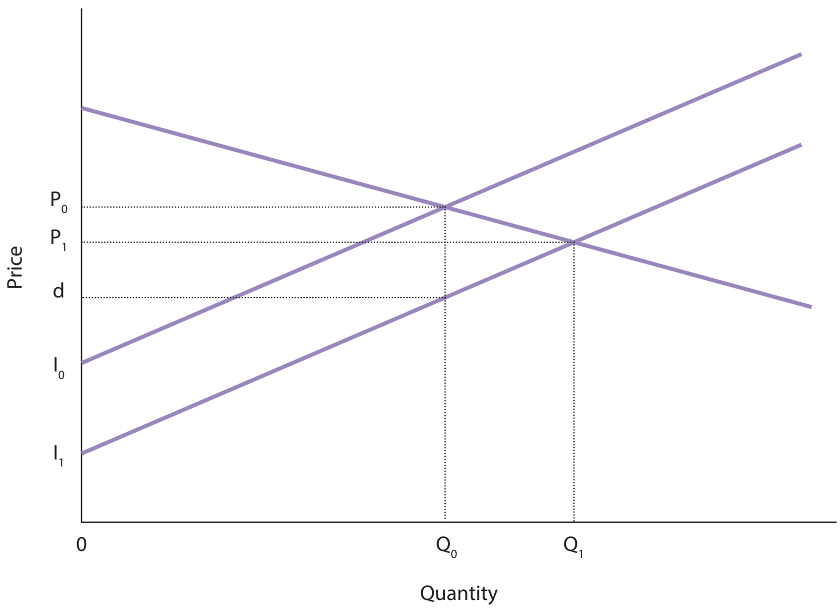

Figure 1. Surplus distribution in a basic model of research benefits for village broiler farmers. See text for explanation.

broilers, *D* in Figure 1 (assumed to be static), slopes downwards because the higher the price, *P* (the y axis), the fewer the number of broilers that will be purchased. The supply curve for village-grown broilers, S_0 in Figure 1, slopes upwards because the higher the market price, *P*, the more they will be produced by village enterprises; their costs and required profitability are met at a broiler price in the market which signals that they should expand their operation, or enter the industry in the case of prospective new growers. The initial condition, where the market clears, is at *a* in Figure 1. This is the point at which the market price, P_0, and the number of broilers sold, Q_0, are determined. While 'long' supply and demand curves are a useful explanatory construct, it needs to be noted that such long curves are illusionary. At any given point in time, village producers and buyers of village broilers are operating very close to the point at which the market clears, *a* in Figure 1.

Research leads to a reduction in the cost of production of broilers, represented by a downward shift in the supply curve (S_0 to S_1). The downward shift in the supply curve is caused by village broiler producers increasing production, hence their total profitability is increased. Competition among broiler producers for sales then ensures that part of the benefit of new technology from the research is passed on to consumers in the form of lower prices (P_0 to P_1), which in turn enables them to buy more broilers (Q_0 to Q_1) given the same demand curve, *D*. In the context of this research and extension program, and project ASEM/2010/053, this occurs because the cost of feeding broilers has been lowered through research showing that broilers can be grown with cheaper local feeds and cheaper mini-mill concentrate, due to the large local feed component in the mini-mill feed.

The total annual benefit (TS = total surplus) from the research-induced supply shift for village broilers is equal to the area beneath the demand curve and between the two supply curves (ΔTS = area I_0abI_1), where Δ represents annual change in flow. The triangular area, *abc*, represents the net economic surplus from the implementation of the new technology. Total benefits can be partitioned into the increment in consumer surplus (CS): ΔCS = area P_0abP_1; and the increment in producer surplus (PS): ΔPS = area P_1bI_1 minus area P_0aI_0. Further details can be found in Alston et al. (1995) which covers both geometric and algebraic treatments of the issue.

It is important to note that the increment in producer surplus is transient in markets where significant competition between producers exists, such as discussed here. Microeconomic theory shows that there is no long-term increase in profitability (producer surplus) because producers are willing to take lower and lower prices until the entire extra producer surplus is eroded. Hence, in the longer term, all the additional economic surplus flows to the consumer.

Two caveats about Figure 1 are noted. First, it illustrates a parallel supply shift, whereas there is likely to be a pivotal component in the supply shift. This can be seen if S_0 and S_1 are drawn through the point of origin—a likely scenario, because if the price of the product is zero, it is unlikely there will be any production. Second, the demand curve for broilers, *D*, may well shift as a result of consumer preferences when the consumer is faced with significantly reduced prices for a number of products in the same general category, i.e. protein products from intensive animal industry village enterprises.

In terms of the first caveat, in markets with many willing buyers and sellers, and where there is free entry and exit of buyers and producers, the assumptions represented in Figure 1 seem a reasonable first approximation of what happens. The number of broilers produced, quantity *Q*, means that the distance of Q_0 and Q_1 from the origin is very great and hence the non-parallelism in the shift from S_0 to S_1 is probably insignificant when those curves start at the origin. In terms of the second caveat, and of greater concern initially at least, is a change in the demand curve for a particular protein product—poultry meat, eggs, pig meat or tilapia—when the lower feed cost technology resulting from ASEM/2010/053 and its predecessors simultaneously impacts all four village grower industries. Consumer preferences may alter the original demand curves, *D*, for individual products. Before the impact of the new technology this factor is unknown, so it may be preferable to initially think in terms of an aggregate impact of the new technology on the four village industries.

Black and Yalu (2010), using the DREAM model, found that consumer surplus was approximately equal to double the value of producer surplus. If the impact of the new technology is initially thought of in terms of aggregate effect on the four village industries, other things being equal, there is no reason to believe that this ratio will differ markedly from that calculated for the village broiler industry in PNG before the impact of the new technology on particular industries can be ascertained. Note that in the longer term, all the additional surplus flows to the consumer, as discussed above.

OBJECTIVES OF MODELLING

The objectives of the modelling were as follows.

1. To provide indicative prices for mini-mill concentrate for feeding broilers, layers, hybrid pigs and tilapia in the highlands (represented by Mount Hagen) and the lowlands (represented by Lae). The purpose was to assess whether mini-mill concentrate is competitive with large mill commercial concentrate.
2. To provide indicative profitability levels of village enterprises growing broilers, layers, hybrid pigs and tilapia in the highlands and lowlands. The purpose was to compare the profitability of these enterprises.

THE MODELS

Table 1 summarises the 24 models derived, and a footnote describes the submodels for layers.

CONSTRUCTION OF THE MINI-MILL MODELS

An attempt to cost all significant resources involved in the businesses was made at 2014 prices and included the following:

- labour, as a standard wage plus a management premium where appropriate;
- mini-mill land, as a yearly rent;
- housing etc., as a straight-line depreciation of useful life;
- equipment, as a straight-line depreciation of purchase cost;
- feed ingredients, at market prices less a discount for bulk purchase;
- mini-mill annual maintenance and office costs;
- mini-mill ingredient transport and product packaging.

If estimates were made before 2013, they have been updated using the relevant PNG price index. An example of how an annual mini-mill capital cost was derived is shown in Table 2. Apart from the Kaliber equipment, the other costs shown in Table 2 are estimates only, however in project workshops in Lae these estimates have been agreed. Table 3 shows an example of the derivation of annual operating costs. An example of total annualised costs, ingredient feed costs and assumptions about market equilibrium mini-mill profits and transport and reseller mark-ups is shown in Table 4.

Other mini-mill prices per tonne vary according to place of manufacture (highlands or lowlands) and price and mixture of ingredients. Fixed annual capital costs (Table 2) and annual operating costs (Table 3) are common to all mini-mill operations in the highlands and lowlands, respectively. The difference between highlands and lowlands models is the extra costs involved in transporting fuel and specialised ingredients from Lae to the highlands.

CONSTRUCTION OF THE VILLAGE FARM MODELS

Table 5 shows an example of costs, revenue and profit for a commercial hybrid layer enterprise in the lowlands. The concentrate feed price is the average reseller price of Kaliber and PSS equipped mini-mills.

RESULTS AND DISCUSSION

'Commercial in confidence' information shows that mini-mill feed is highly competitive with large mill feed for broiler and egg production in village enterprises.

Comparisons resulting from the modelling are shown in Table 6. As a generalisation, the cost of mini-mill concentrate, either at the reseller or the mini-mill gate, is a function of the protein content in the concentrate. The higher the protein content, the higher the price of concentrate.

The high profitability calculated for typical village enterprises that produce broilers, eggs or hybrid pigs is

Table 1. Description of the derived models.

Mill type	Kaliber mini-mill (purchased from Indonesia)		Project Support Services (PSS) mini-mill (purchased from Lae, PNG)	
Region	Highlands	Lowlands	Highlands	Lowlands
Enterprise concentrate produced				
Broilers	Model 1	Model 2	Model 3	Model 4
Eggs	Model 5	Model 6	Model 7	Model 8
Hybrid pigs	Model 9	Model 10	Model 11	Model 12
Tilapia	Model 13	Model 14	Model 15	Model 16
Village enterprise type	**Highlands**		**Lowlands**	
	(Concentrate price is an average of Kaliber and PSS equipped mills at the reseller)			
Village enterprise feed	Sweetpotato + concentrate		Cassava + concentrate	
Broilers*	Model 17		Model 18	
Eggs	Model 19		Model 20	
Hybrid pigs	Model 21		Model 22	
Village enterprise feed	Concentrate		Concentrate	
Tilapia	Model 23		Model 24	

* Village enterprise egg production: submodels for commercial hybrid, well-bred Australorp and inbred Australorp birds have been generated.

Table 2. Annualised mini-mill capital costs for Kaliber equipment.

	Cost (kina)	Updated with PNG price index	Amortisation (years)	Annual cost (kina)
Capital				
Land	5,000	6,000	20	300
Fence	2,000	2,400	10	240
Sheds	4,700	5,640	20	282
Roads, compaction, etc.	3,000	3,600	2	1,800
Mini-mill				
Hammer mill (including electric or diesel motor)	4,243	4,243	10	
Discharge screws (2) (including electric motor)	5,538	5,538	10	
Elevators (3) (including electric motor)	12,636	12,636	10	
Transport screw (including electric motor)	3,796	3,796	10	
Two-way valve with drive	1,742	1,742	10	
Small bin with 2 levels	3,172	3,172	10	
Large bins (3) with 2 levels	12,480	12,480	10	
Dosing conveyors (4) with drives	9,048	9,048	10	
Weighing hopper	3,796	3,796	10	
Screw conveyor with drive	2,522	2,522	10	
Mixer with gear motor and slide below mixer	5,837	5,837	10	
Hopper with frame	3,627	3,627	10	
Pellet mill (including electric motor)	8,632	8,632	10	
Counter-cooler with accessories	6,786	6,786	10	
Blower (including electric motor)	2,184	2,184	10	
Hopper bin with support	3,120	3,120	10	
Bagging scale	17,420	17,420	10	
Support frame	8,710	8,710	10	
Bag closing, hand-held	3,120	3,120	10	
Panels and cabling	10,088	10,088	10	
Level sensors (4), solenoid pneumatic cylinders (2), compressor (3 kW)	7,605	7,605	10	
Power supply and connection to machinery	8,000	8,000	10	
Hand cutting and handling tools	100	100	10	
Storage and materials movement equipment	300	300	10	
Shipment to Lae and installation	16,800	16,800	10	
Discount	19,102	19,102	10	
Total for mini-mill equipment	142,200	142,200	10	14,220
Office equipment	10,000	12,000	5	2,400
Bags, bins etc.	12,500	15,000	5	3,000
Vehicle (second hand)	22,500	27,000	5	5,400
Grand total	**240,104**	**252,044**		**27,642**

Table 3. Annual mini-mill operating costs for Kaliber equipment.

	Operating costs (kina)	
	Lowlands	Highlands
Fuel	16,000	20,000
Municipal rates	0	0
Power	0	0
Phone	500	500
Night security	4,000	4,000
Office supplies	1,000	1,000
Pest control	1,000	1,000
Labour:		
Manager/skilled manual labourer	6,000	6,000
Labourers (2)	6,000	6,000
Repairs, maintenance and replacement	6,000	6,000
Total	**40,500**	**44,500**

Table 4. Mini-mill ingredient prices and concentrate cost/tonne for layers using Kaliber equipment in the highlands.

	Cost (kina/ tonne)	kg used in a tonne mix	Cost/ revenue (kina)
High protein			
Fishmeal	2,374	225	534
Copra meal	950	325	309
High energy			
Palm oil	2,746	75	206
Low-cost by-product			
Millrun	470	275	129
Shell grit	450	125	56
Super layer concentrate	2,750	100	275
Total		**1,000**	**1,509**
800 tonne/year (20 tonne/week for 40 weeks/year for running mill)			1,207,480
Annualised capital cost			27,642
Operating cost			44,500
Total			**1,279,622**
Inclusive of profit margin (30%)			1,663,509
Price per tonne at the mini-mill gate: (total + profit)/(800 tonne/year)			2,079
Price per tonne at the retailer (+30%)			2,703

encouraging (Table 6). Microeconomic theory suggests that this is likely to provide a good stimulus for participation by farmers in these industries. However, a costing approach does not easily cope with significantly reduced profitability that results from the fulfilment of village social obligations—the 'wantok' system whereby produce is either given away or sold at cost.

Figure 2 is an illustration of the effect on profitability of meeting social obligations from the produce of village enterprises. Provided the level of social obligations remains the same, Figure 2 suggests that increasing the initial profitably of village enterprises could have a disproportionately positive effect on the incentive for villagers to start enterprises

Table 5. Costs, revenue and profit for a village layer enterprise using mini-mill concentrate.

	Cost (kina)	Amortisation (years)	Annual cost/ revenue/profit (kina)
Shed	2,000	10	200
Labour: 2 hours/day @ 4,800 kina/year	1,280	1	1,280
Labour: egg sales 4 hours/week	512	1	512
Health (dewormers)	200	1	200
Drums, buckets, scales, feeders, drinkers	600	5	120
Litter (sawdust changed monthly)	750	1	750
100 layers (2 boxes of day-olds)	1,600	2	800
Packaging: 3 kina/filler × 100 fillers	300	1	300
Transport	0	1	0
Total			**4,162**
Feed			
60 kg feed/year/bird × 90 birds (40% concentrate, 60% cassava)	6,624	1	6,624
Total costs			**10,786**
Revenue: eggs, 6 dozen/day @ 12 kina/dozen			26,280
Revenue: old birds, 45 birds/year @ 20 kina/bird			900
Total revenue			27,180
Profit			16,394
Profit (%)			60

Table 6. Village enterprise profitability using mini-mill concentrate plus a local carbohydrate feed, and cost of mill feed (highlands and lowlands averages).

Enterprise	Size (numbers/year)	Profitability (%) (based on mini-mill reseller price)	Reseller cost of mini-mill feed (kina/kg)	Mini-mill gate feed cost (kina/kg)
Broilers	200	55%	2.6	1.8
Pigs*	75 growers	57%	1.7	1.2
Eggs**	100 layers	58%	2.55	1.8
Tilapia	1,000	10%	2.9	2.0

* Landrace cross.
** Average of commercial hybrids and well-bred Australorp crosses.

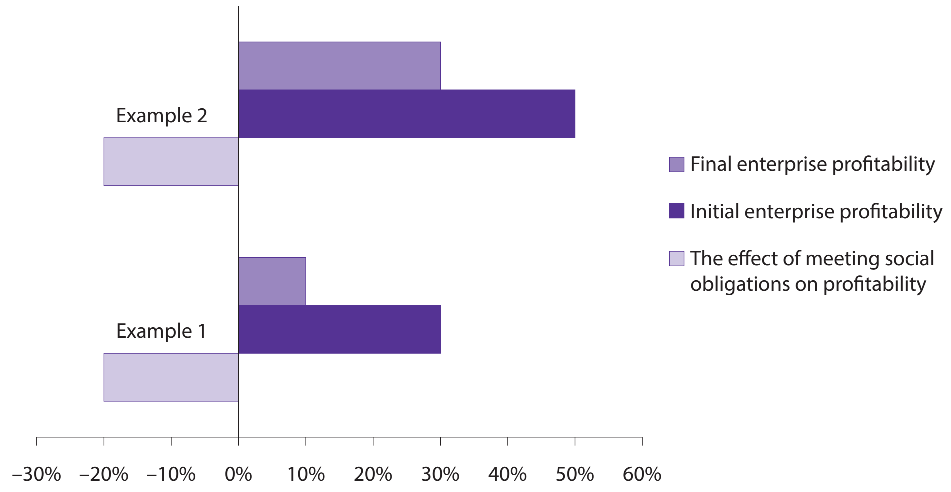

Figure 2. The effect of meeting social obligations on village enterprise profitability.

or, in the case of existing enterprises, to expand them. The reason is that final profitability, after social obligations are met in Example 2, is three times that of final profitability in Example 1 (30% compared to 10%), while initial profitability in Example 2 is only 1.67 times more than that in Example 1 (50% compared to 30%).

The models discussed are based on data that was correct at the time of submission of this paper. Data and models have been updated since but the results discussed here are, in principal, the same. In 2016 the models were transferred to the National Agricultural Research Institute (NARI) for maintenance and further development.

CONCLUSION

Mini-mill concentrate prices are competitive with commercial mill concentrate prices for broiler and egg production (commercial feed is not available for hybrid pigs as a concentrate or for tilapia). Village enterprise profitability is approximately the same for broiler, egg and hybrid pig production. Even with large numbers of tilapia (high production) per facility, this village enterprise does not appear competitive with the others in terms of profitability. This may be because of a lack of premium for tilapia fish on a weight basis compared with eggs, broilers and pigs, and because of the high cost of feed for the high protein mini-mill diet.

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Using mini-mills for chicken feed manufacture in the Domil community of Papua New Guinea: farmers' attitudes, knowledge and constraints

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Abstract

This study aimed to assess farmers' attitudes, knowledge and constraints in relation to the use of mini-mills to process livestock feed. With increases in the price of commercial feed, an alternative is to use locally available materials and mini-mills. Results showed Domil farmers had a very positive attitude toward the use of the technology, believing that it would bring financial returns and other positive outcomes. Farmers had limited knowledge about the mill, and although knowledge on the functioning of the mini-mill equipment may not be necessary for all farmers, better understanding will increase technology adoption and expansion. Most farmers ranked low on constraints related to low market value, non-availability of feed ingredients and lack of marketing, as these constraints, though present, were being addressed by the community as a group. However, lack of training and poor extension, which require external assistance, were causing constraints and seem a major area for intervention. In conclusion, the use of the mini-mill technology was well adopted in the Domil community of Papua New Guinea.

INTRODUCTION

The demand for livestock products (e.g. meat, milk and eggs) in developing countries is increasing with increasing income levels, population growth and migration of people to towns and cities (Delgado et al. 1998). This has led to more land being converted into grazing for livestock, increasing pressure on cropping and horticultural land resources worldwide. Therefore, issues relating to livestock development and production are of major concern for research and development organisations.

Many smallholder farmers who previously practised simple free ranging of livestock have now shifted to intensive production systems. In the poultry industry, these systems are replacing smaller backyard units and traditional free range systems. More efficient breeds of meat and egg laying birds have been developed, nutritionally balanced feed is more commonly available and used, intensive housing systems have been developed, and better poultry equipment is available (Oyeyinka et al. 2011). Rearing poultry has become a cost-sensitive business, and feed typically accounts for up to 70% of the cost of production (Bamiro et al. 2001).

The establishment and operation of mini-mills that produce feed from local ingredients is a cost-effective option to provide quality feed for livestock, especially poultry, pigs and aquaculture. Apantaku et al. (2006) found that poultry farmers in Oyo State, Nigeria preferred self-compounded feed (feed formulated by farmers using locally available resources) compared to commercial feed, as it was considered to be better quality, required no quality control measures and was less expensive. Additionally, farmers choose feed based on its perceived quality, their technical ability to produce feed themselves, the cost of commercially

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compounded feeds, storability of feed, and cost and availability of feed transportation.

Innovation and technology adoption by smallholder farmers lead to increased agricultural productivity, a key strategy in achieving food security. Gains from new technology influence poverty directly by raising incomes of households, and indirectly by raising employment and wage rates of landless labourers (Pinstrup-Andersen et al. 1976; Hossain et al. 1994; Winters et al. 1998; de Janvry and Sadoulet 1992; Irz et al. 2001). As farmers' attitudes, knowledge and constraints are important in assessing the likelihood of a particular technology being adopted, this study focused on these three factors.

Generally, attitude refers to how people react to certain situations and how they behave in general. Parminter (1997) stated that attitudes are formed from beliefs influenced by information and social pressures, as well as personal experience and the inferences made from these. It was further elaborated that farmers had similar beliefs in relation to technologies, but those that adopt a technology have a strong belief that positive outcomes will be greater than negative outcomes; in other words, these farmers have a favourable attitude towards the technology. Cavane (2011) agreed that farmers' attitudes determine adoption of an improved technology where these attitudes are evaluative responses towards the technology, and are formed as farmers gain more information about the technology itself. Generally, the most common reason given by farmers for using a new technology relates to beliefs about expected financial returns from that technology. Parminter (1997) indicated that it was beliefs about the non-financial negative interactions between technologies and farming systems that were the most common reasons given by farmers for not using a new technology.

Knowledge is practical information gained through the learning process, experience or association with others. Sadati et al. (2010) indicated that farmers who have a high level of literacy, participated in extension courses, visited demonstration farms and agricultural fairs, and had access to extension channels, had a positive attitude towards adoption. This type of exposure broadens the farmers' thinking and therefore information gathered creates new knowledge. Rahman (2003) supports this by suggesting that the issue of sustainability of agricultural production (and for that matter, the utilisation of the mini-mill) is largely dependent on the action of farmers and their decision-making abilities, given the level of knowledge and information that is available to them.

In simple terms, constraints are defined as factors that hinder farmers in using technology to its full capacity. In the mini-mill industry, the main constraint is the lack of suitable feed-making equipment (Booth et al. 2006).

Chicken production for meat and eggs is widespread throughout many South Pacific island countries, including Papua New Guinea (PNG). Selling live poultry is a major source of income in PNG. More than 150,000 smallholder households raise chickens and chicken is second to pork in terms of consumption (Macfarlane 2000). During the past 10 years, the trend of rearing chickens in PNG and South Pacific island countries has changed from village-based free range to small-scale intensive production for commercial purposes (Low and Low 2000). Concurrently, the price of commercial feed has increased and feed has become the main constraint in these production systems, accounting for more than 70% of running costs (Aregheore 2001).

Commercial feed in PNG is manufactured by Trukai Industries, Goodman Fielder International and the Mainland Holding Group of Companies through Niu Guinea Table Birds Ltd. The feed is distributed through various outlets, such as Agmark Didiman Stores, Chemica and Farmset. The feed ingredients include fish and meat meal, sorghum, soybean meal and other micro-ingredients. Ingredients such as copra meal and fishmeal are obtained locally, while almost all other ingredients, including sorghum, soybean meal, meat and bone meal, and all micro-ingredients are purchased from overseas (Kumar 1996; ACIAR 2009a). Only small amounts of local ingredients are used by these large feed mills due to the high cost of transport, difficulties in storage, unreliability of supply and variability in quality. The cost of the imported ingredients together with the distribution cost contributes to the high cost of feed.

The use of cheaper, locally available protein and energy sources to formulate feeds could effectively reduce costs. Feeds could also be processed locally using mini-mills. Village farmers have expressed a strong desire to use a variety of local feed resources in monogastric diets, including sweetpotato, cassava, banana, copra meal, taro and fishmeal to make a compound feed.

The mini-mill concept was proposed for PNG by Dr Geoff Allan (ACIAR fisheries consultant) to make local feeds for fish and poultry as an alternative to expensive commercial feed, and to improve returns for farmers. Since the inception of the mini-mill project in 2005 ('Enhancing role of small scale feed milling in the development of the monogastric industries in PNG', project ASEM 2010/053), several other studies relating to feeding systems and the role of mini-mills have been implemented, including 'Poultry feeding systems in PNG' (LPS/2001/077; ACIAR 2006), 'Improving the profitability of village broiler production in Papua New Guinea' (ASEM/2005/094; ACIAR 2008) and 'Feeding village poultry in the Solomon Islands' (LPS/2003/054; ACIAR 2009b). These projects have mainly focused on using feed mills and mixing of locally available ingredients with imported commercial ingredients to develop a nutritionally balanced low-cost diet for poultry and other livestock. However, no studies had been done to document the acceptance of those mills by the communities.

This paper examines the attitudes and knowledge of broiler farmers regarding the set-up and operation of mini-mills in PNG, and the constraints they face in the adoption of the technology. The information generated from this study will guide future research, investment and extension of this technology and help in developing strategies for further improvements in the uptake of the technology. The information may also be useful for improving extension and training, and policy interventions.

METHODS

Study location and community

The survey site was Domil Village (Figure 1), and the study was conducted through the Domil Cooperative Society. The cooperative was started 20 years ago as a community group focusing on health and development, and expanded to include issues such as clean water, cultural tourism, education, insurance, microfinance and savings, coffee, fish, poultry, soap making, housing,

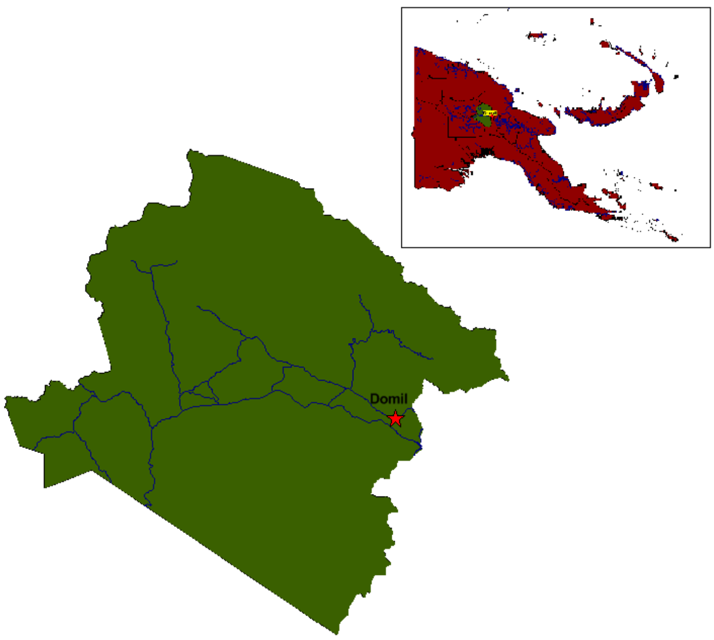

Figure 1. Map showing the location of the project site (Domil) in Papua New Guinea.

church and community government; thus capturing a range of religious, political and economic issues. The cooperative has a total of 240 families and 1,500 people as members.

In 2012, mini-mills were introduced to Domil under a signed contract agreement with NARI. The mills included three pieces of machinery, a diesel hammer mill, a diesel flake mill and an electric feed mixer. Feed from the mill was mainly used in broiler production. At the time of this study, 54 farmers were involved in broiler production, and 50 of them participated in the survey. The survey therefore covered the majority of Domil broiler farmers who had access to the mini-mill facilities.

Data collected

The study involved both quantitative and qualitative data collection. The quantitative data were collected through a farmer survey. A questionnaire collected data relating to farmers' attitudes, knowledge and constraints, and socio-economic attributes that may influence attitude, knowledge and constraints. The first section of the questionnaire gathered socio-economic information about the farmers. The second section included statements relating to attitude, knowledge and constraints which were measured using: (1) the Likert attitude scaling approach (Trochim 2006); (2) knowledge of farmers using scoring methods; and (3) scores on the extent of difficulty each farmer faced using the constraints facing index or CFI (Rahman 2000).

The qualitative approach involved focus group discussions with key stakeholders. Fifteen key informants were asked key questions to stimulate discussion, and probing questions were asked to obtain detailed information on issues of interest. Discussions were guided on issues relating to the mini-mill, spin-off effects of the mini-mill, poultry feed, feed formulation, sources of raw materials, constraints faced and value adding options.

Statistical analysis

A standard operating procedure was developed for coding the data and data entry in Statistical Packages for Social Scientist (SPSS 20). Data on attitudes, knowledge and constraints faced were measured using descriptive statistics (e.g. range, mean, percentage, correlation coefficient and standard deviation).

Table 1 shows how low, medium and high categories were created for attitude, knowledge and constraints variables. To determine the categories within each variable, variables that fell between 1% and 50% of the score range received a low rating (1–50% = first category). Scores between 50% plus one to the mean plus one standard deviation fell in the second category (upper limit). Any scores that fell above the upper limit were included in the third category.

Measuring farmers' attitudes

The attitudes of broiler farmers were measured using Likert attitude scaling (LAS; Table 2; Trochim 2006). There were 18 attitude statements, and each respondent indicated 'strongly agree', 'agree', 'uncertain', 'disagree' or 'strongly disagree'. In this survey, 'strongly agree' had a score of 5 while the other extreme, 'strongly disagree', scored 1; the reverse applied for negative statements. Possible attitude score of the respondents ranged from 0 to 90 for the 18 statements assessed, 0 being a highly unfavourable attitude and 90 being a highly favourable attitude.

Table 1. Method used to create low, medium and high categories for attitude, knowledge and constraint variables.

Variables	Highest expected score (A)	Mean (B)	Standard deviation (C)	Lower limit = 50% of A (D)	Upper limit = (D+1) to (B+C) = E	Scores above the upper limit = E+1 to A
				First category (low)	*Second category (medium)*	*Third category (high)*
Attitude	90	73.78	6.92	0 to 45	46 to 81	82 to 90
Knowledge	30	18.02	6.00	0 to 15	16 to 24	25 to 30
Constraints	27	14.66	3.41	0 to 15	16 to 19	20 to 27

Table 2. Likert attitude scaling used to collect data on attitude.

Attitude statements	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
Positive statements	5	4	3	2	1
Negative statements	1	2	3	4	5

Measuring farmers' knowledge

The knowledge of farmers on local feed and use of the mini-mill was measured using a scoring system. Each participant responded to 10 questions relating to their knowledge on feed ingredients, feed formulation, processing, and mini-mill operation and practices. A correctly answered question was allocated three points, two points were awarded for a partially answered question, and one point for an incorrect answer. Possible knowledge score ranged from 1 to 30 with 1 being least knowledgeable and 30 being most knowledgeable of the feed mill technology.

Measuring farmers' constraints

In this study, 'constraints faced by farmers in producing mini-mill diets' was regarded as a dependent variable. This was measured using nine selected constraints which related to aspects of the mini-mill diet, production of feed and mill utilisation. The independent variables of the study included: (1) poor extension services and lack of information; (2) lack of marketing; (3) low market value; (4) non-availability of inputs (feed ingredients); (5) lack of training; (6) lack of credit or capital to invest; (7) complexity of practice; (8) criticism by family and/or relatives; and (9) poor access to day-old chickens. Each respondent was asked to indicate the extent of difficulty caused by each constraint using a scale from 'very high' to 'high', 'little' and 'not at all'. Weights were assigned to each response: 3, 2, 1 and 0, respectively. Scores from all nine selected aspects were summed together to get the individual constraint score.

RESULTS AND DISCUSSION

Attitude

Table 3 presents attitudes of the farmers to utilisation of the mini-mills, with possible score ranging from 0 to 90. The attitude scores of the farmers ranged from 46 to 81 and 82 to 90 under the categories of favourable and highly favourable, respectively. The results showed that 88% of farmers had a favourable attitude towards the mini-mills, while 12% had a highly favourable attitude towards the technology. The mean score was about 74.

Domil farmers are sourcing feed from the mini-mill to feed their poultry, however when there is a low supply of feed from the mini-mill, farmers need to source feed from the manufacturers and suppliers at Mount Hagen. Given their positive attitude towards the mini-mill, the implication is that if farmers were given a choice between producing feed via a mini-mill and sourcing feed from a manufacturer, they would opt for feed from the mini-mill. These results also imply that farmers believe there will be positive financial returns from the mini-mill, and other positive outcomes (Parminter 1997). This has been shown to be the case, with spin-off benefits to the Domil community including:

- secured bank loans using the mini-mill as collateral;
- employment;
- community policing and security, with farmers protecting the mills from vandalism;

Table 3. Classification of farmers on their attitude to the mini mill.

Category	Number of farmers	Percent	Mean score	Standard deviation
Unfavourable attitude (0–45)	0	0		
Favourable attitude (46–81)	44	88	73.78	6.920
Highly favourable attitude (82–90)	6	12		
Total	50	100		

- strengthened unity and cooperation among villagers;
- positive attitude, purpose and direction within the community;
- the community becoming a model for others;
- farmers maximising use of their time, and reducing non-productive activities;
- alternative cash crop introduced (cassava);
- women are able to sell cassava as a cash crop, as men dominate the coffee crop;
- manure from expanding poultry production is used as fertiliser on vegetable gardens;
- improved nutrition, via chicken offal and occasionally chicken meat as a protein supplement for the family;
- change in the farming system (e.g. from mixed sweetpotato/cassava to monocropping cassava for the mills); and
- increased income-earning opportunities.

Further reasons why the technology was successful in Domil, which emerged from key informant discussions and personal observations, included the following:

- good leadership of the association (transparency, honesty, dedication, education level and direction);
- location of the project site (proximity to a major highway, providing easy access to the mill);
- positive attitude of people towards the mini-mill;
- the scale of the poultry industry, which is growing and needs an increasing amount of feed.

Syamsu and Syamsuddin (2009) supported the view that good human resources (i.e. leaders) and high poultry populations are key issues which influence the success of mini-mill operations.

Due to the highly favourable attitude towards the mini-mill in the Domil area, the demand for feed is 570 kg/day (4 tonnes per week), however the mini-mill can only produce 120 kg/day. Currently there is over-use of the mini-mill due to the high demand for feed, leading to constant breakdown of the mill.

Knowledge

Table 4 shows results for knowledge among farmers. The results show 50% of farmers have a low level of knowledge regarding the mini-mill technology, 30% have a high level of knowledge, and the remaining 20% have a very high knowledge score in relation to the use of the mini-mill. The study identified that the 20% of farmers with a very high knowledge score had an advantage as they had received special training on the operation of the mill and were closely associated with the mini-mill operations. Knowledge on the functioning of the mini-mill equipment may not be necessary for all farmers. However, farmer involvement and participation is important for technology adoption and for expansion, therefore more farmers require a baseline understanding to appreciate how the mini-mill operates and the processes involved.

Constraints

Table 5 presents results on the level of constraints faced by farmers. The total constraint scores were computed for each respondent by summing scores for all the constraints. The possible score ranged from 0 to 27, where a score of 0 indicated no constraints with respect to using the mini-mill, and a score of 27 indicated the highest extent of constraints faced.

The results indicate that 64% of the farmers have a low level of constraints, 24% have a high level, and 12% have a very high level of constraints. More farmers have a low level of constraints than a high level. In the survey, most farmers ranked low on constraints related to low market value, non-availability of feed ingredients and lack of marketing. These constraints, though present, were being addressed by the society as

Table 4. Classification of farmers on their knowledge of the mini mill.

Category	Number of farmers	Percent	Mean	Standard deviation
Low knowledge (≤15)	25	50		
High knowledge (16–24)	15	30	18.02	6.002
Very high knowledge (25–30)	10	20		
Total	50	100		

Table 5. Classification of farmers on the level of constraints they faced.

Category	Number of farmers	Percent	Mean score	Standard deviation
Low constraints (≤14)	32	64		
High constraints (15–19)	12	24	6.0	1.48
Very high constraints (20+)	6	12		
Total	50	100		

a group and this therefore gave farmers an advantage in supplying chicken to the society. However, lack of training and poor extension, which require external assistance, were causing constraints and seem a major area for intervention.

While mini-mills in other parts of the country have yet to be fully assessed, from the Domil experience it seems that poor extension and training is one of the main external challenges for the adoption of mini-mills, along with the sourcing of equipment. Internal challenges include sustainable supply of raw ingredients for feed, sourcing of chicks, and post-harvest or food safety issues during processing. Other internal challenges of adoption include the community's resource endowment as well as socio-cultural practices of the communities.

It has been noted that most farmers in the Domil community have low constraints due to the community addressing issues relating to non-availability of feed ingredients, lack of markets and marketing, and low market value. These issues are however major constraints in many other parts of PNG. Three main constraints that need immediate attention in other areas of PNG are poor extension services, lack of training and poor access to day-old chicks. Other constraints include high chick mortality, lack of knowledge and skills on the right feed formulation, and inconsistent supply of raw ingredients (Kohun et al. 2006).

CONCLUSION

From the findings of the study, it can be concluded that the mini-mill technology has been well adopted in the Domil community. All farmers had a positive or very positive attitude towards the use of the mini-mill. Farmers believe that there is a strong financial return from the mini-mill technology, and the community has seen diverse positive benefits as a result of the mini-mill.

Studies by Cavane (2011), Parminter (1997), Rahman (2003), Syamsu et al. (2009) and Sadati et al. (2010) have shown that attitudes, knowledge and constraints are important factors that determine the adoption of improved technologies. Farmers can promote the positive impact of the mini-mill to their colleagues and increase peer awareness. Social learning and networking by individual farmers, as indicated by Baumüller (2012), can lead to increased awareness on issues affecting individual farmers, including through the creation of knowledge and better decision making on innovation and technology adoption.

Farmers in other areas of PNG may have a positive attitude towards using improved technologies. However, there may be a need to invest in a new plant and new equipment, as well as to improve the exposure of farmers to practices outside their community, to allow them to obtain relevant skills for utilising the mini-mill technology. Positive attitude has to be supported by better organisation that can guide farmers in better planning, backed by internal resources (e.g. human, land and labour) as well as support from extension and development institutions (Parminter 1997).

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Local feed resources for pig production

A survey of pig production in Morobe Province of Papua New Guinea

Stanley Amben[1], Michael Dom[2] and Workneh Ayalew[2]*

Abstract

This paper describes smallholder pig production in Morobe Province of Papua New Guinea (PNG) in terms of farmer motivation, challenges and opportunities. Although pigs play a significant role in rural communities in PNG, the potential for this livestock enterprise to diversify into formal meat markets is not fully realised. Past research efforts were generally directed at improving feeding systems via Lehman feeding regimes, contingent with introducing exotic breeds for crossbreeding. Findings from the Morobe survey indicate that traditional extensive pig husbandry is evolving towards greater use of supplementary feeding, better housing, and farmers realising the need for external inputs such as formulated feeds, medicaments and tools for increasing production and investment returns. These trends should set the agenda for pig research for development as the multifaceted role of pigs in rural livelihoods and social customs is expected to continue. Understanding current and changing trends in pig farming systems, and farmer perceptions, is essential to enable livestock research for development to directly contribute to the national development objectives of food security, wealth creation and rural prosperity.

INTRODUCTION

In recent decades there has been enormous growth in livestock production worldwide, driven by increasing demand for animal-source foods among large segments of the world's population (Robinson et al. 2011). Developing countries account for the main share of this increase (Delgado et al. 1999) and PNG is no exception. The pig (*Sus scrofa*) is the most important livestock species for the country's rural populace (some 85% of the population), given its cultural and economic functions. The PNG native pig (*Sus scrofa papuensis*) is estimated to have been domesticated in the inland highlands of New Guinea some 6,000 years ago (Quartermain 2002). Based on current estimates, there are at least 1.8 million pigs in the smallholder sector raised by over 360,000 smallholders under extensive farming systems using minimal inputs (Ayalew 2013; Kohun and Quartermain 2002). Smallholders produce an estimated 27,000 tonnes of pig meat annually (Bourke and Harwood 2009), compared with 3,200 tonnes from commercial production, with a combined market value of over 200 million kina (Ayalew 2013).

Pigs are intrinsic in many smallholder farming systems in PNG, where sweetpotato-based cropping and small livestock keeping is the mainstay. These animals are either used in cultural events, with periodic slaughtering and exchange of large numbers of animals, or sold live in informal markets. Native pigs and a mix of native and exotic crossbreds are kept in various management systems. Generally, larger and older animals are produced, which are less preferred by formal markets having excessive fat deposits and lower carcass quality. However, these attributes remain relevant in informal live pig markets where the size of the animals matters. This situation appears to be favourable to smallholders, as it provides them with a good income from minimal inputs.

There are opportunities for smallholder pig farmers to sustain the formal pork meat markets currently being served by semi-commercial and commercial piggeries. The in-country demand for animal and

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fish protein is steadily increasing (Ayalew 2011) with the recent economic boom in the mining and petroleum sector as well as rapid population growth. The majority of smallholder pig farmers continue to use low levels of inputs, relying heavily on local feed resources, pastures and garden fodder (Ayalew 2011). Regardless, these farmers supply over 93% of the estimated pork consumed in the country (Ayalew 2011) which is mostly consumed at the farm gate. The commercial meat sector remains inadequate in meeting market demands. Many constraints in production and supplying market demands are shared by smallholder and commercial producers, and in 2009 one-third (30,000 tonnes) of all meat consumed in the country (including pork) was imported (Bourke and Harwood 2009). Wider participation is needed from smallholders to respond to market demands and enhance import replacement.

THE CHANGING ROLE OF PIGS IN PNG

The general perception of pig keeping at household level is to cater for cultural exchange, to provide cash income when needed, and to provide protein in diets. Past research in the highlands reported very little pork meat consumption in the region as pigs were mostly used for societal functions (Purdy 1971). More recently, a household survey in 1996 reported an average of 11 kg of pork consumed per person in a year (Gibson 2001); however this may have been underestimated. The role of pigs as the preferred protein source in PNG is becoming increasingly apparent, and this outlook will continue as pigs convert garden waste into valuable protein. Hence more effective production methods are needed to sustain these key roles of pigs in PNG society, while minimising associated production pressures within PNG's rural agricultural systems.

Decline in village pig numbers after World War II prompted the need to recover pig numbers. Thus, pre-independence research efforts were directed at increasing pig numbers, but their role in social exchange and their minimal contribution to human diets was overlooked. The option for increasing pig production was through a government policy of genetic improvement, which had the objective of increasing pig numbers by capitalising on hybrid vigour. However, without consistent breeding, genetic selection and controlled breeding, as well as minimal interventions in improved feeding and management systems and a lack of understanding of owners' motives for rearing pigs, objectives were not adequately met. Pig research objectives in the 1970s and early 1980s were based on improved feeding using the Lehman feeding regime and husbandry systems to improve village pig production using locally available resources (Hide 2003).

A survey was conducted in 2009 in Morobe Province to identify key constraints and opportunities of smallholder pig farming. The survey was carried out in eight of the 10 districts of the province (excluding Lae and Menyamya) through individual farmer interviews using a semi-structured questionnaire. A total of 348 smallholder pig farmers were interviewed (Table 1).

In addition to pigs, respondents kept other livestock which are also important in contributing to food security and rural household welfare (Table 2). After pigs, chickens and fish in inland fisheries were the most prevalent species. Pig farming is well complemented by poultry and fish farming, as these two types of

Table 1. Demographics of the Morobe Province pig farmer survey (348 respondents).

		No. (%)
Gender	Male	247 (71)
	Female	101 (29)
Age group (years)	<20	4 (1.1)
	20–30	86 (24.7)
	31–45	156 (44.8)
	>46	102 (29.3)
Marital status	Single	21 (6.0)
	Married	312 (89.7)
	Divorced	3 (0.9)
	Other	12 (3.4)
Education level	Primary school	170 (48.9)
	High school	41 (11.8)
	Secondary	2 (0.6)
	Technical college	24 (6.9)
	Other training	6 (1.7)
	None	105 (30.1)

livestock make large contributions to households in terms of regular protein and income generation, while pigs represent a longer term savings asset and business interest. Thus efforts to improve production should consider the different types of livestock, in terms of improved feeding, management and animal health.

About half of the respondents kept sows while others kept gilts (46%) and younger females (43%) as shown in Table 3. Relatively large numbers of castrated pigs are kept, as castration increases growth rates, improves docility and provides better disposal options through slaughter, exchange or sale. There are far fewer boars, but sufficient numbers for breeding purposes.

Figure 1 shows the role of pigs in terms of the benefits farmers derive from raising them (n = number of responses; some farmers indicated more than one benefit). Most of the respondents raise pigs for cash income and social welfare (social welfare includes both cultural and family obligations that require cash). However, the dual role of pigs as farmer savings and as a protein source is not negligible, and may be increasing. These findings are expected to be similar in other localities in PNG.

Table 2. Livestock kept by the interviewed pig farmers.

Livestock	No. of respondents	Total no. of animals	Maximum no. kept by one farmer	Mean no. kept by farmers (± SEM)
Pigs	343[a]	1,232	18	3.6 ± 0.173
Chickens	120	1,082	51	9.02 ± 1.305
Fish ponds	32	82	7	2.56 ± 0.345
Others pigs[b]	16	55	14	3.4 ± 1.076
Sheep	6	50	31	8.3 ± 4.876
Cattle	3	42	6	14 ± 2.0
Ducks	7	22	9	3.14 ± 1.28
Goats	2	15	5	7.5 ± 2.5
Others chickens[c]	3	15	11	5 ± 3.512
Rabbits	3	3		1

[a] Two semi-commercial pig farmers from Situm were excluded due to large herd sizes, while three farmers interviewed were no longer keeping pigs.
[b] Other pigs refer to livestock that were cared for by the respondent but not owned by them.
[c] Other chickens refer to livestock that were cared for by the respondent but not owned by them.

Table 3. Herd structure of pigs kept by the interviewed farmers.

Pig class	No. of respondents (%)	Total no. of animals	Maximum no. kept by one farmer	Mean no. ± SEM
Sows	172 (50.1)	243	5	1.41 ± 0.061
Male growers (castrated)	156 (45.5)	281	8	1.80 ± 0.101
Gilt growers	147 (42.9)	240	5	1.63 ± 0.83
Female piglets/weaners	115 (33.5)	239	7	2.08 ± 0.134
Male piglets/weaners	82 (23.9)	184	6	2.24 ± 0.158
Male growers	34 (9.9)	43	2	1.26 ± 0.88
Young boars (breeder)	22 (6.4)	26	2	1.18 ± 0.107
Old boars (breeder)	8 (2.3)	9	1	1.13 ± 0.125
Total	343 (100)	1,265		1.59 ± 0.107

UNDERSTANDING THE PNG PIG FARMER

Figure 1 reveals farmers' motives for rearing pigs. Cash income is the most important, followed by cultural needs (classified under social welfare). PNG society is more cash oriented today than in the past, and cash is now mostly used for the acquisition of goods and services. Subsistence farming is becoming more cash oriented, and cash is also being incorporated into traditional ceremonial exchange systems (Karikita 1992), but it is unable to replace the role of pigs in these ceremonies.

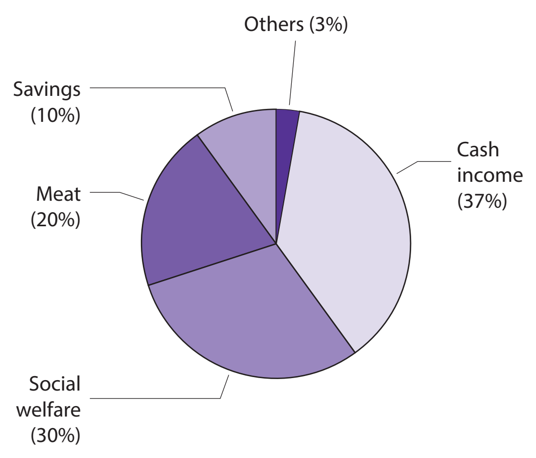

Figure 1. Reported benefits derived from raising pigs in Morobe Province (n = 1,044).

The majority of rural farmers continue to raise their pigs with minimal inputs over an extended period of time (five to six years) for greater size, and geared towards meeting social and cultural needs. This limits the ability of rural farmers to improve their productivity due to the need for additional inputs and competition for garden produce. However, farmers reported substantial returns from the sale of their pigs in the Morobe survey (Figure 2).

With minimal inputs and high cash returns in pig farming, farmers are expressing their intentions to intensify production. This was evident in the general trend of keeping pigs enclosed for better monitoring of their growth and reproductive performance (Figure 3).

The shift from traditional free ranging systems towards keeping pigs enclosed in intensive management systems is increasing rapidly throughout rural Morobe and PNG. However, in keeping the pigs enclosed, constraints arise due to limited knowledge on growth requirements of pigs in terms of feeding and general welfare. A number of studies have reported common production constraints of pig farming in developing countries to be high mortality rate, low off-take, absence of health care, lack of supplementary feeding and improper housing (Wabacha et al. 2004). Similar constraints are faced by farmers in Morobe Province (Figure 4).

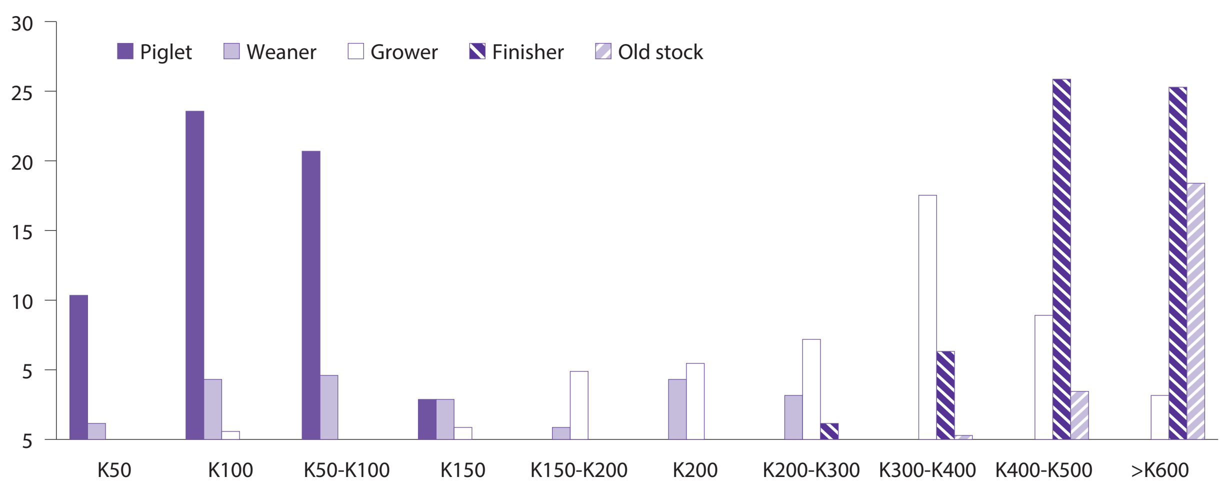

Figure 2. Market prices of different pig classes according to surveyed farmers.

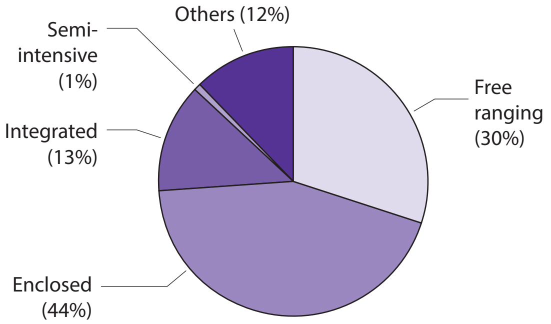

Figure 3. Pig husbandry systems reported by surveyed farmers.

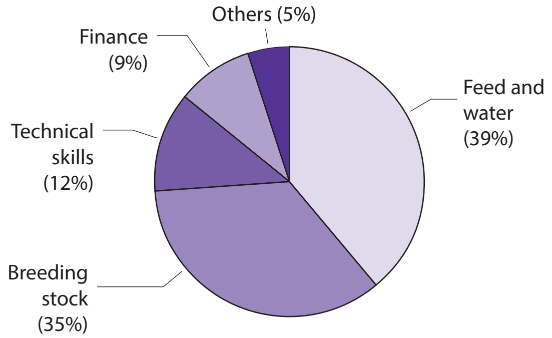

Figure 4. Farmer perceived constraints to pig production in Morobe Province (n = 1,044).

Despite reporting high cash returns from the sale of pigs, farmers are reluctant to re-invest returns in improving production. The irregularity of informal market demands, coupled with the utilisation of locally available resources, as well as the lack of facilitation of domestic meat markets, has hindered farmers from improving their productivity. Hence, smallholders continue to capitalise on minimal investment for greater output over a longer period of time. But farmers are now realising the need for more investment to obtain greater output and the trend is being set.

Pig farmers understand the different growth performance of different breeds, and their responses to management levels. Native pigs continue to hold high value due to their hardiness under low input management and their niche as assets for cultural exchanges. They fetch higher prices if sold in the informal pig exchange market where pigs are bought and sold specifically for cultural exchanges. However, they take much longer (three to five years) to reach their full mature body size and weight under minimal feeding conditions, as compared to crosses and exotic breeds.

Crossbreds of native and exotic breeds are recognised to have preferable meat traits for formal markets. Exotic breeds are noted to be more suitable for formal markets but require high inputs; farmers aspire to have such breeds but their attainment is mostly impractical and too costly.

A growing number of smallholder pig farmers are becoming market oriented, as evidenced by the steadily growing semi-commercial sector as well as the generally vibrant informal market. Most smallholder pig farmers have limited access to formal markets throughout the country. Information on the informal pig exchange market and pig meat market is inadequate to make assertions, but trends indicate that smallholders will continue to produce pigs for all purposes.

ADDRESSING CHALLENGES AND OPPORTUNITIES IN SMALLHOLDER PIG PRODUCTION

Understanding current and changing trends in pig farming systems, and farmer perceptions, is essential to enable livestock research for development to directly contribute to national development objectives of food security, wealth creation and rural prosperity. Hence, important constraints highlighted by farmers in the Morobe pig farmer survey (Figure 4) need to be systematically addressed.

The main challenge in all livestock enterprises is feeding. Feeding accounts for more than 60% of costs involved in raising livestock. The National Agricultural Research Institute (NARI) has responded with two improved feeding technologies in livestock farming: sweetpotato silage for pig feeding, and NARI broiler concentrates. The advantages of these technologies are that they: (1) significantly reduce the cost of feeding animals; (2) open up viable value-addition opportunities for garden produce; (3) create employment opportunities for available household labour; and (4) enhance farm integration towards greater farm production (Ayalew 2011).

Sweetpotato has a dual role in human food and animal feed supply. Greater integration of sweetpotato and pig farming is justified by the ubiquitous presence of this crop in mixed crop–livestock farming communities; the high feed value of sweetpotato vines, leaves and tubers as well as its perishable attributes; and the lack of suitable technologies for preserving fresh sweetpotato tubers after harvest, leading to up to 50% yield loss along supply chains to major market outlets (Ayalew 2011). The sweetpotato ensiling technology offers PNG smallholder pig farmers the opportunity to improve the feed value of sweetpotato without changing its traditional role as a primary feed source.

The role of chicken and fish, especially from inland fisheries, in providing household protein is becoming increasingly important, as shown by the findings of the Morobe pig survey (Table 2). Due to their need for high nutrient density diets, chicken and fish require better feeds. The broiler meat industry in PNG is well established, but high-quality feed costs continue to reflect international grain prices. Domestic grain production is minimal, but utilising locally available tuber crops as an energy source will help reduce the high dependence on imported grains. The NARI broiler concentrate technology was developed to minimise costs in raising broiler chickens by replacing the grain component of commercial broiler finisher feeds with locally available sweetpotato or cassava. This can reduce feed costs by almost 25%. The concentrate can be used in broad spectrum feeding of pigs and fish with appropriate balancing with essential nutrients. Trials have been carried out by NARI on wider use of this concentrate and promising results are forthcoming.

NARI's two feeding technologies can cater for the growing smallholder pig sector, and their utilisation is being promoted in neighbouring countries, including Solomon Islands and Vanuatu. However, the availability and accessibility of these concentrates poses a challenge for most rural farmers. A recent feed mill project implemented by NARI with funding support from the Australian Centre for International Agricultural Research (ACIAR) seeks to address this challenge. Given the high nutrient demands of chicken and fish, quality feed can be processed at community level using mini-mills. This is expected to add value to crops such as sweetpotato and cassava, by providing alternative markets for these important staples. Chicken and fish represent most daily household protein intake and the availability of high-quality, locally produced feed will allow farmers to improve their production while minimising costs. Pig feeding systems can take advantage of this by utilising feed derivatives from the feed mills. Studies on how these systems can improve smallholder livelihoods, while helping farmers to better adapt to food security risks associated with climate change and variability, are currently in progress.

Exotic diseases and pests also pose a threat to smallholder livelihoods, as experienced with cash crop commodities in the country. In responding to this constraint, NARI, the National Agricultural Quarantine and Inspection Authority and other important stakeholders propose to embark on a project to improve the delivery of animal health and production services in the country, with the support of ACIAR. Other challenges lie in building market value chains through the availability of abattoirs, improved road access and meat inspection mechanisms. A previous scheme, initiated by Pelgens Smallgoods Company in the Situm area of Nawae District in Morobe, is worth revisiting. In this scheme, local farmers were given weaned piglets from the company to rear and supply to the abattoir, but the project was unsuccessful. This out-grower scheme needs some improvement based on a similar concept applied by Niugini Tablebirds with broiler chickens.

Overall, the greatest challenge lies in minimising the production burden associated with raising pigs by making it more complementary to existing rural agricultural systems.

THE FUTURE OF SMALLHOLDER PIG PRODUCTION IN PNG

The pig is well embedded in the socio-cultural fabric of PNG and will continue to hold relevance in years to come. Pork has the highest quantity, value (189 million kina) and popularity among meat protein in PNG, followed by chicken and fish (Ayalew 2013). The demand for food will increase in PNG as population increases and pork meat will continue to be on the menu.

Intensive, commercial pig production will become more competitive with the incorporation of local feed resources. Smallholder village farmers will have the competitive advantage in markets, as collectively they can supply much of the deficit in pork production in-country by adopting available improved feeding and housing practices to enhance growth and reduce pre-weaning mortality. The current contribution of commercial piggeries to national pork production is only 4%, but this is expected to grow rapidly as more and more smallholders are encouraged to start commercial and semi-commercial piggeries (Ayalew 2011). A 25% increase in market-orientated pig farming will increase national pork production by 16% (Ayalew 2011).

Pig farming is at a crossroads in PNG and farmers need to make assertive decisions. Despite constraints in infrastructure, extension and animal health services, farmers need to step up to the challenge, to supply both domestic meat and live pig markets.

PIGS IN PNG VISION 2050

The agriculture, fisheries and forestry sectors must be empowered to realise the targets of PNG Vision 2050. These sectors are synonymous with the majority of the country's rural population. Their empowerment will uphold the pillars of wealth creation, natural resources and growth nodes, human capital development, gender, youth and people empowerment, and will influence other cross-cutting issues such as environmental sustainability and climate change (NSPTF 2011). Pig farming is at the epicentre of rural agricultural development and fostering development in this sector will strengthen these identified pillars of the vision.

Wider citizen participation is needed in achieving PNG Vision 2050 targets. The subsistence population must be empowered to increase production to meet the ever-increasing demands for food. This is mandatory for all types of farming, but pig farmers could take the lead in this exercise. The current policy environment is conducive for the growth of small to medium enterprises, and the challenge of meeting market demands must be taken on board by farmers. Import replacement should be the driver, and this will provide a roadmap for addressing deficiencies in infrastructure, extension, market value chain linkages, agricultural subsidies and animal health and biosecurity issues. The pig thus has a great potential role to play in achieving the targets of Vision 2050 (NSPTF 2011).

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Pig husbandry systems in Morobe Province, Papua New Guinea

Stanley Amben[1], Michael Dom[2] and Workneh Ayalew[3]*

Abstract

A survey of 348 smallholder pig farmers was carried out in Morobe Province, Papua New Guinea (PNG). Information was obtained on pig production indicators, namely husbandry practices, genetic resources, animal health, resource use and objectives for pig keeping. Pig keeping is necessary for the wellbeing of respondents, despite the challenges of keeping this demanding animal. Results show that traditional extensive pig keeping is rapidly declining, as 45% of respondents preferred to keep their pigs confined. Respondents' average pig numbers varied widely, with a mean of 3.8 pigs per household, and indigenous breeds were preferred. Sows produced an average of 7.5 pigs/litter and an average of 4.4 piglets were weaned successfully. Feed is dependent on food gardens, as accessibility to markets and external inputs is limited in most surveyed localities. Cash income and social obligations continue to be the driving force for pig keeping in Morobe Province. Development of technology packages for smallholder pig keeping should be targeted at improving farming knowledge in confined husbandry practices.

INTRODUCTION

Pigs (*Sus scrofa*) hold high cultural significance across Melanesia (Huffman 2007), including within the 700 different ethnic groups in Papua New Guinea (PNG). According to Quartermain and Kohun (2002), there is an estimated population of over 1.8 million pigs in the traditional pig sector in PNG, where pigs roam freely to scavenge during the day and are confined at night and fed kitchen waste. However, production information is mostly unknown as farmers rely primarily on local resources to sustain production.

PNG's indigenous pig (*Sus scrofa papuensis*) was first domesticated 6,000 years ago (Quartermain 2002) under extensive farming systems. The introduction of exotic high-performing breeds happened gradually after the arrival of early settlers until it became an explicit government policy in the 1900s to 1920s to improve production traits of indigenous pigs (Black 1957; Sack et al. 1979; Hahl 1980 cited in Hide 2003, p.17). Early research work at the former Tropical Pig Breeding and Research Centre (TPBRC) was directed at developing village husbandry systems suitable for both indigenous and introduced pigs (Anderson 1972; Densely with Purdy et al., no date, cited in Hide 2003, p.17). Relics of these research efforts are seen in current village pig production systems in terms of mixed pedigree pigs, housing designs and feed compositions.

Current research efforts by the PNG National Agricultural Research Institute (NARI) have been directed at improving monogastric nutrition using locally available feed resources, such as sweetpotato (*Ipomoea batatas*) and cassava (*Manihot esculenta*). Two technologies, namely sweetpotato silage for feeding pigs and high/low-energy broiler concentrates, were developed and shown to be viable for smallholder pig and chicken farming (Dom and Ayalew 2009; Ayalew 2013).

It is uncertain whether real economic gains are derived from smallholder pig keeping in addition to the livestock's primary cultural role. Cultural

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functions drive informal live pig markets. There is very little involvement of smallholder traditional pig farming in the formal market, which is driven by a number of commercial farms that have over 20,000 sow units (Quartermain and Kohun 2002). Purdy (1971) suggested intensifying village pig production to increase its viability; however access to external farm inputs is limited in most localities in PNG. Ochetim (1993) reported social traditions as a constraint to pig production in the Pacific region. This was in addition to other prevalent issues of low sow productivity, inadequate feed, poor housing, inbreeding, pest and disease issues, poor marketing and the lack of capital and technical skills.

This study was undertaken to collect baseline information on husbandry practices, genetic attributes of pigs and animal health issues, as well as resource and product utilisation by traditional smallholder pig farmers in Morobe Province of PNG.

THE SURVEY

Location

Morobe Province is located on the northern coast of PNG (Figure 1a and b) with Lae as its provincial capital. The province covers over 33,000 km^2 and has a population of 674,810 according to the 2011 census. The province is geographically diverse, with altitude ranging from sea level to over 4,000 m in the Sarawaget ranges. Average annual rainfall varies from 1,600 to 4,000 mm with long dry seasons in most parts of the province. Detailed information on PNG including Morobe Province can be found in the PNG Rural Development Handbook by Hanson et al. (2001).

Site selection

The surveyed areas were selected based on their accessibility by road, sea or air from Lae, the provincial capital. The districts surveyed were Markham, Nawae, Wau-Bulolo, Huon Gulf, Kabwum, Finschaffen and Tewae-Siasi. Finschaffen and some parts of Nawae were accessed primarily by boat, Kabwum and parts of Wau-Bulolo were accessed by air, and the other sites were reached by road. Menyamya and Lae were not surveyed due to poor road condition and urban status, respectively. A total of 348 pig farmers were interviewed with focus group discussions conducted at 26 different sites.

Survey preparations

Survey questionnaires and lead questions for focus group discussions were formulated based on survey objectives. The structured questionnaire was mostly closed-ended for ease of interview; focus group discussions as well as informal discussions were used to verify results. Local contacts in villages and Department of Primary Industries (DPI) extension officers were consulted before approaching the survey localities. Four enumerators from NARI, who were briefed on the questionnaire and focus group discussion questions prior to conducting the survey, administered the questionnaires.

Sampling methods and data collection

Village communities were assembled and briefed on the survey objectives before the focus group discussions were conducted. Following the focus group discussions, respondents were voluntarily interviewed using the individual questionnaires. All interviews at selected localities were conducted during daytime in one session. Heads of households were interviewed, in most cases with family members also present. A minimum of 23 interviews were conducted for each locality.

Data analysis

The completed questionnaires were collated using the Epi Info statistical software (Carstensen et al. 2015) to derive summary tables. Statistical Package for Social Science (SPSS) 17.0 (SPSS Inc. 2008) was used to derive frequencies, percentages, means and standard deviations (SD) and Pearson's correlation. Tables and figures were developed using Microsoft Excel.

RESULTS

General demography

Of the 348 pig farmers interviewed, 71% were male and 29% were female. Almost 90% were married and in the age range 20–45 years. Almost half of the respondents had received primary education while 30% had no formal education. The average (± standard deviation) household size was 5.7 ± 2.5 persons.

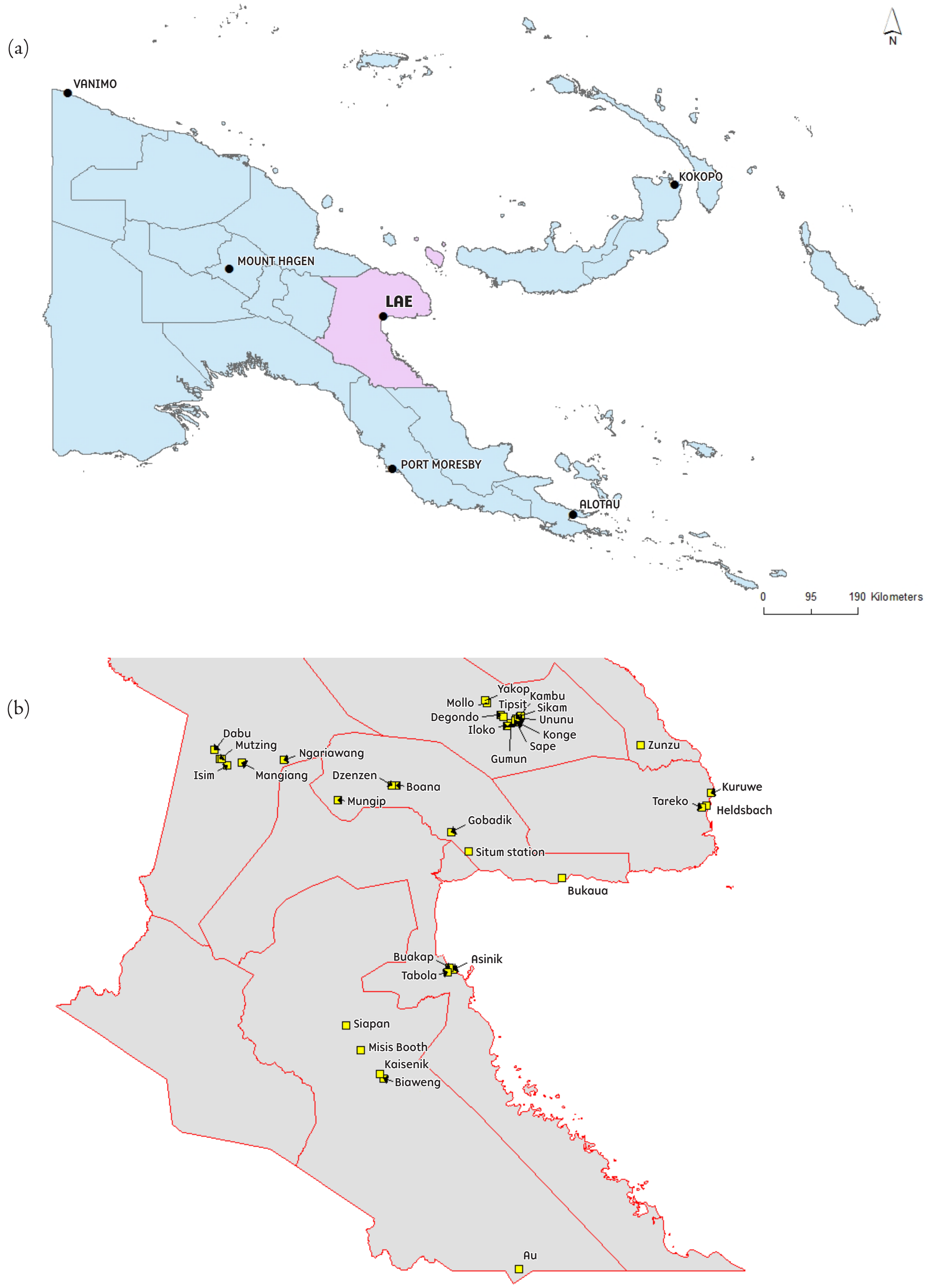


Figure 1. (a) Map of PNG showing the location of Morobe Province in purple with Lae its capital. (b) Location of surveyed villages. Source: NARI GIS.

General keeping

Daily husbandry practices of feeding and cleaning are dominated by women, as reported by 78% of the respondents. Pig herd sizes are independent of the size of the respondent's household, using both bivariate and distances in Pearson's correlation.

Livestock kept

In addition to pigs, other livestock species were also kept by the respondents (Table 1). About 36% of respondents kept chickens, mostly broiler meat birds. Fish farming is gaining popularity with 10% of farmers having fish ponds. Most of these farmers were integrating pigs and fish, especially in the Kabwum district.

Herd characteristics

Most respondents sourced their breeding stock from within their locality (91%), either from their own herd or other herds via cash purchases or cultural exchanges. The majority of pigs kept were of either indigenous origin (39%) or a mixture of indigenous and exotic crosses (21%). Very few respondents obtained their pigs from commercial piggeries, outside their localities or from the wild.

Castrates were highly preferred, comprising 22% of the total pigs. Sows and gilts collectively constituted 38% of the sample herds (Table 2). Boar numbers were generally low, with a boar to sow ratio of 1:27.

Almost 60% of the respondents were able to recall details of sow parity over the past 12 months (Table 3). With sows kept confined, 68% of respondents had experience with their sows giving birth, of which 86 respondents assisted their sows during delivery while 115 respondents left their sows unaided. The remainder (34 respondents) provided birthing assistance occasionally. Weaning is mostly after three months (31%) or after two months (15%).

Housing

Over 60% of respondents provide shelter for their pigs using local timber and grasses and/or discarded metal sheets and rails. The provision of housing or shelter depends on locally available building resources, and respondents' pig housing designs varied, with no specialised rooms/pens for different pig classes. The traditional husbandry practice of extensive pig keeping is still being practised by 30% of respondents, while 45% prefer keeping their pigs confined. The remainder use a combination of traditional and confined husbandry systems as well as occasional tethering ('combined'; Figure 2). The practice of keeping communal herds continues to be practised in the Tewae-Siassi District ('other'; Figure 2). Two

Table 1. Livestock kept by the interviewed pig farmers.

Livestock	No. of respondents	Total no. of animals	Mean no. kept by farmers (± SEM)
Pigs	343[a]	1,232	3.6 ± 0.173
Chickens	120	1,082	9.02 ± 1.305
Fish ponds	32	82	2.56 ± 0.345
Others pigs[b]	16	55	3.4 ± 1.076
Sheep	6	50	8.3 ± 4.876
Cattle	3	42	14 ± 2.0
Ducks	7	22	3.14 ± 1.28
Goats	2	15	7.5 ± 2.5
Others chickens[c]	3	15	5 ± 3.512
Rabbits	3	3	1

[a] Two semi-commercial pig farmers from Situm were excluded due to large herd sizes, while three farmers interviewed were no longer keeping pigs.

[b] Other pigs refer to livestock that were cared for by the respondent but not owned by them.

[c] Other chickens refer to livestock that were cared for by the respondent but not owned by them.

Table 2. Types of pigs kept by interviewed farmers.

Type of pig	No. of respondents	Total no. of animals	Mean no. per household ± SD
Sows	172	243	1.4 ± 0.8
Castrates	156	281	1.8 ± 1.3
Gilts	147	240	1.6 ± 1
Female piglets	115	239	2.1 ± 1.4
Male piglets	109	227	2.1 ± 1.4
Young boars	22	26	1.2 ± 0.5
Old boars	8	9	1.1 ± 0.4
Total	329	1,265[a]	3.8 ± 3.1

[a] Inclusive of 'other pigs'.

Table 3. Sow performance reported by interviewed farmers (n = 204).

Parameter	No. of respondents	Total no. of animals	Mean no. ± SD
Sow 1 parity	202	251	1.2 ± 0.5
Sow 2 parity	35	43	1.2 ± 0.5
Sow 3 parity	5	6	1.2 ± 0.4
Sow herd parity	204	300	1.5 ± 0.8
Sow 1 litter size	203	1,123	5.5 ± 2.3
Sow 2 litter size	57	352	6.2 ± 2.0
Sow 3 litter size	12	54	4.5 ± 3.4
Sow herd litter size	203	1,529	7.5 ± 4.3
Sow 1 litter mortality	53	138	2.6 ± 2.5
Sow 2 litter mortality	12	27	2.3 ± 1.2
Sow 3 litter mortality	4	12	3.0 ± 2.4
Sow herd litter mortality	57	177	3.1 ± 3.4

respondents have reached intensive levels of pig production with more than 20 sows under improved housing and feeding systems using off-farm resources.

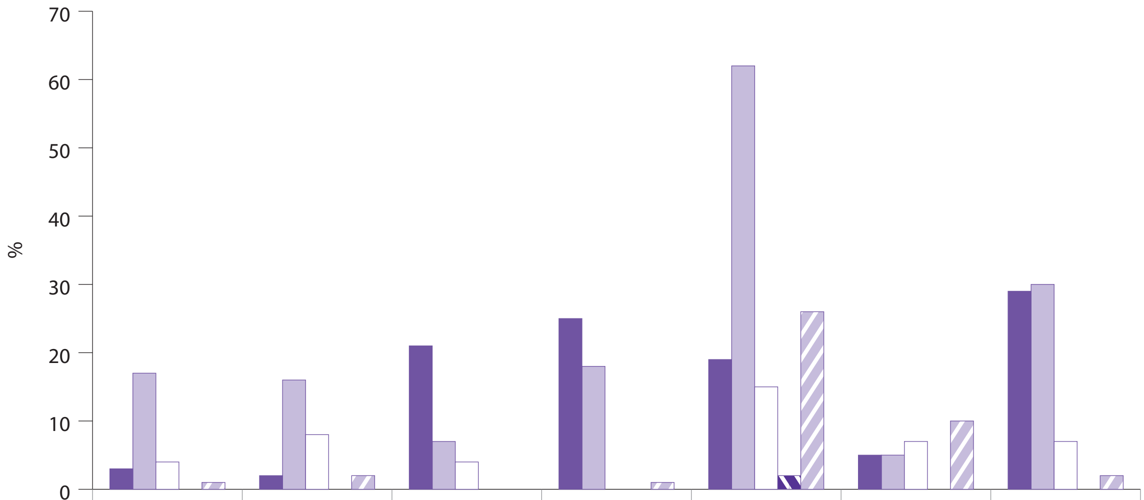
Feeding

Sweetpotato (*Ipomoea batatas*) is the main feed source for feeding pigs (37% of respondents), followed by taro (*Colocasia esculenta*) (32%) and cassava (*Manihot esculenta*) (14%). Banana (*Musa* spp., local name *Kalapua*) is the most popular feed resource in the Markham district. Kitchen leftovers (27%) are also a popular feed source. Scavenging and controlled scavenging using tethering account for 15% and 11%, respectively. Only 8% of respondents had access to off-farm feed sources from agro-industrial by-products and commercial feed mills. Respondents provide water by wet feeding (i.e. providing sweetpotato or other tuber crops cooked in broth; 47% of respondents) or by providing fresh water (47%), but fresh water is not readily available at all times.

Health

Although there are no major exotic swine diseases prevalent in the country, respondents were generally concerned with the health of their pigs. Diseases were not able to be fully diagnosed, however 35% of respondents described symptoms of health issues experienced (Figure 3).

About 68% of respondents reported treating their animals using indigenous or homemade remedies. Others (19%) used conventional medicines, while the remainder did not take any remedial action. About



	Finschaffen	Huon Gulf	Kabwum	Markham	Nawae	Tewai-Siassi	Wau-Bulolo
Freerange	3	2	21	25	19	5	29
Confined	17	16	7	18	62	5	30
Combined	4	8	4	0	15	7	7
Intensive	0	0	0	0	2	0	0
Other	1	2	0	1	26	10	2

Figure 2. Pig husbandry practices of respondents by district (n = 348).

88% of respondents reported success in treatments applied. Overall, there was no historical reporting of disease outbreaks throughout the areas surveyed. Over 50% of the respondents reported their animals suffering injuries caused by external factors, such as humans and dogs.

Marketing and products

As well as informal live pig sales, more than 85% of respondents consumed or sold pork meat, either fresh or cooked, within their localities. Pork was processed within the villages, and 23% of the respondents reported using the shank bone for making peelers, a practice that is widespread in the Markham district. The animals' organs were mostly consumed (95%), while 10% of respondents reported crushing bones to obtain calcium for pig feeding. Respondents also reported other reasons for pig keeping (Figure 4).

Reported constraints

Respondents reported multiple constraints within their husbandry practices (Figure 5).

Highlights of focus group discussions

Farmers in over half of the localities (55%) said pigs were important in their area. The others expressed dissatisfaction with raising pigs, having experienced problems relating to pigs damaging gardens, resulting in social and other health issues. Respondents expressing these sentiments had most of their pigs kept under traditional husbandry practices. Almost all communities expressed a desire to keep pigs enclosed, either through community awareness or by enacting village laws.

DISCUSSION

The role of pigs

The diverse geography, cultural complexities and remoteness of some locations in Morobe Province are representative of other provinces in PNG. With 80% of respondents having limited formal education, and the lack of income-earning opportunities and social security, pig keeping is crucial to livelihoods. Pigs can be sold or used in cultural functions, in lieu of cash,

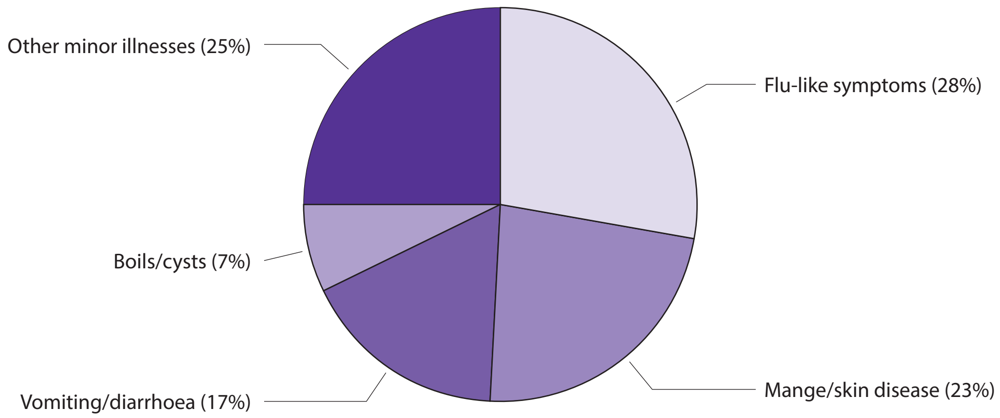


Figure 3. Summary of reported symptoms of unknown pig diseases (n = 123).

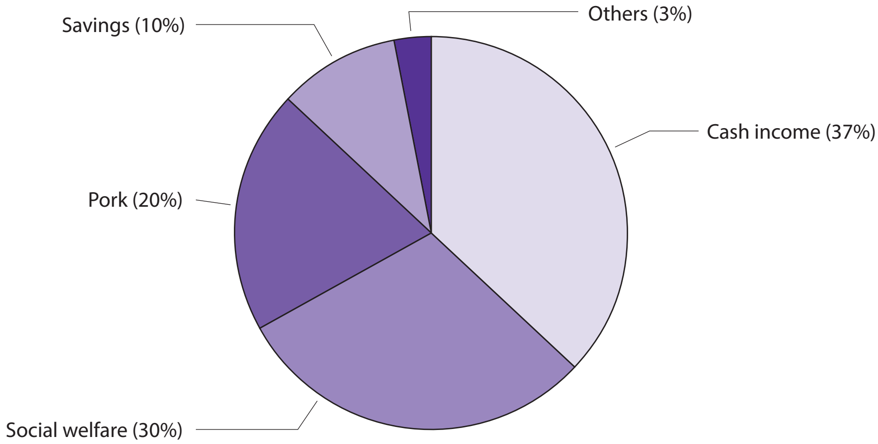


Figure 4. Reported reasons for keeping pigs (n = 1,044).

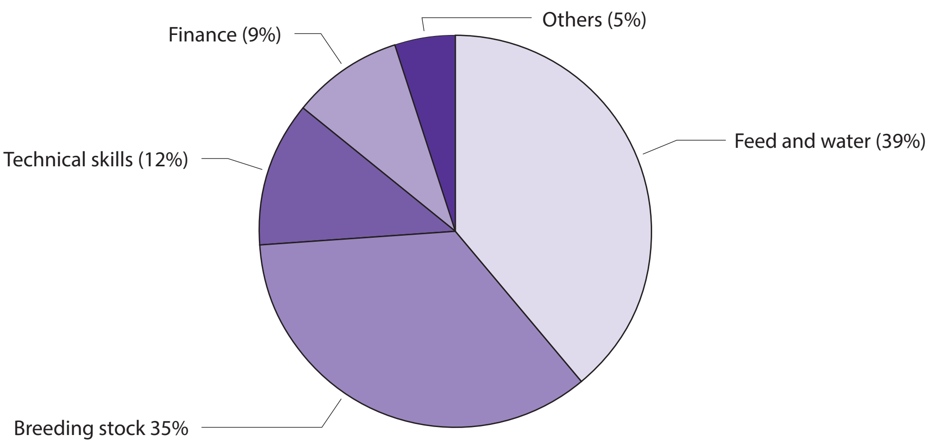


Figure 5. Constraints in pig keeping reported by respondents (n = 1,044).

to maintain social status and wellbeing within family and community. Pork meat is also a popular reason for pig keeping (Figure 4), although past studies showed very little pork in the diets of highlands communities (Purdy 1971). In a survey covering several locations in PNG, including parts of Morobe, Ayalew et al. (2011) reported pork being a main reason for male respondents keeping pigs. Pork consumption is closely associated with ceremonies (Quartermain 2002), especially in rural areas where meat is rarely stored for extended periods.

General husbandry

Husbandry trends are inclining towards keeping pigs confined. This can be attributed to high human population growth rates and land pressures. Bourke et al. (2009), in updating pig-holding characteristics (Quartermain and Kohun 2002), concurred that the practice of confining pigs in pens is growing rapidly among smallholder. Confining pigs subsequently increases the need for farm inputs, especially for feeding. Improving farmer knowledge in keeping confined pigs should be targeted with the development of appropriate technology packages.

Integration of different livestock species has the potential to increase efficiency in smallholder farming systems. Fish and chicken can easily combine with pig keeping to minimise nutrient losses in small-scale farming systems. Pigs provide a long-term investment, while fish and chickens help to sustain daily household food security and nutrition (Amben et al. 2013).

Most health issues highlighted are a result of basic animal husbandry deficiencies. Pigs can succumb to minor pests and diseases, especially parasites, and symptoms reported by respondents are typical of high parasite infestations (Figure 3). Quartermain and Kohun (2002) highlighted the adverse effects of internal and external parasites on pig productivity in traditional smallholder systems. The intensity of parasites within smallholder pig herds in PNG needs to be investigated to determine economic losses. Farmers need to be aware of improved nutrition and hygiene practices when pigs are confined in order to minimise parasites (Lee 2012).

Sow performances, in terms of litter output, are poor (Table 3) and this is attributed to low management inputs. However, current sow litter sizes and survival rates may work to the advantage of respondents with low input production levels. In trials conducted in selected Pacific Island countries, Ochetim (1993) reported higher performances with improved feeding and management of lactating and farrowing sows, as well as reduced mortality rates and improved sow condition, using locally available feed ingredients and slightly improved farrowing practices.

Women are responsible for the daily chores involved in keeping this demanding livestock. Labour constraints can limit inputs and reduce livestock productivity, as respondents' herd sizes were independent of their household sizes.

Feeding

Respondents rely primarily on their food gardens for pig feed. Despite an array of garden food crops, sweetpotato is the most important feed source. This crop has the advantages of wider propagation, short growing season and high yield, making it available year round unlike other root crops. The wide practice of sweetpotato–pig feeding systems in the highlands regions is being adopted in the lowlands, as well as the practice of tethering pigs. The NARI-released technology, adapted from Vietnam, where sweetpotato is preserved (ensiled) for pig feed, is highly relevant for PNG smallholder farmers. Ensiling increases the feed value of sweetpotato, and it can be used to replace 50% of a standard commercial pig grower (Dom and Ayalew 2009).

Low protein inclusion in the feed sources for respondents' pigs may have contributed to poor growth performance. With limited access to improved feed and agro-industrial wastes, sources of protein from locally available ingredients need to be investigated. The increasing popularity of fish farming will increase the availability of protein at household level for both humans and livestock. The ACIAR mini-mill project ASEM 2010/053, 'Enhancing the role of small-scale feed milling in the development of the monogastric industries in Papua New Guinea', is looking at factors affecting the development of mini-mills and formulating diets using local feed resources.

Fresh water is not freely available to pigs and many farmers use wet feeding for water provision. However, the low nutritional status of diets offered through wet feeding cannot meet the pigs' high nutritional needs.

Genotypes

Respondents (91%) have more confidence with indigenous pigs that are well adapted to their husbandry conditions. Ayalew et al. (2011) reported 20% of respondents sourced their pigs within their village and 44% within their districts. Genetic differentiation of indigenous pig populations is yet to be explored, and even in isolated villages up to one-third of pigs maintained by subsistence farmers are considered to be admixtures of indigenous and introduced genotypes (Ayalew et. al. 2011). Indigenous–exotic crosses are preferred by intensive farmers as they capitalise on economic traits of both lines, i.e. fast growth rates and the ability to digest high-fibre diets.

Young male pigs are usually castrated after first breeding. This is for breeding control but it also removes them from the breeding pool in the population. Farmers prefer to keep docile castrates than boars, and they are favoured over female pigs for disposal through sales, consumption or ceremonial functions.

Marketing

Ochetim (1989) reported that the main market for pigs in the Pacific region, including PNG, was the traditional market where pigs are consumed, exchanged or given away. More recently, pigs with live weights exceeding 60 kg were reportedly valued at more than A$1,000 in the highlands regions during festive periods (Amben et al. 2013). Purdy's (1971) concern about bringing pigs into the cash economy seems to have been achieved without losing the social value attached to this livestock. However, the informal live pig market needs to be properly assessed to determine real gains by pig farmers. Commercial markets for fresh meat are restricted to areas with abattoir facilities and are dominated by commercial piggeries. Lack of accessibility to markets and farm inputs limits the opportunities for smallholder traditional pig farmers to venture into formal meat markets. Two respondents in the current survey had benefited from formal market opportunities, in terms of improved productivity and profitability, despite some constraints due to feed costs. Ayalew (2013) estimated that if 25% of traditional pig farmers progressed into market-oriented pig keeping, the combined contribution of commercial and smallholder piggeries to national pork production would increase to 16% from 4%.

CONCLUSIONS

Pigs remain vital to rural households in PNG; however the transition to keeping pigs confined is posing challenges to smallholder pig farmers. Issues that need addressing include improving feeding and general welfare of the animal. More research and development effort needs to be directed at integrated farming systems for pigs, chickens, fish and crops as these hold great potential for addressing feeding constraints. The ACIAR mini-mills project (ASEM 2010/053) is already looking at some of these feeding challenges. However, the greater challenge is to enable pig farming to be more complementary to smallholder farming systems, and to reduce the burden of ceremonial functions intricately linked with this livestock (Amben et al. 2013). Economic modelling for different pig husbandry systems and linkages to formal and informal markets is needed to investigate the real gains for pig holders.

ACKNOWLEDGMENT

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Effect of blending sweetpotato silage with high-energy and low-energy poultry concentrate feed on performance of local crossbred growing pigs in Papua New Guinea

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Abstract

High-energy (HE) and low-energy (LE) village broiler concentrate feeds offer a convenient protein source for growing pigs. This feed trial compared diet treatments of 28% HE and 30% LE broiler concentrates blended with sweetpotato silage as the major energy source (HESPS and LESPS respectively) with a 100% ration of pig grower standard diet, in terms of body weight gain and feed conversion efficiency. The trial had a completely randomised design with six entire male pigs of the same farrowing offered the three treatment diets (two pigs per diet) ad libitum over 10 weeks. Dry matter intake and average daily gain was similar ($P > 0.05$) between the treatment diets but their feed conversion ratios were statistically significantly different ($P < 0.05$). LESPS had a superior FCR of 3.99 to that of HESPS, which was 4.28. There was also indication of better carcass quality of pigs fed the LESPS. As a next step, digestibility testing of rations balanced for protein and amino acids is recommended.

INTRODUCTION

High-energy (HE) and low-energy (LE) broiler concentrates have been developed in a poultry feed research project in Papua New Guinea (PNG) implemented by the National Agricultural Research Institute (NARI) with a research grant from the Australian Centre for International Agricultural Research (ACIAR). The village broiler concentrates developed by the project have a nutrient composition that is suitable for growing pigs. The concentrates can be produced in bulk and are more economical than other available feed ingredients, such as fishmeal or copra meal, or the standard commercial pellet feed.

In general, a lack of protein in the diet limits the growth of local pigs in PNG. To feed their pigs, village pig farmers use any available concentrate feeds (e.g. commercial poultry diets) and blend them with garden vegetables and fruits. Sweetpotato is a major feed resource for the pig farmers. The roots are high in starch (70%) and dietary fibre (10%) but low in protein (5% crude protein; CP). The leaves have 28% CP and the vines 13% CP. The sweetpotato roots, vine and leaves can be conserved using an ensiling technique adapted for small-scale pig farming.

Given the wide availability and use of sweetpotato by pig and poultry keepers throughout PNG, and the tested and proven HE and LE broiler concentrates, it was decided that the two feed resources should be used in pig-feeding trials that may have immediate on-farm application. Previous trials established the performance of crossbred pigs raised on mixed sweetpotato silage (SPS) and a commercial wheat-based feed (Dom and

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Ayalew 2010; Dom et al. 2011). Other trials have compared SPS mixed with copra meal and fishmeal concentrates (Dom et al. 2010). In this experiment, we compared the two blended broiler concentrates against the standard commercial pig grower in terms of growth and feed conversion efficiency of crossbred pigs.

MATERIALS AND METHODS

Location, pens and pigs

The trial was conducted at the NARI Labu Livestock Research Station, Lae, Morobe Province, located about 16 km from Lae town on the Wau–Bulolo road (6°40′27″ S, 146°54′33″ E). The altitude is about 150 m above sea level and the climate is typically warm and wet with an average temperature of 32°C and relative humidity of 85–90%. The pig trial shed consisted of a partially open-walled concrete block with a high, corrugated iron roof and containing 16 back-to-back pens (4 m × 5 m) running north–south. Each pen was fitted with steel nipple drinkers at the central end wall, and had a slanted floor allowing excess water to drain out. Feed was placed inside large concrete troughs. Six crossbred weaned pigs were selected from Labu Station piggery on 4 April 2011 at 16.3 ± 3.0 kg body weight and they were maintained in a single pen on standard pig grower until 4 May 2011, by which time they weighed 20.0 ± 3.6 kg. Five of the weaners were from the same sow while the sixth piglet was farrowed at the same time by a closely related sow.

Treatments and experiment design

The nutritional composition of the ingredients and the test diets for the three treatments are shown in Table 1. Sweetpotato roots and vine silage (SPS), made at 1:1 fresh weight ratio with 0.5% salt added, was the major starch energy source and was blended with either a low-energy (LE) or high-energy (HE) broiler concentrate. The LE concentrate was based on meat meal, soybean meal and wheat millrun, while the HE concentrate contained sorghum, blood meal, tallow and copra meal but no millrun. The test diets were blended to similar crude protein (CP) and metabolisable energy (ME) content as the standard commercial pig grower pellet feed produced by Associated Mills, Lae. The trial had a completely randomised design, with six entire male crossbred pigs at eight weeks of age kept in individual pens and maintained on the three treatment diets (two pigs on each diet), fed ad libitum over 10 weeks. Variables measured were feed offered, refusal and weekly body weight. Feed intake, weight gain and feed conversion ratios were calculated. Data for all parameters were aggregated by week and analysed by one-way ANOVA, separating means by least significant difference (LSD) using GenStat v.7.22DE (Lawes Agricultural Trust 2005).

RESULTS AND DISCUSSION

The DM contents of the two test diets were less than 50% of the standard commercial pig grower and there were small differences in CP, lysine, ME content and the Lys:ME ratio (Table 1).

Table 1. Nutritional composition of the treatment diets and their ingredients.

Feed component/diet	DM (%)	CP (%)	Lysine (%)	ME (MJ/kg)	Lys:ME
HE poultry concentrate	90.0	41.7	3.18	12.0	2.65
LE poultry concentrate	90.0	39.9	3.23	9.8	2.14
Sweetpotato silage	33.2	2.0	–	16.2	–
Treatment diets (DM basis)					
PGSTD (100%)	91.8	16.0	0.89	14.0	0.63
HESPS (HE 28%, SPS 72%)	40.3	17.3	0.90	15.0	0.60
LESPS (LE 30%, SPS 70%)	41.0	17.5	0.96	14.3	0.67

HE = high energy; LE = low energy; PGSTD = pig grower standard diet; HESPS = high-energy broiler concentrate blended with sweetpotato silage; LESPS = low-energy broiler concentrate blended with sweetpotato silage; DM = dry matter; CP = crude protein; ME = metabolisable energy; Lys = lysine; Lys:ME = lysine to metabolisable energy ratio.

Feed intake, growth and carcass measurements are provided in Table 2. DM intake and average daily gain (ADG) were statistically similar for all diets ($P > 0.05$). Feed conversion ratio (FCR) was significantly influenced by diet ($P < 0.05$). Despite their much lower DM content, the HESPS and LESPS diets matched the commercial pig grower diet by providing in excess of 340 g CP/day, which is close to the nutritional requirement of growing pigs in this class (NRC 1998). A slightly better Lys:ME ratio benefited feed efficiency but not growth rate for the LESPS diet. Dressing percentages were high, with a distinctly leaner carcass from the LESPS diet, but these data were from a single pig per group. Despite the small sample size, the results are similar to other small-scale feeding trials conducted on crossbred pigs at the same research station.

Sweetpotato silage blended with 50% commercial pig grower gave a lower ADG of 540 g/day but a better FCR of 2.70 (Dom and Ayalew 2010). Sweetpotato silage blended with 75% pig grower gave an ADG of 634.1 g/day and an FCR of 2.84 (Dom et al. 2011). Pig grower alone provided an ADG of 730 g/day and an FCR of 2.33 (Dom and Ayalew 2010), while another related study also showed an ADG of 743.4 g/day and an FCR of 2.51 (Dom et al. 2011). Dilutions of the pig grower protein content appear to affect growth rate but not FCR. The higher energy feed was not an advantage to feed conversion but did boost growth rates. However, the carcass weight, dressing percentage and back-fat depth indicate that the improved body weight gain may have been more from fat than lean meat.

In this work, sweetpotato silage blended with HE and LE broiler concentrates and the commercial pig grower feed all catered to the grower pig nutrient requirements, resulting in good overall performance. By contrast, an ADG of 442 g/day and an FCR of 3.80 were found when station crossbred pigs were fed sweetpotato silage blended with fish meal (52% CP) and copra meal (21% CP) (Dom et al. 2011). Crossbred village pigs fed sweetpotato silage blended with copra meal and fish meal also had much reduced performance (ADG 371.4 ± 142.9 g/day and FCR 2.99), as well as on the standard pig grower (ADG 585.7 ± 144.5 g/day and FCR 3.16) (Dom et al. 2010). The performance on HE/LE broiler concentrate compared to either station or village crossbred pigs was greatly improved. By comparing the performance response to pig grower feed, the influence of genotype, growing environment and health status (as interrelated factors) provided 19% and 8.5% reduction

Table 2. Feed intake and growth performance of experimental pigs, and carcass measurements for three selected pigs.

Parameter	Grand mean	Treatment diet			SEM	LSD (5%)	Sig.
		PGSTD	HESPS	LESPS			
DM intake (g/day)	2397	2133	2545	2513	239.2	679.1	0.406
Average daily gain (g/day)	657.0	722.2	615.2	634.9	36.2	102.8	0.094
Feed conversion ratio	3.72	2.89[a]	4.28[b]	3.99[a]	0.387	1.100	0.035
Finish weight (kg)	–	52.5	56.0	60.0	–	–	–
Carcass weight (kg)	–	40.5	41.5	49.0	–	–	–
Processing loss (kg)	–	12.0	14.5	11.0	–	–	–
Frozen weight (kg)	–	41.0	43.0	50.0	–	–	–
Dressing (%)	–	78.1	76.8	83.3	–	–	–
Back-fat thickness (mm):							
Fore leg	–	22	24	10	–	–	–
Mid rib	–	14	19	9	–	–	–
Hind leg	–	17	15	10	–	–	–

Means with different superscript within a row are significantly different at $P < 0.05$.
PGSTD = Pig grower standard diet; HESPS = high-energy sweetpotato silage; LESPS = low-energy sweetpotato silage.

in ADG and FCR, respectively, for pig grower-fed village crossbred pigs compared to results for station crossbred pigs. Lower performance for the village pigs on pig grower, reported by Dom et al. (2010), suggest that it was not as appropriate for their requirements, particularly for energy. Since the growth rates in this trial were not significantly different ($P < 0.05$), the higher ME levels in the HE and LE concentrates may provide an additional energy boost for village pigs, where these are maintained semi-extensively on forage feeds high in dietary fibre.

CONCLUSIONS

The conveniently available LE and HE broiler concentrates provided sufficient nutrition for good growth but with less efficiency than the commercial pig grower feed when provided to young crossbred pigs. Carcass measurements gave numerically superior results for the test diets compared to the control (commercial pig grower). Further digestibility testing is needed to establish the nutritional balance required by growing crossbred pigs on sweetpotato silage-based diets as a major source of energy, with suitable digestible energy protein and amino acid balance.

ACKNOWLEDGMENT

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4

Local feed resources for egg production

Egg production performance of Australorp × Hyline Brown spent layers fed a local diet compared with a commercial diet on smallholder farms in Papua New Guinea

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Abstract

Smallholder village poultry farmers in Papua New Guinea (PNG) often purchase spent commercial layers to use for egg production on their farms. The spent layers are cheap and are used for an extended period before being culled, however their productive performance is not known. Given the high cost of commercial layer feed, a trial was conducted to determine the production performance of spent layers (77–85 weeks of age) fed a diet based on local ingredients, compared with a commercial layer diet. The trial was conducted at Boana, a wet mountainous area of PNG. Four farmers participated in this trial, with two pens each, each pen housing five birds at 77 ± 0.30 weeks of age. The local diet comprised cassava flour, maize, fishmeal, limestone, copra meal, sweetpotato, cassava leaves (fresh), kikuyu leaves (fresh), peanut meal, banana meal, cooking oil, low-energy layer concentrate, table salt and methionine. The local diet and a commercial diet were fed to the birds from 77 to 85 weeks. Daily egg production, egg weight, weekly feed intake and body weight were measured. The results showed that egg production percentage was significantly lower for birds fed the local diet compared to the commercial diet (56% vs 76%; $P < 0.05$). However, feed consumption, egg weight, body weight and feed conversion were not significantly affected by the dietary treatments. Moreover, the feed cost per unit of egg weight produced was significantly lower for the local compared to the commercial diet (1.57 kina vs 6.70 kina; $P < 0.05$). It was concluded that spent layers can be fed on a local diet for a second period of egg production.

INTRODUCTION

The main challenge to smallholder layer production in Papua New Guinea (PNG) is the high cost of commercial feed, which accounts for 70% of the cost of poultry production (Black and Yalu 2010). Retail prices of commercial livestock feeds in the market in Lae increased by 110% from 2003 to 2011 (Ayalew 2011). In addition, there have been continuing increases in freight charges, products and services in PNG. Several studies have been undertaken on ways to reduce the cost of feeding poultry, which has led to the development and promotion of poultry concentrates (Glatz et al. 2010; Pandi et al. 2017; Besari et al. 2017a, b; Ahizo et al. 2017). The poultry concentrates have been shown to reduce feed costs and still maintain acceptable production performance in both broiler and layer birds.

Another problem for farmers in smallholder layer production is the cost of purchasing commercial layer hybrids, either as day-old chickens or as starter pullets, from breeder organisations. In addition, a significant capital investment is required to establish the infrastructure to house the birds. A further challenge is to ensure the health of the birds is maintained and appropriate management is used, given most farmers have a lack of technical knowledge.

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According to North and Bell (1990), in commercial farms, after a year of egg production layers are culled and processed to produce meat products, but their full genetic potential could be exploited by moulting the birds and allowing them to have a second production cycle.

Smallholder farms near commercial layer facilities in PNG usually obtain spent layers to use for meat or to produce eggs. The spent layers have the advantage of being cheap to purchase (15 kina/bird) and can be used for a second production cycle or allowed to continue their first production cycle. However, the production performance of the spent layers after they have been sold by commercial farms is not known. In particular, given the high cost of commercial layer feed, information is needed on the performance of spent hens fed diets based on local ingredients rather than a commercial feed.

A trial was conducted to determine the production performance and profitability of spent layers (77–85 weeks of age) fed a diet based on local ingredients compared with a commercial layer diet. The findings will be used to determine if smallholder layer farms using spent hens could contribute to the nutrition and food security of rural communities engaged in subsistence agriculture.

MATERIALS AND METHODS

Location and housing

The experiment was conducted at Boana, a remote location (6°42′98″ S, 146°80′58″ E) in the Wain/Erap government area of Nawaeb District in Morobe Province, PNG. The area is only accessible by road through steep mountainous terrain, and it is impossible to use the road during the rainy season. The trial started on 13 August 2013. The average air temperature during the trial was 21.4°C and relative humidity was 80%. Four farms participated in the trial. At each, long sheds were built using bush timber and iron roofs. The walls were made from bamboo with chicken wire 1 m above the ground to provide ventilation. Each shed had two pens (approximately 6 ± 0.24 m^2) that were partitioned so that five birds could be securely housed in each pen. One pen was assigned for the local diet treatment, and the other for the commercial diet. Each pen had a round plastic drinker 28 cm in diameter which provided 17.6 cm linear drinking space per bird, and a round plastic feeder 30 cm in diameter providing 18.8 cm linear feeding space per bird. Five nest boxes, each with dimension 20 × 20 × 20 cm, were placed in each pen. Woodchip was used as deep litter to a depth of 3–4 cm on the floor.

Experimental birds

The spent layer birds were sourced from the National Agricultural Research Institute (NARI) Livestock Research Station in Lae. They were crosses between a male Australorp maintained over the years at the research station and female Hyline Brown birds acquired from the Christian Leaders Training College (CLTC) farm in Banz, Jiwaka Province. The progeny from this cross (F1) were raised as egg layer birds during the first egg production cycle until they were 77 ± 0.30 weeks of age. The average initial body weight was 1.92 kg for the local diet group and 1.90 kg for the commercial diet group.

Experimental protocols

Each farmer was given a standard spring scale weighing up to 50 kg, a kitchen scale weighing up to 5,000 g, 80 kg of test diet, 80 kg of standard diet, a note pad, a pencil and data sheets (body weight sheets, egg production sheets, feed and mortality sheets). These were stored in the shed for taking and recording daily measurements.

The experimental protocols were demonstrated to farmers so that they could follow the procedure. Every morning the farmers fed 2 kg of the local diet or 2 kg of commercial diet to the five hens in each pen, and this was topped up in the afternoon on an ad libitum basis. The remaining feed in the feeder and refusals were weighed and recorded at the end of each week. Clean water was provided to the hens twice daily. Eggs were collected, counted and weighed at the end of each day. Body weights were recorded at the end of each week. No mortality occurred during the eight weeks of the trial.

Experimental diets

The local diet contained the following (per 100 kg):

40 kg cassava flour
16 kg maize
13.75 kg fishmeal
7.55 kg limestone
6 kg copra meal
4.7 kg sweetpotato
4 kg cassava leaves (fresh)
2.3 kg kikuyu leaves (fresh)
2.13 kg peanut meal
2 kg banana meal
0.90 kg cooking oil
0.28 kg low-energy layer concentrate
0.20 kg table salt
0.06 kg methionine

To prepare the local diet, the fresh peeled cassava tubers, fresh unpeeled sweetpotato tubers, and fresh peeled banana flesh were grated into fine chips and these were dried in the sun for approximately 24 hours until 70–75% of the moisture was eliminated. The dried cassava, sweetpotato and banana were ground into a fine powder using a flake hammer mill at 600 kg/h. The dried corn and peanuts were also ground into a fine powder. The fishmeal and copra were acquired already in powdered form from International Food Corporation and Markham Farm respectively, as industrial by-products. The fresh young kikuyu grass and cassava leaves were prepared and cut into fine pieces ready for inclusion in the formulation.

The low-energy layer concentrate developed by Besari et al. (2017a) was used to balance the nutrients. Salt, methionine, low-energy concentrate and limestone were weighed and mixed in a bowl as a pre-mix. After all the major ingredients were mixed together, the pre-mix and cooking oil were added a little at a time until all were mixed uniformly. Water was added (10%) and the mixture was pelleted. Pelletised feed was dried in the sun until 11–13% of moisture was removed.

The commercial diet was egg layer pellet sourced at the Goodman Fielder's International feed mill in Lae.

Chemical analyses

Feed samples were subjected to chemical analysis using AOAC (1990) methods at the PNG Unitech Analytical Service Laboratory (UASL).

The Kjeldahl method was used to determine crude protein in the feeds. The petroleum ether method was used to analyse crude fat based upon extraction and subsequent weighing of the lipid residue after solvent extraction. Crude fibre was analysed by passing the digested sample through a sintered-glass filter after sulphuric acid digestion and ashing at 5,000°C. The nitric/perchloric method was used to analyse calcium and phosphorus.

Statistical analyses

The data from the four farms were entered and sorted in a Microsoft Excel spreadsheet. Calculations for measuring production performance were as follows:

$$\text{Feed intake} = \text{feed offered} - \text{feed refused}$$

$$\text{Egg production percentage} = \frac{\text{average number of eggs produced per day}}{\text{total number of hens surviving to the end of that period}} \times 100$$

$$\text{Egg weight} = \frac{\text{total daily egg weight}}{\text{number of eggs laid}}$$

$$\text{Feed conversion ratio (egg weight)} = \frac{\text{kg of feed consumed}}{\text{kg egg produced}}$$

$$\text{Feed conversion ratio (for a dozen eggs)} = \frac{\text{kg of feed consumed}}{\text{kg egg produced}} \times 12$$

$$\text{Body weight} = \frac{\text{total weight}}{\text{number of birds}}$$

$$\text{Weight change} = \text{final weight} - \text{initial weight}$$

$$\text{Weight gain} = \text{end average body weight} - \text{initial average body weight}$$

$$\text{Feed cost/egg weight} = \frac{\text{cost of dry matter feed consumed}}{\text{weight of eggs produced}}$$

$$\text{Feed cost/unit of egg weight} = \frac{\text{cost of dry matter feed consumed}}{\left(\dfrac{\text{total egg weight}}{\text{number of eggs produced}}\right)}$$

These data were aggregated for all farms, and were imported into SPSS software and the *t*-test used to detect statistical differences ($P < 0.05$) between treatments.

RESULTS

Table 1 shows the nutrient profiles of the local and commercial diets as analysed at UASL. The local diet had marginally higher metabolisable energy (>0.3 MJ/kg), lower crude protein (<0.1%), lower fat (<2.95%), higher fibre (<1.0%), higher calcium (>0.64%), higher available phosphorus (>0.11%) and lower moisture content (<0.12%) than the commercial diet.

Table 2 shows the production variables, treatment means, standard errors of means and *t*-tests. There was no significant difference in feed intake, body weight, weight change, egg weight, feed conversion ratio, feed per dozen eggs or feed cost per gram egg. There was however a significant difference in egg production and feed cost per unit of egg weight. The egg production

Table 1. Nutrient profiles of the test diets from chemical analysis, and layer requirements.

Treatment diet	Metabolisable energy (MJ/kg)	Crude protein (%)	Fat (%)	Fibre (%)	Ca (%)	P (avail.) (%)	Moisture (%)
Local diet	11.3	15.9	1.05	4	3.64	0.52	10.00
Commercial diet	11	16	4	3	3	0.41	10.12
Layer requirements*	11.2	16	3	3	3.6	0.5	–

* Figures sourced from Hyline International (2009) and set as standard requirement for comparison between two test diets.

Table 2. Egg production variables of spent layers (77–85 weeks) fed either the local or commercial diet. Data for each variable under the different treatments are aggregated for the four farms.

Variable	Diet	Mean ± SEM	*t*	Significance (2-tailed)
Feed intake (g/bird/day)	LD	126.0 ± 10.99	−1.1	0.3
	CD	148.8 ± 17.40		
Body weight (kg/bird)	LD	2.0 ± 0.08	0.9	0.4
	CD	1.9 ± 0.025		
Weight change (g/bird/week)	LD	143 ± 50.00	−0.4	0.7
	CD	206 ± 139.66		
Egg production (%/day)	LD	56.3^{b} ± 4.07	−2.7	0.03
	CD	76.3^{a} ± 6.05		
Egg weight (g)	LD	51.8 ± 1.65	−2.1	0.1
	CD	58 ± 2.55		
FCR (g feed/g egg)	LD	2.5 ± 0.22	−2.7	0.8
	CD	2.6 ± 0.29		
FCR (kg feed/doz eggs)	LD	2.5 ± 0.46	1.2	0.3
	CD	3.04 ± 0.15		
Feed costs/gram egg (kina)	LD	1.3 ± 0.04	−2.1	0.1
	CD	1.5 ± 0.07		
Feed costs/unit egg weight (g) (kina)	LD	1.6^{a} ± 0.14	−6.4	0.001
	CD	6.6^{b} ± 0.77		

LD = local diet; CD = commercial diet; FCR = feed conversion ratio.
Values with different superscripts within a row are significantly different ($P < 0.05$).

of birds fed the commercial diet (76.25 ± 6.05%) was higher than those fed the local diet (56.25 ± 4.07%), but the feed cost per unit egg weight was less for birds fed the local diet (1.57 ± 0.141 kina) compared to the commercial diet (6.61 ± 0.77 kina).

DISCUSSION

Large commercial farms in PNG sell their spent layers as live birds between 71 and 72 weeks of age. Generally, some smallholders and households keep these hens until the end of the first production cycle. In this study, the egg production percentage for NARI crossbred (F1) spent layers fed a commercial diet was significantly better than those fed a local diet, however the feed costs per unit egg weight for hens on the local diet were significantly less than for those on the commercial diet. Although performance was not as good when local feed was used, this is compensated by farmers maximising returns from cheap local feed.

Feeding a commercial diet to spent layers is not economically viable, despite the increase in egg production and feed intake, compared to feeding a diet made from local ingredients. Feeding spent layers on local diets reduces feed cost per unit egg weight from 6.60 kina to 1.70 kina. This reduction in feed cost can increase profitability and improve the use of local feeds on smallholder farms in PNG where culled spent layers are readily sourced from commercial farms.

The local diet was roughly balanced in terms of estimated nutrient content, however chemical analysis indicated that crude protein and crude fat were lower in the local diet, the likely reason for lower egg production percentage. In addition, although the egg weights and feed conversion ratios were statistically similar, hens on the commercial diet had heavier egg weights and were more efficient feed converters in terms of feed conversion ratio per dozen eggs.

Feed conversion ratio and kilogram feed per dozen eggs were similar for birds fed the commercial diet and local diet, however spent layers fed the commercial diet produced significantly more and heavier eggs. Hendrix (2009) reported that the level of fat in the diet influenced egg production and egg weight. Halle (1996) reported an increase in egg production and egg weight when crude fat was included at 2.5% or 5% in the diet of commercial layers from 19 to 71 weeks. Grobas et al. (1999) reported that the addition of 4% crude fat brought about an increase in dietary energy intake, body weight gain, rate of lay and egg weight compared to added oil at 0% and 4%. These results were clearly in line with a low level of crude fat and low egg production of birds on a local diet.

Availability of local feed resources

The cassava tuber is used as human food, while the spoiled tubers, stems and leaves from the garden and kitchen are fed to village pigs, chickens and dairy cattle (Peyrot 1969; Rojanaridphiched 1977; Normanha 1962). Cassava leaves are a good source of protein (about 20% protein). Cassava is the fifth most important staple crop in PNG, after sweetpotato, taro, yam and banana. Cassava is fed to farm animals either cooked or raw, but the fresh leaves are not used to feed pigs. Kikuyu leaves and limestone, which are regarded as inedible in village human diets, are available throughout PNG and could be utilised in livestock diets. Singh et al. (2013) have observed that Cobb 500 broilers eat a substantial quantity of kikuyu grass under free-range which is advantageous in reducing the cost of expensive commercial feed.

Agro-industrial by-products used in the formulation were fishmeal and copra meal. The ingredients are by-products of fish canneries and coconut oil extraction. They are underutilised local ingredients in layer feed but have the potential to be included in diets for spent layers. Below 5% inclusion of fishmeal is recommended, however there were no signs of fishy taints in the eggs. These ingredients are rarely distributed and are used in the lowland region as feed ingredients for livestock and fish (Ayalew 2011).

CONCLUSION

The development of a low-cost layer diet containing 99.6% local ingredients resulted in a significant reduction in egg production performance. However, the local diet is economically viable because there was a significant reduction in feed cost per unit egg weight compared to feeding with the commercial diet. It is recommended that spent layers (70–90 weeks of age) be provided a diet comprising local ingredients. This also potentially has a significant contribution to human nutrition (especially in young children) by promoting the consumption of high-quality protein in eggs.

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Egg production performance of village chickens fed a local diet compared with a commercial diet on village farms in Papua New Guinea

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Abstract

The low egg production of village chickens may be attributed to genetic and non-genetic factors, especially poor nutrition. Due to their high price, balanced commercial feeds are not usually fed to village chickens in Papua New Guinea (PNG). This trial was conducted on village farms in Domil in the Jiwaka Province of PNG, to compare egg production performance of village chickens fed on a diet prepared from local ingredients with that of chickens fed on a commercial layer diet. The ingredients used to prepare the local diet included cassava tuber meal, maize, fishmeal, limestone, copra meal, sweetpotato leaves, cassava leaves, kikuyu leaves, peanut meal, banana meal, cooking oil, low-energy layer concentrate, common salt, dry sweetpotato tubers and methionine. The local diet had 11.3 MJ/kg apparent metabolisable energy (AME), 15.9% crude protein and cost 1.42 kina/kg. The commercial diet had 10.97 MJ/kg AME and 16% crude protein and cost 2.71 kina/kg. The trial was conducted on two village farms with poultry houses partitioned into two pens each holding five hens. Birds were 38 weeks of age and approximately 1.45 kg body weight. The treatment diets were fed to the birds from 38 to 45 weeks of age, and production performance was measured. Percentage egg production, egg weight, feed intake, feed conversion ratio, and hen body weight change were similar for hens fed on both the local and the commercial diet. However, feed costs were significantly lower for the local diet than for the commercial diet. The higher cost of the commercial diet is partly due to the high cost of transport from the feed mill at Lae to Domil. Findings suggest that feed costs could be significantly reduced by using feeds formulated from local ingredients without adversely affecting egg production of village chickens. This is especially relevant in locations that are far from commercial feed mills.

INTRODUCTION

The village chicken was introduced to Papua New Guinea (PNG) from South-West Asia, and is related to the wild jungle fowl (Alders 2001; Nthimo 2004). Over the years it has been crossed with the Rhode Island Red and the Australorp, which were introduced for nutritional purposes during the colonial era and when the Department of Primary Industry was first established in PNG (Quartermain 2002).

Village chickens make a significant contribution to food security and livelihoods, especially in rural areas of PNG where the majority of the population live. Village chickens are kept by 29% of households (up to 50% of households in some provinces), and the country overall produces about 2.3 million meat birds and 6 million eggs per year from village chickens (Bourke and Harwood 2009). Usually these birds are raised under free-range, low-input systems with little or no attention paid to proper nutrition, disease management, provision of adequate shelter or genetic improvement, leading to generally poor productivity (Quartermain 2002; FAO 2010; Lobao 2011; FAO 2014). With respect to nutrition, balanced commercial feeds are

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almost never given to village chickens in PNG due to their high cost, low availability and poor response of the chickens to such feeds. Rather, village chickens are usually allowed to scavenge for food, and kitchen wastes and crop by-products are also sometimes fed to them. An earlier experiment reported that when village chickens are kept under an improved management and husbandry system, they tend to perform better than under the normal extensive and scavenging systems (Besari et al. 2017b).

Local ingredients, including agro-industrial by-products and crops grown locally by smallholder farmers, when converted to egg and meat products, improve the nutritional status of people. The main objective of this study was to compare egg production performance of village hens fed on diets prepared from local ingredients with that of hens on commercial feed.

MATERIALS AND METHODS

Location

The trial was conducted at Domil (5°86′72″ S, 144°74′99″ E) in Jiwaka Province over an 8-week period from 20 July to 14 September 2013, on two smallholder farms approximately 0.5 km apart. The area has an elevation of 1,200–1,800 masl and an average annual temperature ranging from 12°C to 27°C. During the feed trial, the temperature ranged between 13°C and 24°C. Domil is 10 km inland from the national highway, and goods and services were accessed in Banz, the main township 20 km from Domil. The price of goods was higher by 10–15% in the area compared to in Lae.

Most people in Domil practice subsistence agriculture and are involved in informal markets. Domil Integrated Community Development Cooperative operates a feed mill and mobilises resources in the community.

Experimental birds

Twenty village hens with an average age of 38.1 ± 1.2 weeks and body weight of 1.45 ± 0.18 kg were purchased in Domil village and randomly assigned to two pens on each of the two smallholder farms. The birds were exposed to the feed and environment in the pen for 1 week prior to the start of the experiment.

Experimental diets

The two treatments were a local diet and a widely used commercial diet. The local diet was made by mixing a low-energy layer concentrate (LELC) with 40% cassava flour and other local ingredients (Table 1). The unit cost of each ingredient is shown in Table 1. The commercial diet was egg layer pellets sourced from the Goodman Fielder International (GFI) feed mill in Lae and sold locally in Mount Hagen at 2.71 kina/kg.

Local diet preparation

The preparation of diets at the Domil mini-mill facility was similar to that described in the previous paper (Besari et al. 2017a). Equipment at the feed mill included a Guangi Qiuzhou brand flake mill (model 9F-26, able to process dried tubers at 657 g/minute and leaves at 680 g/minute); a modified mini-multipurpose bench grinder (75 mm 150 W electric power, able to grind fresh tubers at 460 g/minute); a modified manual mincer (RC Brand, size #12, cast iron) run by 140 W electric motor, also used for the pelletiser (processing pellets at 500 g/minute); and a manual cast-iron grinder (RC brand, size #500, able to process dried peanuts at 100 g/minute).

Housing and husbandry

The chicken houses measured 4 × 2.5 m and were partitioned into two equal pens of 2 × 2 m providing average spacing of 0.8 m^2/bird. The floor was covered with litter (wood chips) to a depth of 5 cm. Each pen was equipped with a bell drinker (28 cm in diameter) to provide 17.6 cm linear drinking space per bird and a round feeder (30 cm in diameter) providing 18.8 cm linear feeding space per bird. The chicken houses had 1 m high walls made of hand-woven bamboo stem and a roof covered with kunai grass (*Imperata cylindrica*). The birds were exposed to light for 24 hours, with artificial light (from a kerosene lamp) provided during the night.

Variables measured

Treatment diets (2 kg) were provided to each pen in the morning and feed was topped up in the afternoon

Table 1. Dietary composition of the local diet and cost of ingredients.

Ingredient	kg/100 kg (dry matter)	Unit cost (kina)	Total cost (kina)
Cassava meal	40.00	0.77	30.80
Maize	16.00	1.60	25.60
Fishmeal	13.75	1.95	26.81
Limestone	7.55	1.45	10.95
Copra meal	6.00	1.50	9.00
Sweetpotato	4.70	0.68	3.20
Cassava leaves (fresh)	4.00	0.50	2.00
Kikuyu leaves (fresh)	2.30	0.50	1.15
Peanut meal	2.13	10.00	21.30
Banana meal	2.00	1.50	3.00
Oil palm	0.90	5.00	4.50
Low-energy layer concentrate	0.28	10.11	2.83
Salt	0.20	2.00	0.40
Sweetpotato tubers (dry)	0.13	2.24	0.29
Methionine	0.06	13.20	0.79
Total	100.00		142.62

ad libitum. Leftover and spilled feed was collected at the end of each week, weighed and recorded. The weight of feed allocated, the number of eggs laid and weight of eggs were measured daily (morning and afternoon) using kitchen scales (2 kg capacity, accurate to 10 g). Hens were weighed weekly and pen temperatures were also recorded.

The following calculations were made:

Pen feed intake = total feed offered – feed refused

$$\text{Egg production percentage} = \frac{\text{average number of eggs produced per day in a period}}{\text{total number of hens surviving to the end of that period}} \times 100$$

$$\text{Feed conversion ratio} = \frac{\text{weight of feed consumed}}{\text{weight of eggs produced during that period}}$$

Weight change = initial body weight – final body weight

The feed cost per egg weight on the local diet was calculated from Table 1 as the cost of dry matter feed consumed divided by the weight of eggs produced. The feed cost of the commercial diet was 2.71 kina/kg; the feed cost per egg weight was similarly calculated by dividing by the weight of eggs produced.

Chemical analyses

Duplicate samples of the local and the commercial diet were analysed at the PNG University of Technology Analytical Services Laboratory (UASL). Feed samples were subjected to chemical analysis using the methods of AOAC (1990). Gross energy, crude protein, crude fat, crude fibre, calcium and phosphorus were analysed as in the previous paper (Besari et al. 2017a).

Statistical analyses

The weekly production measurements of each diet treatment from the farms were aggregated and presented as: egg production percentage, egg weight, feed intake, body weight and feed cost per kilogram egg. The dependent variables include feed conversion ratio and body weight changes. Data were analysed using SPSS software and *t*-tests were used to detect statistical differences at $P < 0.05$ between the two diet treatments.

RESULTS

Nutrient compositions of the local and commercial diets from analyses at UASL are shown in Table 2. The production measurements are shown in Table 3. The dietary treatments had no significant effect on any of the production variables except for the cost of feed per kilogram egg produced. The cost of feed per kilogram of egg produced on the local diet was less than half the cost on the commercial diet, and the difference was statistically significant ($P < 0.05$).

DISCUSSION AND CONCLUSION

The fact that all the major production variables were not significantly different between the two diets leads to the recommendation that use of local ingredients in village layer diets can reduce cost of feed without affecting biological performance of chickens. Pandi et al. (2016) reported a 30% reduction in cost of feeding broiler chickens when concentrates were blended with either sweetpotato or cassava diet with no adverse effects on production performance. Cheon et al. (2008) also reported a reduction of layer feed cost when corn distillers' dried grain was included in layer feeds. Maina (2013) reported higher economic return with inclusion of 10% coarse bran in the diet without adverse effects on percentage egg production.

The results suggest raising village chickens, especially for egg production using a diet made from local ingredients, could be an option for farmers at Domil in Jiwaka Province, as well as in other highland provinces, pending a full economic analysis. The eggshell thickness and yolk colour were not analysed in this trial.

The hens fed on the commercial diet not only ate more of the more expensive feed but also tended to have poor feed conversion ratio and subsequently

Table 2. Nutrient values of the local and commercial diets from chemical analysis.

	ME (MJ/kg)	Crude protein (%)	Fat (%)	Fibre (%)	Ca (%)	P (avail.) (%)	Moisture (%)
Local diet	11.3	15.9	1.05	4	3.64	0.52	10.00
Commercial diet	10.97	16	6.9	4.4	3.4	0.64	10.12

ME = metabolisable energy; Ca = calcium; P (avail.) = available phosphorus.

Table 3. Egg production performance of village hens fed on a local diet or a commercial diet from 38 to 45 weeks of age.

Variable	Diet	Mean ± SE	t-value	*P*
Egg production (%)	LD	31.0 ± 3.0	−1.05	0.403
	CD	40.0 ± 8.0		
Egg weight (g)	LD	49.5 ± 11.5	0.28	0.806
	CD	46.0 ± 5.0		
Feed intake (g)	LD	111.5 ± 6.5	−1.41	0.293
	CD	124.5 ± 6.5		
Feed conversion ratio (kg feed/kg egg)	LD	2.85 ± 0.55	−0.66	0.576
	CD	3.25 ± 0.25		
Weight change (g)	LD	17.5 ± 37.5	0.46	0.692
	CD	2.5 ± 22.5		
Feed cost per kg egg (kina/kg eggs)	LD	4.03^{a} ± 0.77	−4.36	0.049
	CD	8.40^{b} ± 0.64		

Means with different superscripts within each rows of variable are significantly different ($P < 0.05$).
LD = local diet; CD = commercial diet.

higher feed costs per unit egg weight. These results suggest that cassava could be included in village chicken layer diets to reduce the cost of feed and improve egg production, especially in parts of PNG remote from the commercial feed mills. This necessitates that micro-ingredients and premixes be widely distributed and marketed by commercial outlets throughout PNG.

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Egg production performance of village hens fed on concentrates blended with sweetpotato or cassava in Papua New Guinea

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Abstract

The village chicken is capable of producing eggs in a harsh tropical environment by scavenging for food and kitchen scraps. A trial was conducted at the Lutheran Development Service site in Lae, Papua New Guinea to demonstrate the production responses of village hens fed sweetpotato and cassava blended with layer diets. A total of 40 village hens (approximately 28 weeks of age) were randomly assigned to eight pens with five birds per pen. The feed treatments included three pens of birds fed a 60% high-energy layer concentrate blended with 40% boiled mashed sweetpotato, three pens of birds fed a 60% low-energy layer concentrate blended with 40% boiled mashed cassava, and two pens of birds fed a commercial layer pellet. The diets were fed from 28 to 35 weeks of age, and egg production, egg weight, feed intake, feed conversion ratio, feed cost, egg shell thickness and egg yolk colour were monitored. The egg production percent of the village chickens fed the sweetpotato-based diet (41.3%) and the cassava-based diet (46%) were similar to hens fed the commercial diet (37.0%) ($P > 0.05$). However, egg weight of hens fed the cassava-based diet (46.7 g) was significantly lower than for hens fed on the sweetpotato-based diet (51.3 g) and the commercial diet (51.0 g) ($P < 0.05$). The cost of the sweetpotato-based diet was 9.95 kina/kg, compared to 9.26 kina/kg for the cassava-based diet and 6.57 kina/kg for the commercial diet. The trial demonstrated that cassava- and sweetpotato-based diets can be used to feed village hens and maintain production.

INTRODUCTION

The village chicken is the most common type of poultry in many rural areas of Papua New Guinea (PNG). Even very poor households with scarce labour resources normally keep some chickens. Village chickens are also known as rural, indigenous, scavenging, traditional or family chickens, and have various names in local languages (Ahlers et al. 2009).

Quartermain (2000) stated that there is no commercial poultry keeping in rural villages of PNG as household poultry production is primarily for household consumption. This has however changed recently, and farmers are entering the market and selling village birds and eggs. Village chickens have a reputation in smallholder household production as converters of food surplus and kitchen waste into meat and eggs for household consumption. Some advantages of the village chicken genotype are their low feed intake, superior food conversion ratio (FCR) when fed on highly nutritional diets, ability to survive under harsh conditions and resistance to exotic diseases (Ahlers et al. 2009). It was found in a related study at the National Agricultural Research Institute (NARI) that an improved husbandry, management and feeding system could improve the performance of village chickens (Besari et al. 2017).

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This study was conducted at the Lutheran Development Services (LDS) layer facility in Lae, PNG, to further demonstrate the production responses of village hens fed sweetpotato and cassava blended with layer concentrates. LDS is a non-government organisation operated under the Evangelical Lutheran Church of PNG and is involved in extension services throughout the country with a head office in Lae. The organisation has motivators and trainers in lowland and highland areas of PNG. An aim of this trial was to demonstrate the feeding system to LDS staff so that they could disseminate the use of cassava and sweetpotato to village poultry farmers in PNG.

Eggshell thickness and yolk colour were studied to determine egg quality of village chickens under the improved feeding systems. Eggshell thickness is an important parameter used to assess egg quality (ISA 2009). Various consumer groups have preferences for egg yolk colour, with darker hues generally preferred. The Roche yolk colour fan, which is widely accepted throughout the food industry as the standard for measuring yolk colour (Beardsworth 2012), was used in the trial (Figure 1). The visual evaluation of egg yolk colour using the Roche scale is more convenient than the measurement of the carotenoid content expressed as beta-carotene. The visual evaluation gives clear information and corresponds better with the sensorial perception of egg yolk colour (Bovskova et al. 2014).

Figure 1. The Roche yolk colour fan.

MATERIALS AND METHODS

Location

The experiment was conducted at the village chicken breeding and distribution facility at the LDS Centre in Malahang, Lae (6°70´67″ S, 147°02´56″ E). The area has an elevation of 0–100 m above sea level and temperature varies between 19°C and 32°C.

Birds and housing

A total of 40 village hens (approximately 28 weeks of age) with an average body weight of 1.3 kg were randomly allocated to eight pens with five hens in each pen. The birds were sourced from a free-ranging system at Malahang breeding facility and were a common strain of PNG indigenous chicken with mixed colour plumage and feathers.

The shed housing the hens was 18 × 7 m with a central corridor 1 m wide and 12 m long, and an open room (42 m^2) for feed preparation and storage. The shed had wire mesh walls and a corrugated iron roof, and was naturally ventilated. Each pen measured 3 × 3 m and the concrete floor area of 9 m^2 was filled with wood chips to 5 cm depth. Each room had a bell drinker of 28 cm diameter providing a 17.6 cm linear drinking space per bird, and a bell feeder of 30 cm diameter providing a 18.8 cm linear feeding space per bird. Drinking water was sourced from a rainwater tank. Two electric fluorescent lights 4 m above the floor in the corridor were switched on at 5.00 pm and switched off at 7.00 am to provide a light regime of 13 hours artificial light at night and 11 hours daylight (the natural daylight hours in Lae are between 5.30 am and 6.30 pm).

Experimental diets

There were three dietary treatments in this trial. The first treatment (sweetpotato-based diet) consisted of a high-energy layer concentrate (HELC) mixed with boiled and mashed sweetpotato (BMSP) tubers. The second treatment (cassava-based diet) consisted of a low-energy layer concentrate (LELC) mixed with boiled mashed cassava (BMC) tubers. The third treatment (commercial diet) consisted of a standard commercial layer diet supplied by a local feed mill (Lae Feed Mills), which is widely used by egg producers throughout the country. Both HELC and LELC are proprietary concentrates developed as part of a multi-institutional collaborative research project to improve the profitability of smallholder broiler and layer production in PNG. The concentrates are produced by a local feed mill (Lae Feed Mills). The concentrates contain protein meals, pure amino acids, vitamins, minerals, mould inhibitors and antioxidants.

Both the sweetpotato (*Ipomoea batatas* cv. 'Waghi besta') and cassava (*Manihot esculenta*, a local variety) were bought from Lae market. The sweetpotato and peeled cassava tubers were prepared daily; they were washed in cool water, weighed to 12 kg and boiled for 25 minutes in separate bowls (15 cm in diameter) half-filled with water over a wood-fired stove. The cooked sweetpotato tubers and cassava were then mashed by hand in different bowls (4 L capacity) and mixed with HELC and LELC, respectively, according to the proportions shown in Table 1.

Chemical analysis

Duplicate samples of each test diet were analysed using AOAC (1990) methods at the Analytical Services Laboratory of the PNG University of Technology, Department of Agriculture. The results are shown in Table 2. The commercial diet had a higher crude protein, calcium and phosphorus content than the sweetpotato-based and cassava-based diets. However, the cassava- and sweetpotato-based diets contained more metabolisable energy and crude fat. Crude fibre content was highest in the cassava diet and lowest in the sweetpotato diet.

Experimental design and protocol

A completely randomised experimental design was used, with three replicates for each experimental diet and two replicates for the control diet.

The trial was conducted over seven weeks, from 8 June to 27 July 2012. Four kilograms of the experimental feeds in boiled-mashed form was prepared each day. Half of the amount was provided to the hens in the morning and the remaining half

Table 1. Proportions of major ingredients in the treatment diets.

	Treatment 1		Treatment 2	
	HELC	BMSP	LELC	BMC
Proportion (%, dry matter basis)	60	40	60	40
Quantity (g, as-fed basis) per day for 15 hens	963	2118.6	963	1926
Mixing ratio	1	2.2	1	2

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers.

Table 2. Nutrient composition of concentrates, test diets and control diet, and nutrient requirements of layer chickens.

	ME (MJ/kg)	Crude protein (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Avail. P (%)
HELC	8.67	14.42	5.85	3.89	2.74	0.49
LELC	10.92	21.95	8.84	4.55	4.4	0.79
HELC+BMSP	12.83[i]	15.47	6.06	2.14	2.73	0.47
LELC+BMC	11.63[i]	14.57	5.66	4.69	2.76	0.48
Commercial	11.0	16.0	4.0	3.0	3.0	0.41
Requirements[ii]	11.20	17	4.0	3.0	3.7	0.44

[i] Estimates from UNEFORM (Thomson 2012).
[ii] Hyline Brown International (2009).
HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers; ME = metabolisable energy; Avail. P = available phosphorus.

was given in the afternoon. The commercial feed was provided to hens in the pelleted form. Leftover and spilled feed was collected and weighed each morning before fresh feed was provided. Feed intake was estimated as the difference between feed given each day and feed left over plus spilled feed. Drinkers were refilled every morning with clean water. The hens were weighed at the commencement of the trial and weekly thereafter with a Salter® spring weighing scale (50 kg capacity, accurate to 0.1 kg). Eggs were collected daily from each pen and recorded and weighed. The number of cracked eggs was also recorded and included in the total production calculation.

Nine eggs from each pen were randomly chosen from the eggs laid in week five of the trial and used for eggshell thickness and egg yolk colour measurements. The eggs were weighed, cracked open and the shells were separated from their contents. Four readings were taken from random sides of each eggshell and used to calculate mean eggshell thickness. The thicknesses were measured using a micrometer screw thread gauge (accurate to 0.001 g). For yolk colour measurements, the egg contents were poured into a clear glass bowl (10 cm in diameter) and the albumen was carefully separated into another container. The Roche yolk colour fan was then placed alongside the glass bowl containing egg yolk and scores of colour of egg yolk were tallied.

Table 3. Costs of sweetpotato, cassava, layer pellets and layer concentrate.

Feed ingredient	Quantity (kg)	Total price (kina)	Cost/kg (kina)
Sweetpotato (bag)	80	60	0.75
Cassava (bag)	24	16.8	0.61
Commercial (bag)	40	95	2.38
HELC/LELC (bag)	40	100	2.50

HELC = high-energy layer concentrate; LELC = low-energy layer concentrate.

Feed costs

The commercial layer feed was purchased from Farmset distributors in Lae at 95.20 kina for a 40 kg bag. The sweetpotato and cassava were purchased at 0.75 kina/kg and 0.61 kina/kg, respectively, at the Lae main market (Table 3). Prices excluded freight costs, overhead costs and other associated production costs. The unit costs of the complete rations are shown in Table 4. Feed cost per kilogram egg weight was calculated from these figures and weight of eggs produced.

Data analysis

Feed intake, weight gain and feed conversion ratio were calculated as follows:

$$\text{Feed intake} = \text{feed offered} - \text{feed refused}$$

$$\text{Weight gain} = \begin{matrix}\text{final week}\\\text{body weight}\end{matrix} - \begin{matrix}\text{initial week}\\\text{body weight}\end{matrix}$$

$$\begin{matrix}\text{Feed conversion ratio}\\\text{(egg weight)}\end{matrix} = \frac{\text{kg of feed consumed}}{\text{kg egg produced}}$$

The data were recorded into Microsoft Excel spreadsheets and all variables were arranged into replicates with treatments and weekly averages calculated. Moisture factors of sweetpotato (3.2) and cassava (3) were considered and the final intake was calculated on a dry matter basis. The average eggshell thickness readings from nine samples of each replicate were arranged by treatment. Then, the format of the spreadsheet was arranged according to SPSS software

Table 4. Estimated unit cost of dietary treatments on an as-fed and dry matter basis.

Diet	Ratio concentrate:boiled mashed tuber	Quantity/kg feed		Cost/kg (as-fed basis) (kina)	Cost/kg (dry matter basis) (kina)
		Concentrate	Boiled mashed tuber		
HELC+BMSP	1:2.2	0.3125	0.6875	1.30	2.51
LELC+BMC	1:2	0.333	0.667	1.24	2.21
Commercial	–	–	–	2.38	2.65

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers.

(Version 17.0, 2008) specifications with missing samples of a replicate representing the commercial diet (–). The data were then transferred into the software and analysed by treatment using one-way ANOVA for descriptive statistics with missing values, and a post-hoc test for multiple comparisons was used. The significant effect on the variable and mean separation was carried out using the least significant difference method (LSD; $P = 0.05$).

RESULTS

The main results are shown in Table 5. Egg production percent was highest for hens fed on the cassava-based diet followed by hens fed on the sweetpotato-based diet, and lowest for hens fed on the commercial diet. However, the numerical differences in egg production were not significant. The lack of significance between the treatments is probably due to the low number of replicates in the trial. Nevertheless, the experiment demonstrated that local feeds resulted in satisfactory egg production relative to the commercial feed. The highest average egg weight was obtained from village hens fed on the sweetpotato diet, which was equivalent to the egg weight of hens fed on the commercial diet and significantly higher than the mean egg weight of hens fed on the cassava-based diet ($P < 0.05$). While it is difficult to draw sound conclusions without significant differences being observed in egg production on different treatment diets, hens fed on the cassava diet tended to lay more eggs and their egg weight was significantly lower than that of hens fed on the other diets. On the other hand, hens fed on the sweetpotato diet tended to have similar egg production percent and egg weight compared to hens fed on the commercial diet. Generally, it appears the sweetpotato diet produced the same results as the commercial diet in terms of egg production percent and egg weight.

The dry matter intake tended to be highest for hens fed on the cassava diet and lowest for hens fed on the commercial diet, but these averages were not statistically different. The results indicate that the village hens fed on commercial diets had slightly lower FCR (superior) compared to FCR of hens fed on the cassava and sweetpotato diets but the differences were not statistically significant (LSD; $P = 0.05$).

Live weights of hens on all diets did not change significantly during the trial.

The eggshell thickness tended to be highest for hens fed on the cassava diet and lowest for hens fed on the commercial diet but these means were not significantly different from each other.

The commercial diet produced 64% of yolks at number 13 (at the darker end of the range) on the Roche yolk colour fan (Table 6) with 18% within the range of number 1 (the palest yellow) and the remaining 18% within a number 4 value. The HELC+BMSP and LELC+BMC diets produced 90% and 55% at number 1 and 10% and 45% at number 4, respectively.

Table 5. Mean egg production, egg weight, feed intake, feed conversion ratio, weight change, feed cost per kg egg and eggshell thickness of village chickens fed the three different treatment diets. All figures are means of three (HELC+BMSP and LELC+BMC) or two (commercial diet) replicates ± the standard error of the mean.

Parameter	Treatment			Std error	*P*
	HELC+BMSP	LELC+BMC	Commercial diet		
Egg production (%)	41.3 ± 9.64	46.6 ± 11.02	37.0 ± 0.50	3.07	0.59
Egg weight (g)	51.34 ± 0.58	46.77 ± 1.00	51 ± 0.00	0.86	0.004
Feed intake (g/bird/day)	116.67 ± 30.66	123 ± 23.51	73 ± 2.83	10.64	0.15
FCR (kg feed/kg egg)	2.28 ± 0.64	2.64 ± 0.55	1.44 ± 0.05	0.24	0.13
Body weight change (g)	66.67 ± 76.38	66.67 ± 28.87	0.00 ± 70.71	21.13	0.46
Feed cost per kg egg (kina)	9.95 ± 2.63	9.26 ± 1.77	6.57 ± 0.30	0.79	0.26
Eggshell thickness (mm)	41.43 ± 7.0	46.0 ± 0.50	43.80 ± 0.7	1.5	0.50

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers; FCR = feed conversion ratio.

Table 6. Percentage range of egg yolk colours observed on the three treatment diets (1 = palest yellow; 13 = darkest yellow).

Diet	Colour fan value			Total
	1	4	13	
HELC+BMSP	90%	10%		100
LELC+BMC	55%	45%		100
Commercial diet	18%	18%	64%	100

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers.

DISCUSSION

Local genetic resources, as in village chickens, dominate the family poultry production systems in the village environment despite their lower genetic potential in terms of meat and egg production (FAO 2014). The average egg production percent of hens fed on the cassava, sweetpotato and commercial feeds was found to be 46.6%, 41.3% and 37% respectively. This performance appears to be better than egg laying rates reported for scavenging village chickens under field conditions. Labão (2011) stated that a village hen can lay only 24 eggs per year in three clutches of eight eggs each. The low rate of lay is caused by prolonged brooding and rearing periods. Most importantly, village hens have not been selected for egg production; rather natural selection has enabled them to survive in a difficult environment.

The similar egg weight of hens fed on the sweetpotato and commercial diets suggests that the sweetpotato diet had sufficient nutrients. The sweetpotato diet had higher metabolisable energy and available phosphorus but slightly lower crude protein, fibre and calcium contents compared to the commercial diet. Ladokun et al. (2007) also found no negative effects of feeding sweetpotato meals on albumen and yolk weights of Yaffa (native) chickens. Afolayan et al. (2013) similarly found no negative effect of feeding up to 40% sweetpotato meal on egg weight at 50% production in layer chickens. The significantly lower egg weight of hens fed on the cassava diet may be due to differences in nutrient content, digestibility and utilisation in the diets. It may also be due to anti-nutrients in the cassava diet but this depends on how the cassava was cooked. Cassava roots have varying concentrations of cyanogenic glycosides, mainly linamarin that is hydrolysed by the endogenous enzyme linamarase to form cyanohydrins, which are then metabolised to cyanide and acetone. Deactivation of the linamarase enzyme occurs when cassava is cooked. Temperatures above 70°C will deactivate the enzyme and prevent the formation of cyanide.

The cassava diet had the lowest crude protein content and highest crude fibre content of the three treatment diets. The tendency of hens to consume higher amounts of the cassava diet may be due to the better adaptation of village chickens to consume such local feeds but hens on this diet had inferior FCR. This result is in agreement with Aina and Fanimo (1997) who found no significant differences in feed intake of genetically improved hens which were fed three different diets: one contained 52.3% maize, another contained 52.3% chipped and dried cassava, and the third diet contained 52.3% chipped and dried sweetpotato meal. However, other studies which involved genetically improved hens found significantly decreased intake of feeds containing appreciable amounts of cassava (Anaeto and Adighibe 2011; Kana 2013). Other studies using sweetpotato and genetically improved hens have demonstrated that intake of sweetpotato diets depended on the overall energy content of the diets.

Eggshell thickness is an important factor in eggshell strength and is dependent on the calcium and phosphorus content of the diet and bird feed consumption. The egg yolk colour reflects the carotenoid content of the diet, which contributes to giving the yolk a bright colour and enhancing the consumer perception of the quality of the egg. Eggshell thickness is important in terms of storage and handling of eggs, and prevention of invasion and contamination by microorganisms, while egg yolk colour must satisfy customer preferences in terms of appearance and taste (Washburn 1982).

No significant differences in eggshell thickness were found between eggs from hens fed on the three treatment diets in this trial. This suggests that the diets provided similar amounts of the major nutrients involved in eggshell formation, i.e. calcium and phosphorus. Afolayan et al. (2013) found no significant differences in eggshell thickness of hens fed diets containing 0%, 10%, 20%, 30% and 40% sweetpotato meal but these diets were formulated to contain similar amounts of calcium and phosphorus. However, Ladokun et al. (2007) found that hens on a diet containing 42% sweetpotato tuber meal produced significantly thicker eggshells compared with eggs of hens on diets which contained 0% and 21% sweetpotato meal.

Egg yolk colour was best (most deeply hued) for hens fed on the commercial diet followed by hens fed on the sweetpotato diet and then hens fed on the cassava diet. The low content of pigments and fats in cassava tuber meal has often been given as a reason for poor yolk colour.

The results of this trial also indicated that the treatments had no significant effects on the feed cost per kilogram egg weight. This tendency may be due to the lower feed intake of hens fed the commercial feed.

CONCLUSION

The village chickens that were fed diets containing cassava and sweetpotato had statistically similar egg production percent, feed intake, feed conversion ratio, weight changes, feed cost per unit egg weight and eggshell thickness as village hens fed the commercial diet, regardless of differences in the nutrient content of the different diets. Furthermore, egg weight of village hens fed on the sweetpotato diet was found to be statistically similar to that of hens fed on the commercial diet. Village hens fed on the cassava diets had lower egg weights and poorer egg yolk colour compared to hens fed on the sweetpotato and commercial diets.

The local tubers are available to smallholder farmers and can be blended with layer concentrates. Yellow tubers could be used to improve yolk colour; and further processing, proper storage and handling of sweetpotato, cassava and concentrates could also improve the performance of hens.

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Egg production performance of Hyline Brown hens fed on concentrates blended with sweetpotato or cassava in the highlands of Papua New Guinea

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Abstract

This trial was conducted to evaluate the production performance of Hyline Brown commercial layers fed cooked cassava or sweetpotato blended with a layer concentrate, at Banz campus of the Christian Leaders Training Centre in the Jiwaka Province of Papua New Guinea. Specifically, the trial compared egg production and egg quality of the layers (21–35 weeks of age) which were fed on one of two blended test diets or a control diet. The diets were: (1) 60% low-energy layer concentrate blended with 40% boiled and mashed cassava tuber (BMC); (2) 60% high-energy layer concentrate blended with 40% boiled and mashed sweetpotato tuber (BMSP); and (3) a commercial layer diet. Hens fed the commercial layer diet had significantly higher feed intake, poorer feed conversion ratio (FCR), lower egg production, higher feed costs and a deeper hued egg yolk colour compared to hens fed on the BMC and BMSP diets. Egg weight, eggshell thickness and body weight changes were similar for all treatments. Hens fed on the BMSP and BMC diets had statistically similar egg production, feed intake, egg weight, body weight, FCR and shell thickness. Hens fed on BMSP diet had significantly better FCR and produced deeper hued egg yolk colours than hens fed the BMC diet. These results and the lower costs of the BMSP and BMC diets compared to the commercial control diet suggest that the sweetpotato and cassava diets could be a viable alternative to the commercial layer diets.

INTRODUCTION

The high cost of layer feed is a major constraint to table egg production in Papua New Guinea (PNG) and other parts of the world (Black and Yalu 2010; Tijjani et al. 2012). It is thought that the cost of layer chicken feeds could be minimised and profits increased by using diets prepared from locally available ingredients, especially in remote parts of PNG which are some distance from commercial feed mills (Pandi and Ayalew 2010). However, the type, supply and price of these local ingredients vary from place to place within the country due to the physical environment and other socio-economic factors. It is therefore necessary to evaluate diets prepared from local ingredients in terms of relative performance of hens and cost of feeds in different parts of PNG, and both on-station and on-farm. This paper reports an on-station trial which was carried out at the Christian Leaders Training Centre (CLTC) campus near Banz in Jiwaka Province of PNG. The purpose of this study was to examine the egg production and egg quality of Hyline Brown hens which were fed on diets prepared from a layer feed concentrate blended with either boiled and mashed sweetpotato or boiled and mashed cassava.

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Several authors have reported a decline in egg production when cassava and sweetpotato are included in layer diets. Lodakun et al. (2007) reported a significant reduction in egg production for hens fed diets which contained different combinations of sweetpotato meal and sweetpotato tops compared to diets which contained maize but no sweetpotato products. The authors recommended that no more than 50% of maize and wheat bran should be replaced by sweetpotato products in layer diets. Similarly, Afolayan et al. (2013) reported a significant reduction in egg production for hens fed diets containing 30% and 40% sweetpotato meal compared with a diet containing 41.15% maize and no sweetpotato. The authors suggested that sweetpotato meal should not be included beyond 20% in layer diets. Aina and Fanimo (1997) and Chauynarong (2010) also reported reduction in performance of layers which were fed diets containing cassava and sweetpotato products. Some reasons given for the poorer egg production performance of hens on sweetpotato and cassava diets are: the lower crude protein content; lower digestibility; the viscous nature of cassava meal caused by high levels of non-starch polysaccharides which create a gut-filling effect thereby reducing appetite and intake; deficiency of some amino acids and fats; and the presence of anti-nutritional factors (trypsin inhibitor in sweetpotato and cyanogenetic glucoside linamarin in cassava). Some of these anti-nutritional factors are however destroyed by heat treatment (Tilahun et al. 2013) such as boiling.

Eggshell thickness is an important parameter used to assess egg quality (Hunton 2005). Studies have shown that egg specific gravity and eggshell thickness decrease with increasing age in hens (ISA 2009). As the hen ages, the egg size increases and the rate of lay gradually declines. The egg size increases more quickly than the shell weight (Butcher et al. 1991) and there is an increase in egg size rather than calcium deposition in the eggshell (Curtis et al. 1985). Hen age also affects the proportion of yolk, albumen and eggshell (Fletcher et al. 1981; Akbar et al. 1983; Danilov 2000). The balance between egg production rate and egg weight usually determines eggshell thickness.

Various consumer groups have preferences for egg yolk colour, with darker hues generally preferred. The Roche yolk colour fan is widely accepted throughout the food industry as the standard for measuring yolk colour, and was used in this trial (Beardsworth 2012).

MATERIALS AND METHODS

Location

This trial was conducted at the CLTC in Banz, Jiwaka Province (5°78´36˝ S, 144°55´01˝ E). The area has an elevation of 1,200–1,800 masl and average annual temperature range of 12–27°C. The temperature ranged from 13°C to 25°C during the trial. The CLTC has a layer chicken farm and is ranked the third largest egg producer in PNG after Zenag and Niugini Tablebirds Ltd.

Experimental birds

Hyline Brown chickens were obtained from New Zealand under special arrangements between CLTC management and the Egg Producers Federation of New Zealand, as CLTC is operated under the support of New Zealand. The pullets used in this trial were from fertile eggs obtained from the breeder shed and incubated in the hatchery facility. They were raised on broiler starter feed (12.13 MJ/kg metabolisable energy (ME), 21% protein, 7.7% crude fat and 4.1% crude fibre) from day 1 to day 70 and pullet grower (10.95 MJ/kg ME, 17.5% protein, 4.6% crude fat and 4.8% crude fibre) from day 71 to day 126. They were given egg layer crumbles (10.97 MJ/kg ME, 16% crude protein, 6.9% crude fat, 4.4% crude fibre) from day 127 to day 146. These rations were supplied by the Goodman Fielder feed mill in Lae.

Housing and husbandry

The trial was carried out in a naturally ventilated shed (12 × 5 m) with sides of wire mesh. The shed was constructed using local timber and roofed with kunai grass leaves (*Imperata cylindrica*). The shed was partitioned into 12 pens (2 × 1 m) in two rows of six, and each row was considered to be an experimental block.

A total of 120 Hyline Brown hens of 21 weeks of age were randomly allocated to the 12 pens (10 birds in each pen, i.e. 0.6 m^2/bird). The floor was covered with woodchips (5 cm deep) and each pen had a bell drinker 36 cm in diameter which provided 11.3 cm linear drinking space per bird, and a tube feeder 30 cm in diameter which provided 9.4 cm of linear feeding space per bird. The drinking water was sourced from the mains water supply. Artificial fluorescent light (17 lux intensity) was switched on at 5pm and off at 6am, providing 24 hours of light.

An allowance of 2 kg of test diet was fed to the hens in each treatment pen every morning on an ad libitum basis and feed was topped up where necessary in the afternoon. Leftover and spilled feeds were collected at the end of each week, weighed and recorded.

The eggs were collected daily and weighed. Data on bird numbers, mortality and ambient temperature were also recorded daily. Feed refusal weight and body weight were recorded at the end of each week. Eggs were sampled for eggshell thickness, and yolk colour was scored from 1 to 15 using the Roche Colour Fan as a guide. Eggs were stored in a fridge for further analysis. Faeces were sampled, dried and stored in the freezer at −5°C.

Experimental diets

There were three dietary treatments evaluated in this trial: a sweetpotato-based diet consisting of a high-energy layer concentrate (HELC) mixed with boiled and mashed sweetpotato (BMSP) tubers; a cassava-based diet consisting of a low-energy layer concentrate (LELC) mixed with boiled mashed cassava (BMC) tubers; and a commercial diet supplied by the Lae feed mills as the control. HELC and LELC are proprietary concentrates developed as part of a multi-institutional collaborative research project to improve profitability of smallholder broiler and layer production in PNG, and are produced by the Lae feed mills. The concentrates contain protein meals, amino acids, vitamins, minerals, mould inhibitors and antioxidants.

The sweetpotato ('Waghi besta' variety) and cassava (various local varieties) were purchased from a local market near the site of the trial. The sweetpotato and peeled cassava tubers were washed in cool water and 12 kg of the tubers were boiled for 25 minutes in separate bowls half-filled with water over a wood-fired stove. The cooked sweetpotato and cassava tubers were then mashed by hand in different bowls (4 L capacity) and mixed with HELC and LELC respectively, in proportions shown in Table 1.

Chemical analysis

Chemical analysis was carried out on duplicate samples of each test diet using the methods of AOAC (1990) for dry matter and moisture, crude protein, crude fat, crude fibre, calcium and phosphorus at the Analytical Services Laboratory of the PNG University of Technology, Department of Agriculture. The results of the analysis are shown in Table 2.

Experimental design and measurements

The trail was carried out over a period of 14 weeks from 13 May to 12 August 2012. Prior to the trial, CLTC farm staff involved in the experiment were given training on the protocol and data collection.

Percent egg production was calculated as the number of eggs produced each day divided by the number of hens alive on that day and multiplied by 100. The daily measurements were averaged over the trial period to obtain the overall average egg production percent of each pen. Eggs were collected once daily from each pen and weighed using a 2 kg weighing scale (accurate to 0.01 kg). Cracked eggs were also counted and weighed. Egg weight was calculated as the total weight of eggs divided by the number of eggs in each pen. Feed intake of hens was obtained by deducting the weight of leftover and spilled feed from the total weight of feed given each week and averaging the results over the trial period. Feed conversion ratio (FCR) was calculated as total feed intake divided by total egg weight. Weight gain of hens

Table 1. Proportions of ingredients in the test diets.

	Treatment I		Treatment II	
	HELC	BMSP	LELC	BMC
Proportion (%, dry matter basis)	60	40	60	40
Quantity (g, as-fed basis)	2,568	5,649	2,568	5,136
Mixing ratio	1	2.2	1	2

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers.

was calculated by subtracting the initial weight from the final weight of birds over the trial period. The hens were weighed with a Salter® spring weighing scale (50 kg capacity accurate to 0.1 kg) every week. There were no mortalities during the trial period.

Average feed cost per kg egg was calculated for each diet as the cost of ingredients consumed divided by the weight of egg produced. Feed cost on the control diet was similarly calculated using the cost of the complete layer feed as sold near the trial site.

Nine eggs from each pen were randomly chosen from the eggs laid in week five of the trial and used for eggshell thickness and egg yolk colour measurements. The eggs were weighed then cracked open and the shells were separated from the rest of the contents. Four readings were taken from the equatorial sides of the eggshell (with egg membrane removed) and these were used to calculate mean eggshell thickness. The thickness of the eggshells was measured using a micrometer screw thread gauge (accurate to 0.001 g). The contents of the sampled eggs were emptied into a clear glass bowl and the albumen was carefully separated into another container. The Roche fan was placed against the glass bowl containing the egg yolk and used to score the colour of the egg yolk.

Statistical analysis

Single factor analysis of variance (ANOVA) was carried out on each variable to compare treatment means using SPSS 2012 software, version 17.0 (IBM Corp 2012). Where the treatments were found to have significant effect on the variable, mean separation was carried out using the least significant difference method (LSD; $P = 0.05$).

RESULTS

The main results are shown in Table 3. The treatment diets had highly significant effects on all variables measured except egg weight, body weight changes and eggshell thickness. Hens fed on the commercial diet had significantly higher egg production feed intake, FCR and feed costs than hens fed on the cassava and sweetpotato-based diets ($P < 0.05$).

With respect to egg yolk colour, hens fed on the commercial diet had more deeply hued eggs (higher score) compared to hens fed on the cassava and sweetpotato diets (Table 4). Birds fed the cassava-based diet tended to have darker coloured yolks than birds fed the sweetpotato-based diet (Table 4).

DISCUSSION

Birds fed the control diet had higher egg production and higher feed intake than birds fed the sweetpotato- and cassava based-diets. Birds fed the sweetpotato-based diet had the lowest production of all diets. However, the FCR of the birds fed the sweetpotato and cassava was better than birds fed the control diet, and the feed cost per kg of egg produced was lower with these local diets. The higher intake of the commercial diet may be due to its lower ME content (Table 2) since hens tend to increase or decrease feed consumption to maintain energy intake by consuming

Table 2. Nutrient composition of concentrates, test diets and control diet as analysed at the Analytical Services Laboratory of the PNG University of Technology, and nutrient requirements of layer chickens.

	ME (MJ/kg)	Crude protein (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Avail. P (%)
HELC	8.67	14.42	5.85	3.89	2.74	0.49
LELC	10.92	21.95	8.84	4.55	4.4	0.79
HELC+BMSP	12.83[i]	15.47	6.06	2.14	2.73	0.47
LELC+BMC	11.63[i]	14.57	5.66	4.69	2.76	0.48
Control	10.97	16.0	6.9	4.4	3.4	0.64
Requirements[ii]	11.20	17	4.0	3.0	3.7	0.44

[i] Estimates from UNEFORM (Thomson 2012).
[ii] Hyline International (2009).
HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers; ME = metabolisable energy; Avail. P = available phosphorus.

Table 3. Egg production, egg weight, feed intake, feed conversion ratio, body weight change, feed cost per kg egg and eggshell thickness of Hyline Brown hens fed the three different diets from 21 to 35 weeks of age.

Parameter	Treatment			Std error	*P*
	HELC+BMSP	LELC+BMC	Control		
Egg production (%)	66.3[a]	74.3[a]	86.2[b]	2.49	0.002
Egg weight (g)	55.5	52.8	56.5	1.07	0.091
Feed intake (g/bird/day, dry matter basis)	94.8[a]	101.8[a]	123.5[b]	3.2	0.001
FCR (kg feed/kg egg)	1.69[a]	1.95[b]	2.17[c]	0.063	0.002
Body weight change (g)	0.19	0.18	0.153	0.015	0.076
Feed cost per kg egg (kina)	4.25[a]	4.92[a]	5.76[b]	0.152	0.001
Eggshell thickness (mm)	0.46	0.45	0.45	0.011	0.507

HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers; FCR = feed conversion ratio.
Means within rows with different superscripts are significantly different at $P < 0.01$.

Table 4. Observed egg yolk colour categories by treatment diets.

Treatment	Colour fan value							Total
	1	3	4	5	6	9	12	
HELC+BMSP	22	50		9	19			100
LELC+BMC		23	35		42			100
Control						18	82	100

more of a low-energy than a high-energy diet (Hyline International 2009).

The egg yolk was more deeply hued on the commercial diet than on the cassava- and sweetpotato-based diets. This may be due to carotenoid inclusion in the commercial diet, or ingredients containing this pigment. The mixed colour sweetpotato ('Waghi besta') and white cassava variety resulted in much paler yolks. Using yellow sweetpotato and cassava varieties might improve yolk colour.

CONCLUSION

Hens fed on the commercial diet laid more eggs but consumed more feed and had poorer feed conversion ratio compared to hens fed on the cassava- and sweetpotato-based diets. Feed costs were significantly higher for hens fed on the commercial diet but egg weight and average body weight changes during the trial were similar for hens fed on the local and commercial diets. These results, and the lower cost of the sweetpotato- and cassava-based diets, suggest that these diets could be a viable alternative to commercial diets, especially in parts of PNG which are located far from commercial feed mills.

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Comparison of egg production performance of three genotypes of layer hen (Hyline Brown, Hyline Brown × Australorp and village chickens) fed on concentrates blended with sweetpotato or cassava, in Papua New Guinea

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Abstract

This study was conducted to evaluate the egg production performance of three genotypes of layer hens—village chickens (V), Hyline Brown (HB) and Hyline Brown × Australorp F1 cross (HB×A)—fed concentrate diets blended with cooked local ingredients sweetpotato and cassava. The two test diets were compared with a commercial layer pellet diet as a control. Forty-two hens of each genotype were used, at 25 weeks of age, and there were two replicates of each diet treatment for each genotype. Egg production, body weight, egg weight, feed conversion and feed costs were monitored for an eight-week period. The HB×A and the V hens fed with the two test diets had zero and 3.6% mortality, respectively, compared to 10.7% mortality for the hens fed the control diet. Percent egg production was significantly higher in the HB×A hens fed with the cassava- and sweetpotato-based test diets ($P < 0.001$). The HB hens fed on the control diet had the highest egg weight, while the village hens had significantly higher feed conversion ($P < 0.001$). The feed cost of a 53 g egg produced from hens fed on a cassava-based test diet was 0.082 kina. This was lower than hens fed on a sweetpotato-based diet (0.093 kina), while the control diet cost was 0.14 kina. It was concluded that the best option for village poultry producers is to use the HB×A crossbred strain and to feed them with sweetpotato- and cassava-based diets given their lower mortality, higher egg production and lower feed costs.

INTRODUCTION

Smallholder egg production in Papua New Guinea (PNG) is a source of income, helps meet social obligations and improves human nutrition. About 80% of the estimated 7.2 million current population of the country (FAOSTAT 2013) live in rural areas and are engaged in smallholder subsistence agriculture. Additionally, about 42% (or about 360,000 rural households) are engaged in village chicken production (NSO 2002). Smallholder commercial and semi-commercial poultry production, using commercial hybrid and local crossbred chickens, is rapidly expanding in response to increasing demand for quality poultry products.

Globally, feed constitutes a major part of the total cost of production in any commercial poultry enterprise (Renkema 1992). As the entire supply of grains used for making feed in PNG is imported, market prices for feed in the country are vulnerable to price changes of grains in the global market. As a result

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retail prices of, for example, layer pellets in the Lae market have more than doubled since 2003 (Ayalew 2013). Research and development work in smallholder poultry production in PNG and the Pacific region has focused on developing lower cost feeding strategies that maximise the use of local resources in the formulation of complete broiler and layer rations (Glatz et al. 2010; Glatz 2012). The present research is part of this effort and examines layer feeding value of two local staples, sweetpotato and cassava.

This trial was undertaken to test if layer concentrates supplemented with cooked sweetpotato or cassava could reduce the cost of production. Based on successful experiences in developing lower cost broiler finisher diets using sweetpotato and cassava as major energy sources (Glatz et al. 2010), low- and high-energy concentrates (containing protein meals, amino acids, vitamins and minerals) were formulated for mixing with sweetpotato and cassava to make a complete layer ration. This paper reports on the first phase of a series of experiments to evaluate the performance of different layer chicken genotypes and to develop best-bet feeding options.

The village chicken was introduced to PNG from South-West Asia and is related to the wild jungle fowl (Alders 2001; Nthimo 2004). Over the years, these birds have been crossed with the Rhode Island Red and Australorp chickens introduced to PNG during the colonial era and during the first crossbreeding scheme initiated by the Department of Primary Industry in 1964, purposely for improved family nutrition (Quartermain 2000). The Hyline Brown birds first came to PNG as fertile eggs from New Zealand, imported by the Christian Leaders Training College in Banz for its breeder farm, and semen has since been imported for breeding.

The specific objectives of this study were to: (1) evaluate the egg production performance of the three layer chicken genotypes fed with sweetpotato- or cassava-based layer rations or a commercial layer diet; (2) determine the best-bet feeding option for local poultry farmers in PNG; and (3) compare the feed cost of egg production for the sweetpotato- and cassava-based diets with the commercial layer diet.

MATERIALS AND METHODS

Experimental site

The experimental work was conducted at the PNG National Agricultural Research Institute (NARI) Livestock Research Station at Labu (6°40′27″ S, 146°54′33″ E), located outside Lae. The climate is typically warm and wet, and had an average temperature of 32°C and relative humidity of 88–90% during the experimental period.

Experimental birds

Day-old Hyline Brown (HB) chicks were obtained from the Christian Leaders Training College (CLTC) hatchery in Banz. Chicks were raised on starter crumble (12.13 MJ/kg, 21% protein, 7.7% fat and 4.1% fibre) during the first ten weeks. Thereafter, birds were fed on pullet grower feed (10.95 MJ/kg, 17.5% protein, 4.6% fat and 4.8% fibre) until they reached week 18. Feed was then switched to commercial layer pellets (10.97 MJ/kg, 16% protein, 6.9% fat and 4.4% fibre) up to point of lay at 24 weeks.

A similar feed strategy was used for the F1 crosses of Hyline Brown (female) × Australorp (male) (HB×A). These birds were hatched in a Multiquip (Model E3) incubator at Labu Research Station. The parent HB hens were previously obtained from CLTC and the Australorp male strain has been maintained since the 1980s at Labu.

Village chicks (V) were sourced from villages around Lae city at 0.15 ± 0.03 kg body weight, with an estimated age between four and seven weeks. These chicks were fed on starter crumble until they were between eight and 11 weeks of age and switched to a pullet grower diet until 18 weeks of age. Birds were then fed on commercial layer pellets to 24 weeks of age.

Housing

The experimental shed had dimensions of 30 × 6 m and faced in a north-east direction with natural ventilation. It had an iron roof, Masonite and wire mesh walls and a concrete floor. The shed was partitioned into two blocks of 10 pens each, each pen measuring 3 × 2.5 m. The floor was covered with 5 cm of wood chip litter. Each pen had a round drinker 28 cm in diameter providing 3.4 cm linear drinking space per bird, and a round feeder 30 cm in diameter providing 3.9 cm linear feeding space per bird.

Fluorescent light (17 lux intensity) was switched on at 5pm and off at 6am to provide 24 hours of light (natural during the day and artificial at night). Ambient temperature was monitored daily and ranged from a minimum of 23.4°C to a maximum of 37.7°C.

Experimental diets

The commercial layer pellet was procured from a local retail shop. High-energy and low-energy layer concentrates (HELC and LELC) were produced and costed by a commercial feed mill in Lae. Fresh sweetpotato and cassava tubers were purchased from the main vegetable market in Lae. The white local cassava was mostly used while 'Waghi besta' was the variety of sweetpotato used.

Birds were fed three different diets: (1) high-energy layer concentrate blended with boiled mashed sweetpotato (HELC + BMSP); (2) low-energy layer concentrate blended with boiled mashed cassava (LELC + BMC); and (3) the commercial layer pellet as the control diet. The nutritional specifications of the concentrates, the test diets and the commercial diet were estimated using UNEForm (Thomson 2012) and compared with the standard layer nutritional requirements (Hyline International 2009) (Table 1).

Quantities of ingredients in experimental diets

Based on the guidelines for average daily feed intake of Hyline Brown layers (107 g/hen/day), 4.5 kg of feed was weighed and fed to the layers in each diet group (i.e. 107 g/bird × 42 hens = 4.494 kg). The mixing of rations of the concentrate diets with respective boiled mashed tubers was based on the moisture factor of 3.3 for sweetpotato and 3.0 for cassava.

HELC + BMSP diet:

60% HELC + 40% BMSP

Amount of sweetpotato: 40/100 × 4.494 = 1.798 kg

1.798 × 3.3 = 5.932
= approx. 5.9 kg cooked sweetpotato tubers

Amount of HELC: 60/100 × 4.494 = 2.696
= approx. 2.7 kg

Mixing ratio: 5.9 kg BMSP to 2.7 kg HELC

LELC + BMC diet:

60% LELC + 40% BMC tubers

Amount of cassava: 40/100 × 4.494 = 1.798 kg

1.798 × 3.0 = 5.394
= approx. 5.4 kg boiled cassava tubers

Amount of LELC: 60/100 × 4.494 = approx. 2.7 kg LELC

Mixing ratio: 5.4 kg BMC to 2.7 kg LELC

Table 1. Estimated nutrient composition of concentrates, the two test diets and the control diet, and nutrient requirements of layer chickens.

	ME (MJ/kg)	Crude protein (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Avail. P (%)
HELC	8.67	14.42	5.85	3.89	2.74	0.49
LELC	10.92	21.95	8.84	4.55	4.4	0.79
HELC + BMSP	12.83[i]	15.47	6.06	2.14	2.73	0.47
LELC + BMC	11.63[i]	14.57	5.66	4.69	2.76	0.48
Commercial diet	10.97	16.0	6.9	4.4	3.4	0.64
Requirements[ii]	11.20	17	4.0	3.0	3.7	0.44

[i] Estimates from UNEFORM (Thomson 2012).
[ii] Hyline International (2009).
HELC = high-energy layer concentrate; BMSP = boiled mashed sweetpotato tubers; LELC = low-energy layer concentrate; BMC = boiled mashed cassava tubers; ME = metabolisable energy; Avail. P = available phosphorus.

Experimental design

The experimental period covered 10 weeks from point of lay at 25 weeks. Forty-two pullets from each of the three genotypes (HB, HB×A and V) were allocated to 18 feeding pens arranged in two rows of nine, with an experimental layout of three diets, three genotypes and two replicates, with seven hens per pen. First, the genotypes were randomly allocated to pens independently for each row, followed by allocation of dietary treatments within each genotype (Table 2). The hens were provided fresh wood chips as litter and a nest box and perches were provided. Hens had ad libitum access to feed and clean rainwater.

Variables measured

Production data were recorded for each pen. Hen inventory, number of eggs laid, weight of eggs and number of cracked eggs were recorded daily. Weighed amounts of feed were topped up twice daily to ensure hens had ad libitum access while minimising feed spillage. Feed refusals in the hoppers were removed every day and weighed. The feed hoppers were thoroughly washed at weekly intervals. Body weight of pullets was recorded at the start of the trial and at monthly intervals thereafter until the trial was terminated.

Chemical analyses of feed and faeces samples

Weekly feed and faeces samples were collected from each pen for analysis. These samples were dried in the sun, ground into fine powder and stored in the refrigerator at 5°C. Before the analyses, all samples were checked, mixed and packed by treatment group.

The moisture content of feed and faeces samples was measured as the difference between initial fresh sample weight and desiccated sample weight after samples were heated in an oven at 100°C for 24 hours, expressed as a percentage of the initial weight. The calculated values of replicate feed and faeces samples of each treatment were averaged to arrive at a moisture level for each treatment group.

The feed and faeces samples were analysed at the PNG University of Technology Analytical Laboratory following procedures described by AOAC (1990).

Statistical analysis

Microsoft Excel was used to compile data and Genstat (2012) was used for the analysis. A two-way ANOVA was used to analyse diet and genotype effects in the model:

$$Y_{ij} = \mu + r_i + \beta_j + \gamma_{ijk}$$

where Y is the response variable, μ is the overall mean response, r_i is the effect due to the i-th level of factor diet, β_j is the effect due to the j-th level of factor genotype, γ_{ijk} is the effect due to any interaction between the i-th level of diet and the j-th level of genotype, and k denotes the k-th observation in the treatment.

Table 2. Experimental design.

Row 1			Row 2		
Pen #	**Genotype**	**Diet**	**Pen #**	**Genotype**	**Diet**
1	HB×A	Commercial	20	HB×A	LELC+BMC
2	V	Commercial	19	HB	Commercial
3	HB×A	HELC+BMSP	18	V	Commercial
4	HB	LELC+BMC	17	V	HELC+BMSP
5	V	LELC+BMC	16	V	LELC+BMC
6	HB	HELC+BMSP	15	HB×A	HELC+BMSP
7	V	HELC+BMSP	14	HB×A	Commercial
8	HB	Commercial	13	HB	LELC+BMC
9	HB×A	LELC+BMC	12	HB×A	HELC+BMSP

HB×A = Hyline Brown (female) × Australorp; HB = Hyline Brown chickens; V = village chickens; HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers.

The following formulae were used:

$$\text{Pen feed intake} = \text{feed offered daily} - \text{feed refusals at the end of each day}$$

$$\text{Egg production \%} = \frac{\text{average number of eggs produced per day in a period}}{\text{total number of hens surviving to the end of that period}} \times 100$$

$$\text{Feed conversion ratio} = \frac{\text{weight of dry matter feed intake in a period}}{\text{weight of eggs produced during that period}}$$

$$\text{Weight gain} = \text{final average body weight} - \text{initial average body weight}$$

RESULTS

Table 3 gives the results of the analyses of feed and faeces samples. The results suggest that the protein in the commercial diet and the LELC+BMC diet was utilised more efficiently by HB and HB×A hens than by the V hens. However, V hens utilised protein from the HELC+BMSP diet more efficiently than both HB and HB×A hens. It might be suggested that V chickens have a genetic predisposition to utilise local feed more efficiently. The results also indicate that V hens fed the commercial and HELC+BMSP diets had a high level of calcium and phosphorus in their faeces. This might suggest a low utilisation of calcium and phosphorus for eggshell formation. The moisture level of feeds was higher in the HELC+BMC and the LELC+ BMSP diets than in the commercial diet.

The cost of feed was calculated using the market price of feed ingredients excluding the cost of labour and equipment. The unit costs were used to determine the cost of experimental diets (Table 4). By this method, the unit costs of diets per kg on a dry matter (DM) basis were 1.75 kina for the HELC+BMSP diet, 1.55 kina for the LELC+BMC diet and 2.64 kina for the commercial diet, indicating that the test diets had a lower cost (Table 5).

No mortality was recorded during the first week of the experiment. Mortality recorded thereafter to the end of week 10 (35 weeks of age) was overall 4.8% each for the HB×A and V hens, significantly lower than the 25.86% mortality recorded for the HB birds ($P < 0.05$). Similarly, layers fed on the HELC+BMSP

Table 3. Results of the analyses of feed and faeces samples by bird genotypes and experimental diets.

Diet	Sample	Genotype	Ash (%)	Calcium (%)	Crude fat (%)	Moisture (%)	Phosphorus (%)	Crude protein (%)
Commercial	Feed		10.4	2.43	7.8	5.11	0.67	16.3
HELC+BMSP	Feed		9.66	2.16	3.52	6.82	0.54	15.5
LELC+BMC	Feed		12.9	2.99	3.30	7.43	0.85	14.6
Commercial	Faeces	HB	19.9	3.05	2.10	8.08	1.03	19.6
Commercial	Faeces	HB×A	13.1	2.28	4.28	9.61	0.99	21.2
Commercial	Faeces	V	18.8	4.79	1.48	9.64	1.64	23.5
HELC+BMSP	Faeces	HB	22.2	3.18	4.28	9.13	1.18	29.5
HELC+BMSP	Faeces	HB×A	21.8	3.50	5.09	9.05	1.06	25.9
HELC+BMSP	Faeces	V	24	4.91	2.18	9.40	1.51	25.5
LELC+BMC	Faeces	HB	15.8	2.86	3.30	10.6	1.98	22.9
LELC+BMC	Faeces	HB×A	18.1	2.61	4.56	9.28	1.38	25.6
LELC+BMC	Faeces	V	24.5	3.18	4.28	9.13	1.18	29.5

HB×A = Hyline Brown × Australorp chickens; HB = Hyline Brown chickens; V = village chickens; HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers.

and the LELC+BMC diets had a significantly lower mortality rate of 2.04% and 7.14%, respectively, compared with birds fed on the commercial diet with mortality of 26.18% at the end of the experiment ($P < 0.001$) (Table 6). HB hens fed the commercial diet had higher mortality than HB×A and V hens from the second week of the trial (Table 6).

The high mortality for HB and HB×A hens on the commercial diet was almost exclusively caused by injurious pecking. It was also noted that HB and HB×A hens fed on the HELC+BMSP diet had low mortality compared to the LELC+BMC diet. This finding indicates that HB and crossbred hens fed a commercial diet under cage-free conditions have a high propensity for cannibalism relative to locally bred strains. On the other hand, the V hens fed on HELC+BMSP and LELC+BMC diets had zero mortality compared to 10.7% mortality on the commercial diet.

The HB×A hens achieved consistently higher egg production throughout the trial compared to the HB hens (Figure 1). It was expected that the HB hens would achieve peak egg production of between 94% and 96% (Hyline International 2009). The observed cannibalism and feather pecking must have had a substantial impact on egg production; birds only achieved a peak egg production of 70–75% during 34 and 35 weeks of age.

The results in Table 7 also show that the HB×A hens achieved the highest average egg production (70.4%), and significantly higher than that of the HB hens (52.6%) and V hens (38.1%) ($P < 0.05$). Hens fed the LELC+BMC diet had significantly higher egg production (61.9%) than those fed the HELC+BMSP diet (52.7 %) and the commercial diet (46.5%) ($P < 0.05$). As expected, the V hens had the lowest egg production percentage: 29% in week 32 and 37% in week 10. Generally, hens fed on the LELC+BMC diet performed best until week 31. The birds fed the commercial diet initially had the lowest egg production but this increased gradually from week 28 until it reached 68.2% in week 34.

The average daily feed intake per bird (calculated on a dry matter basis) for the three diets is presented in Table 7. The average daily feed intake was highest for HB×A hens followed by HB and V hens ($P < 0.05$). The average feed intake for HB hens of 122.5 g /day/hen agrees with the commercial management guide for

Table 4. Unit market prices of sweetpotato, cassava, commercial layer feed and concentrates.

	Quantity (kg)	Price (kina)	Unit cost (kina)	Peel (%)	Total cost per kg (kina)
Sweetpotato	80	60.0	0.75	–	0.75
Cassava	24	16.8	0.70	0.13	0.16
Commercial feed	40	95.0	2.38	–	2.38
HELC/LELC	40	100.0	2.50	–	2.50

HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers.

Table 5. Calculated unit costs of experimental diets.

Diet	Boiled mashed: concentrate ratio	Concentrate (kg)/kg feed	Sweetpotato or cassava (kg)/kg feed	Cost/kg (kina)	Cost/kg (kina) DM basis
HELC+BMSP	5.9:2.7	0.31	0.69	1.25	1.75
LELC+BMC	5.4:2.7	0.33	0.67	1.19	1.55
Commercial	–	–	–	2.32	2.64

HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers.

Table 6. Average weekly cumulative mortality in diet × genotype groups and overall mortality percentage from 26 to 35 weeks of the experiment.

Diet/genotype	Wk 26	Wk 27	Wk 28	Wk 29	Wk 30	Wk 31	Wk 32	Wk 33	Wk 34	Wk 35	% mortality	% mortality
HELC+BMSP/HB×A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
HELC+BMSP/HB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	9.4	2.04
HELC+BMSP/V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
LELC+BMC/HB×A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.50	19.1	
LELC+BMC/HB	0.00	0.21	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00	11.4	7.14
LELC+BMC/V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
Commercial/HB×A	0.00	0.00	0.43	0.50	0.50	0.50	6.50	6.50	6.50	6.50	39.9	
Commercial/HB	0.00	0.00	0.50	1.79	2.57	3.00	3.29	3.50	3.93	4.00	32.2	26.18
Commercial/V	0.00	0.14	0.50	0.86	1.00	1.00	1.00	1.00	1.00	1.00	10.7	
Grand mean	0.00	0.04	0.25	0.46	0.56	0.61	1.31	1.33	2.92	3.62	15.9	15.9
Diet x genotype (*P* value)	0	0.008	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		

HB×A = Hyline Brown × Australorp chickens; HB = Hyline Brown chickens; V = village chickens; HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers.

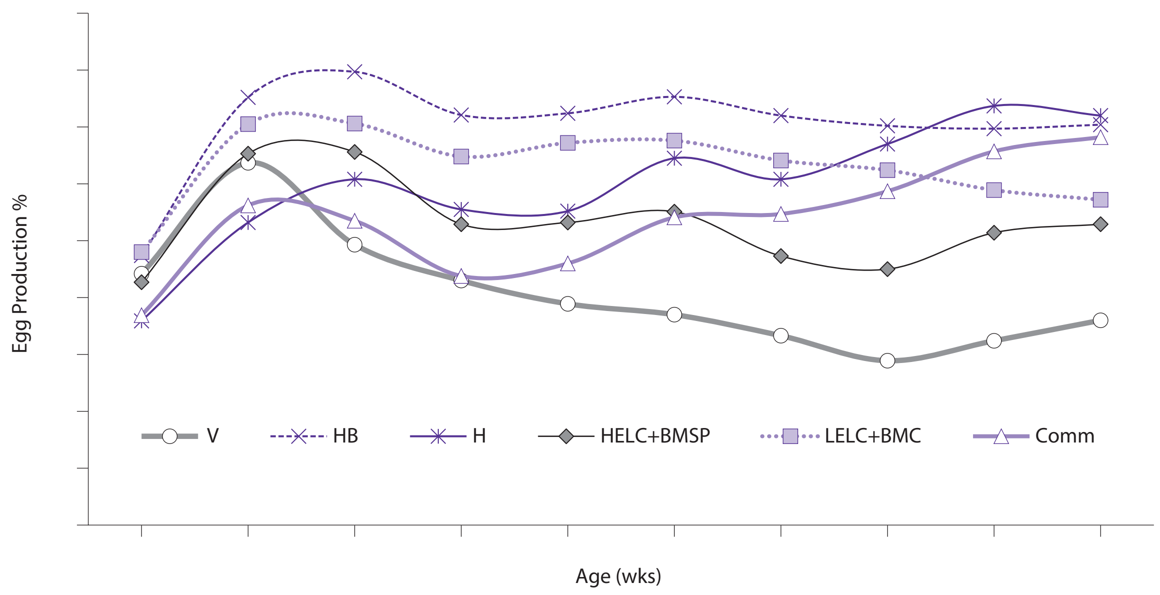

Figure 1. Weekly percent egg production by genotype and treatment diet from 25 to 35 weeks of age.

Table 7. Average feed intake, egg weight, percent egg production, feed conversion ratio and body weights of experimental hens for the different genotypes and treatment diets from 25 to 35 weeks of age.

	DM feed intake (g/day/bird)	Egg weight (g)	Egg production (%)	FCR (g feed/kg egg)	Average body weight (kg)	Average weight gain (g)
Genotype						
V	92.6a	50.2c	38.14c	1.9c	1.497a	10
HB×A	128.9b	55.9b	70.38a	2.3b	1.790b	45
HB	122.5c	57.9a	52.60b	2.1a	1.620c	40
P value	<0.001	<0.001	<0.001	<0.001	<0.001	0.356
Diet						
HELC+BMSP	111.4a	54.3a	52.72b	2.1a	1.672	56
LELC+BMC	129.9b	53.5a	61.89a	2.4b	1.625	3
Commercial	96.7a	56.1b	46.5c	1.7c	1.612	36
P value	<0.001	<0.001	<0.001	<0.001	0.066	0.141
Grand mean	114.7	54.7	53.7	2.1	1.636	31
LSD 5%	4.712	0.539	2.705	0.0825	0.0523	52.9

HB×A = Hyline Brown × Australorp chickens; HB = Hyline Brown chickens; V = village chickens; HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers; DM = dry matter; FCR = feed conversion ratio.
Means followed by a common letter are not significantly different ($P > 0.05$).

HB hens, which specifies feed intake per bird from 18 to 72 weeks of 115–122 g/day (Hyline International 2009). The HB hens produced the highest egg weight, as expected, followed by the HB×A hens then the village hens (Table 7). The differences in egg weight between genotype were statistically significant ($P < 0.05$). In addition, chickens fed the standard commercial layer pellet achieved the highest egg weight compared to hens fed on HELC+BMSP and LELC+BMC diets.

The feed conversion ratio (FCR) results showed a significant difference between hen genotypes and diets ($P < 0.05$). The most efficient converters of feed were the V hens followed by the HB and then the HB×A hens (Table 7). When feed type is considered, birds fed on the commercial diet had significantly better FCR than birds fed on the HELC+BMSP and LELC+BMC diets ($P < 0.05$).

The average body weight of the HB×A hens was significantly different from the HB and V hens ($P < 0.05$), while body weights for the birds fed the commercial, HELC+BMSP and LELC+BMC diets were similar ($P > 0.05$). At the end of the trial, the body weights of the HB×A and HB hens were

Table 8. Effects of diet and genotype on average feed intake, average egg weight, egg production, feed conversion ratio (FCR) and body weight of birds from 25 to 35 weeks of age.

Diet/genotype	DM feed intake (g/day/bird)	Egg weight (g)	Egg production (%)	FCR (g feed/kg egg)	Average body weight (kg)	Average weight change (g)
HELC+BMSP/V	93.9	49.7f	36.8g	1.88	1.48	50
HELC+BMSP/HB×A	134.2	56.6b	64.9d	2.38	1.89	97
HELC+BMSP/HB	124.2	56.6b	56.4e	2.2	1.64	21
LELC+BMC/V	108.4	49.8f	42.7f	2.17	1.53	–26
LELC+BMC/HB×A	140.9	54.9d	74.8a	2.58	1.74	40
LELC+BMC/HB	140.2	55.9c	68.2c	2.51	1.61	–4
Commercial/V	75.5	51.1e	34.9h	1.49	1.48	6
Commercial/HB×A	111.6	56.3b	71.4b	1.99	1.74	–1
Commercial/HB	103.1	61.0a	33.2i	1.67	1.61	102
Grand mean	114.7	54.7	53.7	2.10	1.64	31
P value (D×G)	0.50	<0.001	<0.001	0.16	0.04	0.07
SEM	2.94	0.34	1.69	0.05	0.03	32.2
LSD 5%	8.16	0.93	4.69	0.14	0.09	91.7

HB×A = Hyline Brown × Australorp chickens; HB = Hyline Brown chickens; V = village chickens; HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers; DM = dry matter; FCR = feed conversion ratio.
Means followed by a common letter are not significantly different ($P > 0.05$).

Table 9. Egg weight equivalent of feed intake and feed cost of eggs produced by diet.

Diet	DM feed intake (g/bird)	Cost/kg DM feed (kina)	Cost of daily DM feed consumed (kina)	FCR to eggs	Egg weight equiv. of feed intake (g)	Daily feed cost of egg (kina)	Feed cost of 53 g egg (kina)
Commercial	96.7	2.64	0.255	1.7	56.9	0.150	0.140
HELC+BMSP	111.4	1.75	0.195	2.1	53.0	0.093	0.093
LELC+BMC	129.9	1.55	0.201	2.4	54.1	0.084	0.082

HELC+BMSP = high-energy layer concentrate + boiled mashed sweetpotato tubers; LELC+BMC = low-energy layer concentrate + boiled mashed cassava tubers; DM = dry matter; FRC = feed conversion ratio.

higher compared with the V hens. Birds fed the HELC+BMSP and LELC+BMC diets had numerically different body weights but these were not statistically different ($P > 0.05$). Overall the average body weights of hens (Table 7) were significantly different for genotypes ($P < 0.05$). The HB hen average body weight was within the range (1.5–1.91 kg) given in the guidelines for the breed (Hyline International 2009).

The diet × genotype interaction showed no significant differences in feed intake, FCR, body weight and weight change ($P > 0.05$) (Table 8); however, egg weight and egg production showed highly significant differences between groups ($P < 0.001$). The HB×A hens laid more eggs when fed on the LELC+BMC diet (74%), the commercial diet (71%) and the HELC+BMC diet (64.9%) than the HB hens and produced heavier eggs when fed the HELC+BMC diet (56.6 g).

Average feed cost of egg production was derived from calculated values of daily feed intake, cost of rations and the FCR (Table 9). Combining dry matter feed intake with FCR gives egg weight equivalent of feed intake of 56.9 g per day for the commercial diet, 53.0 g for the HELC+BMSP diet and 54.1 g for the LELC+BMC diet. Relating these with the average cost of diets gives an estimate of daily feed cost of egg production for each diet, i.e. 0.15 kina for the commercial diet, 0.093 kina for the HELC+BMSP diet and 0.084 kina for the LELC+BMC diet. Correcting these average values for the differences in average egg weight (egg weight equivalent of feed intake) gave the feed cost of a 53 g egg of 0.14 kina for the commercial diet, 0.093 kina for the HELC+BMSP diet and 0.082 kina for the LELC+BMC diet. On this basis, it can be inferred that the overall feed cost of egg production was reduced by 66.4% and 58.6% on the HELC+BMSP and LELC+BMC diets respectively, compared to the control commercial layer pellet.

DISCUSSION

The high mortality in HB and crossbred hens was related to injurious pecking, which can be controlled by beak trimming (Bourke et al. 2002). This concurs with an earlier report of high pecking-related mortality rates in HB layers (Häne et al. 2000). The routine use of HB layers in cage-free production has led to the inaccurate conclusion that high death rates result from cage-free systems, when in fact the hen strain or an interaction between the hen strain and the environment may be the cause (Berg 2001; Blokhuis et al. 2007). A similar earlier study by Aerni et al. (2005) also reported differences in mortality, in which the production system was confounded with the genotype of hen, unlike the present study. The difference that genotype makes to mortality rates can be understood by examining studies that have compared different hen strains in the same environment. Sørensen (2001) compared the mortality rates of four hen genetotypes (ISA Brown, New Hampshire, White Leghorn and a cross between New Hampshire and White Leghorn hens) under identical conditions of indoor rearing in pens until they reached 16 weeks of age, after which they were given free-range access. The mortality rates observed were 19.9% for the ISA Brown hens, 13.8% for the New Hampshire hens, 6.7% for the White Leghorn hens and 3.9% for the cross. It was concluded that where mortality was high, a primary cause was injurious pecking behaviour, a common problem in commercial flocks.

The fact that the two test diets were presented as wet feeds may have contributed to the significantly higher dry matter feed intake compared with the commercial layer pellet. Tadtyanant et al. (1991) observed that wet feeding increased the dry matter intake and thereby partially alleviated the effect of heat stress on feed intake and laying performance. Those wet diets contained 50% moisture, which is equivalent to 51.3% and 53.6% moisture content respectively in the LELC+BMC and HELC+BMSP diets in this study on an as-fed basis. Okan et al. (1996) reported that dry matter intake, egg production and egg weight were all enhanced by wet feeding, which was prepared by adding tap water to the diet at the ratio of 1:0.5–1.3. This is closely related to enhanced solubility of the diet due to cooked sweetpotato and cassava and nutrients being more digestible. In laying hens, the improved performance as a result of wet feeding is due to elevated intake but the feed conversion remains the same (Okan et al. 1996).

Diet and genotype interaction led to significant differences in egg weight and egg production. The HB×A hens had superior performance in terms of egg weight and egg production when fed sweetpotato- and cassava-based diets. The HB hens had heavier eggs when fed the cassava-based diet and the commercial diet but their egg production declined compared to the HB×A hens when fed sweetpotato- and cassava-based diets. Afolayan et al. (2013) found that egg weight of hens increased significantly as the amount of sweetpotato meal increased from 10% to 40%. This result is similar to a study by Aina and Fanimo (1997) which indicated that diets containing cassava and sweetpotato did not affect egg weight but significantly reduced egg production of ISA Brown layer hens. When comparing diets, egg production of HB hens improved when fed on the sweetpotato- and cassava-based diets compared to the commercial diet. The egg weight of the V hens was similar on both sweetpotato- and cassava-based diets and it was better than on the commercial diet. Peak egg production percent (Figure 1, at 26 weeks and 34 weeks of age) for the HB×A hens fed on cassava-based diets was reasonably close to that expected of Hyline Brown hens (Hyline International 2009).

The feed cost of producing a 53 g egg on a cassava-based diet (0.08 kina) and sweetpotato-based diet (0.09 kina) was much less than on the commercial diet (0.14 kina). The result confirmed that using locally produced sweetpotato and cassava as major sources of energy in layer diets leads to reduced cost of feeding birds while maintaining egg production.

CONCLUSION

The three genotypes adapted well to consuming the sweetpotato- and cassava-based test layer diets and they maintained similar egg production levels by increasing their feed intake. Average mortalities of the HB×A and V hens fed the sweetpotato- and cassava-based diets were also lower compared to HB fed the commercial layer pellet. In particular, it is remarkable that the V hens maintained good overall performance levels close to those of the exotic crosses when fed the lower cost feeding options.

Given the effects of genotype and diet on egg production performance and mortality, the best-bet option to recommend to village poultry producers is to use F1 hens and feed them with sweetpotato- and cassava-based concentrate layer diets. The village chickens fed commercial layer pellets or HELC+BMSP diets had high conversion efficiency. The results indicate that HB×A and V hens can be effectively used for egg production when fed on cassava- and sweetpotato-based concentrate diets in PNG and other Pacific island countries with similar agro-ecological zones where sweetpotato and cassava are the main staple crops. It is recommended that these lower cost feeding options be further tested at other research facilities as well as on-farm in areas where interest in egg production is on the rise. Moreover, locally grown sweetpotato and cassava can be effectively used in layer diets for HB×A and V hens and should be promoted in PNG.

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Egg production performance of two crossbred strains of hen (Australorp × Shaver Brown and Shaver Brown × Hyline Brown) fed on concentrate blended with cassava, in Papua New Guinea

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Abstract

Recently in Papua New Guinea there has been emphasis on using crossbred strains of poultry to improve egg production, and reducing feed costs by including greater proportions of local ingredients in poultry diets. This study compared the egg production of two crossbred strains of hen, Australorp × Shaver Brown (A×SB) and Shaver Brown × Hyline Brown (SB×HB), fed a local diet (60% low-energy layer concentrate blended with 40% cooked cassava; LELC+Cas) or a commercial layer ration comprising mainly imported ingredients. Feed intake, egg production, egg weight and feed costs were measured from 19 to 30 weeks of age. Dry matter intake of hens fed LELC+Cas was significantly higher than hens fed the commercial diet (115.2 vs 103.1 g/day/hen; $P < 0.01$). The A×SB strain consumed significantly more feed (117.0 vs 101.3 g/day/hen; $P < 0.01$) and had a significantly higher hen-housed egg production than the SB×HB strain (91.31% vs 83.57%; $P < 0.01$). Feed conversion ratio was not significantly different between the genotypes but birds consuming the commercial ration had slightly better feed conversion than birds fed the local diet (2.43 vs 2.55; $P = 0.076$). The LELC+Cas diet was 7.9% more profitable than the commercial ration, providing a promising feed option for small-scale layer farming. Further evaluation on smallholder farms is recommended to verify associated costs and profit margins over a full laying cycle.

INTRODUCTION

The livestock sector is gaining importance in developing countries driven by population growth, urbanisation and increasing incomes (Delgado 2005; Abidin et al. 2011). The small-scale sector provides up to 90% of the total poultry production in some of the least developed countries (Mack et al. 2005). This is the case for Papua New Guinea (PNG) as indicated by the rise in the informal market for live meat birds and table eggs. The development of this sector is driven by small-scale informal poultry farmers but the industry is largely constrained by the rising cost of commercial feed, which is mainly due to the cost of imported ingredients. From 2003 to 2011, the annual increase in feed costs in PNG was 8% for both broiler starter and finisher feeds, and 15% for layer ration (Table 1).

Feed represents as much as 60–70% of the total cost of poultry production in some countries (Haitook 2006). In PNG, the poultry and pig industries rely heavily on commercial feeds that consist of mostly imported raw materials that are quite expensive (MAL 2004). The freight charge adds a further cost to

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Table 1. Changes in retail prices of commercial poultry feed for a 40 kg bag in the Lae market from 2003 to 2011.

Feed type	Price (kina)							Percent increase
	2003 (Q1[a])	2005 (Q3)	2007 (Q3)	2008 (Q1)	2009 (Q4)	2010 (Q3)	2011 (Q2)	
Broiler starter	57.1	58.9	59.0	65.4	75.8	83.1	89.1	56.0
Broiler finisher	55.0	56.7	56.8	63.7	73.0	82.0	87.5	59.1
Layer pellets	44.5	54.5	58.3	58.3	77.7	80.0	93.5	110.1

[a] Q: Denotes year quarter: January, February and March are quarter 1 (Q1).
Source: Archives of NARI Labu Livestock Station, from stock feed purchase records (W. Ayalew, in press).

the final selling price of commercial stock feeds at retail outlets. High feed cost is a constraint for smallholder farmers, especially in remote communities and those located a considerable distance from commercial feed mills. The unreliable supply of feed in some of the highland and island provinces of PNG, due to poor road infrastructure or unreliable shipping and distance from producers, is an added constraint to small-scale poultry production. Poultry feed supply in East New Britain (ENB) Province, for instance, depends on shipping. Most often, supplies run out before new stocks arrive, forcing farmers to use other feeding alternatives. In such cases, inconsistent feeding and feed restrictions can exert significant negative effects on growth and egg production (Oguntunji and Alabi 2010) and poultry health (Lister 2010).

The use of a broiler finisher concentrate technology, developed by the PNG National Agricultural Research Institute (NARI) and South Australian Research and Development Institute (SARDI), using a high- and low-energy protein concentrate blended with sweetpotato (*Ipomoea batatas* L.) and cassava (*Manihot esculenta* Crantz) respectively, as an alternative feeding approach has shown promising results (Glatz et al. 2013). The feeding system has been shown to reduce input costs by 25–30%. When sweetpotato and cassava were obtained from a farmer's own garden, farm profitability was further improved by at least 50% (Pandi 2010). Apart from adding value to cassava and sweetpotato crops, the crops are available year-round from gardens and local markets, which is an additional benefit for adoption of the feed technology. The concentrates are readily available from commercial feed mills and can be stored in bulk for long periods, provided suitable storage conditions are available.

In continuing this work on feeding systems with broilers, a similar concept was developed for layers, aimed at reducing feed costs by utilising local feed ingredients, mainly sweetpotato and cassava. Glatz et al. (2013) reported optimal laying performance in village chickens and F_1 crossbreds of Australorp × Shaver Brown fed 60% low-energy later concentrate (LELC) blended with 40% cooked cassava and 60% high-energy layer concentrate (HELC) blended with 40% cooked sweetpotato. Small variations in average weight gains were observed for Australorp (102 g), Shaver Brown (116 g) and F_2 crossbreds of Australorp × Shaver Brown (116 g) from 11 to 14 weeks of age. The Shaver Brown birds had better feed conversion efficiency (3.1) than the Australorps (7.0) and Australorp × Shaver Brown crossbreds (4.0). However, the Australorp × Shaver Brown crossbred strains were recommended for farmers due to their low replacement costs and slightly better feed conversion efficiency.

Based on these observations, a study was conducted to measure production performance of two crossbred strains of hens, Australorp × Shaver Brown (A×SB) and Shaver Brown × Hyline Brown (SB×HB), fed with 40% cooked cassava blended with 60% low-energy layer concentrate. The use of crossbred female progeny has the potential to result in hybrid vigour by improving egg production, liveability and hatchability. Crossbreeding can also be used as a breeding strategy to improve performance of indigenous chickens (Kgwatalala and Segokgo 2013).

The objective of this study was to demonstrate that feed costs could be reduced for small-scale layer farmers in ENB and other parts of the PNG islands region with crossbred layers fed on a basal diet of cooked cassava blended with a layer concentrate.

MATERIALS AND METHODS

Study area

The study was conducted at NARI's Islands Regional Centre, also known as the lowlands agricultural experimental station. The centre is located in Keravat, ENB (152°01′50″ E, –4°19′56″ S) at an elevation of 25 m above sea level. The annual rainfall ranges from 1,930 to 3,300 mm, environmental temperature ranges from 16.5°C to 34.6°C, and relative humidity averages 84%.

Experimental birds

Australorp is a dual purpose breed from Australia derived from the Black Orpington, and noted for its adaptability to local scavenging conditions. Australorps are characterised as medium body weight of just over 2 kg and heavy black plumage. They can lay up to 270 eggs annually and normally do well under local conditions, but there are concerns that hens are often not broody (Say 1987). The Australorp chickens at Keravat were a closed inbred flock kept over two generations. Shaver Brown and Hyline Brown are commercial hybrids and birds were obtained from Christian Leaders' Training College at Banz in the Jiwaka Province of PNG. These breeds have brown plumage and produce brown eggs as a result of a cross between a red cock and a white hen. These hybrids require high management inputs and can lay over 300 eggs annually. The hybrids are produced from parent stocks that are usually imported from overseas. The two crossbred strains used in the study were obtained by crossing Australorp cocks with Shaver Brown hens and Shaver Brown cocks with Hyline Brown hens.

All fertile eggs were obtained from Hyline Brown hens crossed with Shaver Brown males at 30 weeks of age and 24-week-old Hyline Brown hens crossed with 52-week-old Australorp males. The parent stocks were fed on a commercial layer ration and placed together in a ratio of one male to five females, in floor pens in a naturally ventilated shed with corrugated iron roofing. The fertile eggs were wiped clean with a cloth soaked in warm water and placed in an air-conditioned room for 1–2 days at a temperature of 18°C. These eggs were then placed in an incubator for 21 days at a temperature setting of 37.5°C and relative humidity of 88.5%. Incubated eggs were candled on day six, 12 and 18, respectively, and non-fertile and dead embryos removed with hatchability rates varying from 70% to 85%. Day-old chicks were raised on a starter ration in a brooder from weeks 1 to 6. Rice husks were placed as deep litter on the floor while artificial light (an 18 W incandescent light bulb) was used to provide 24 hour lighting and heat for the first six weeks.

Housing and experimental design

The feeding trial was conducted in a naturally ventilated shed with corrugated iron roofing, wire mesh partitioned walls and floor pens. Room temperatures ranged from a minimum of 21.8°C to a maximum of 31.9°C. A total of 24 A×SB and 24 SB×HB crossbred laying hens at 19 weeks of age were randomly allocated into eight floor pens of equal dimensions (2 × 2 m) with six hens per genotype in a pen and two replicates per dietary treatment using a complete randomised design. Birds were exposed to natural daylight during the day (8am to 6pm) while artificial lighting was provided at night (6pm to 8am) by four 18 W fluorescent light tubes. Five nest boxes (30 × 30 × 25 cm) were also provided in each of the pens.

Diet preparation, feeding and management

The two dietary treatments were a LELC mixed with cooked cassava (LELC+Cas) and the commercial layer ration fed as the control. Each pen was equipped with a hanging tube feeder (with capacity of 6 kg of feed) and drinker (with capacity of 6 L of water). Rice husk was evenly spread as deep litter on the concrete floors of all experimental pens to a depth of 5 cm to absorb droppings and spilled water from drinkers. The LELC (Table 2) was blended with cassava in a proportion of 60% LELC to 40% cassava. The cassava was cleaned, boiled for 40–50 minutes, drained of water and mashed, and left to cool before mixing with the LELC. The commercial starter, pullet and layer rations were manufactured by Lae Feed Mills (LFM) in Lae, Morobe Province and supplied in the study area by Spirit of Kokopo, Farmset Ltd and NGIP AgMark Ltd under LFM's Flame brand.

All birds were raised on a starter ration from day-old to six weeks of age and then switched to the pullet grower ration until the point of lay at week 19. The test and control diets (Table 3) were introduced when birds reached 19 weeks of age and they were fed over a 10-week period until completion of the trial when birds were nearly 30 weeks of age. Both diets were offered ad libitum (in excess of 330 g/hen) every morning to ensure feed was available throughout the day. Drinkers and feeders were checked daily, cleaned and refilled with clean water and feed, respectively. Deep litter was turned when soiled and replaced with dry litter once per month.

Table 2. Composition of the low-energy layer concentrate.

Ingredient	%
Soybean meal	12.67
Wheat	27.20
Meat meal	15.67
Millrun	30.83
Layer pre-mix	0.417
Salt	0.06
Sorbasafe	0.167
Tallow	4.17
Sunflower oil	1.17
Limestone fine	7.33
Rhodimet-88 liquid methionine	0.334
Choline chloride	0.03
Total	100.0

Feed cost

Feed costs were calculated based on the feed intake of each feed type. The unit costs per kilogram of feed for each feed type were determined using equation 1 (below) before calculating the overall feed costs, as per equation 2.

$$\text{Unit cost of feed (kina per kg)} = \frac{\text{cost per bag of feed (kina)}}{\text{total weight of feed (kg)}} \quad (1)$$

$$\text{Total cost of feed (kina)} = \text{unit cost of feed} \times \text{total feed intake (kg)} \quad (2)$$

Revenue and profit margins were then projected based on the 2012 selling price of a dozen eggs in Kokopo, East New Britain Province.

Data collection and analysis

Data on feed offered and refused, egg production, egg weight and cost of feed for each diet were recorded over 10 weeks commencing at point of lay (19 weeks of age). Group body weights for each crossbred strain in each pen were measured weekly (from one to six weeks of age) when the birds were fed the starter ration, and on a monthly basis thereafter at 10, 14, 18, 22, 26 and 30 weeks of age. Feed offered and refusals were recorded daily using an electronic kitchen scale (30 ± 0.02 kg). Eggs laid were recorded and weighed daily with a smaller kitchen scale (3,000 ± 1.0 g). Data on all parameters (dry matter intake (DMI), feed conversion ratio (FCR), eggs produced, egg weight and hen-housed egg production (HHEP; the number of eggs laid by surviving hens over the trial period)) were sorted and aggregated by weeks using Microsoft Excel 2007 version.

Table 3. Nutrient specifications of the test diets used in the experiment.

Diet	Moisture (%)	Ash (%)	Fibre (%)	Fat (%)	CP (%)	Ca (%)	P (%)	NFE[a] (%)	ME (MJ/kg)
Starter	10.2	9.8	4.2	4.1	21.3	1.26	0.70	47.19	12.13
Grower	8.5	5.7	4.2	3.9	15.3	–	–	–	–
LELC+Cas	44.0	12.9	4.6	5.6	14.5	2.7	0.4	36.9	11.6
Commercial	10.2	10.4	3.0	4.0	16.0	3.0	0.4	38.9	11.0

[a] NFE consists of carbohydrates, sugars, starches and a major portion of materials classed as hemicellulose in feeds.
LELC+Cas = low-energy layer concentrate + cassava; CP = crude protein; Ca = calcium; P = phosphorus; NFE = nitrogen-free extracts; ME = metabolisable energy.
Source: modified from Glatz et al. (2013).

DMI was calculated using equation 4 (below), based on feed intake (as-fed basis) of birds after calculating the DM content of the feed using equation 3. DM was derived based on the moisture content of the feed or feed ingredient through the oven drying method (24 hours at 105°C) as explained by Teye et al. (2011).

$$\% \text{ DM} = \frac{\text{Dry weight of feed}}{\text{Total weight of feed (as is or wet basis)}} \times 100 \quad (3)$$

$$\text{DMI} = \% \text{ DM} \times \text{Total weight of feed (as-is or wet basis)} \quad (4)$$

Egg counts and weights involved daily counting and weighing of eggs laid per pen. FCR was obtained by dividing the amount of feed consumed by kg of egg produced. HHEP was derived using equation 5.

$$\text{HHEP } \% = \frac{\text{Total no. of eggs laid during the period}}{\text{Total no. of hens housed at beginning of laying period}} \times 100 \quad (5)$$

The data were then analysed using an analysis of variance (ANOVA) in GenStat discovery edition 3 (Lawes Agricultural Trust 2005) to determine the main effects of genotype, diet and interactions on production variables. Least significant difference (LSD) was then used to separate differences between means where significant main effects were detected in the ANOVA.

RESULTS AND DISCUSSION

Feed intake, feed conversion and egg production

The main results are given in Table 4. DMI was significantly higher for birds fed the LELC+Cas ration compared to the commercial diet (115.2 vs 103.1 g/day/hen; $P < 0.01$). The high moisture content of the LELC+Cas diet may have led to a higher DMI (see below). The high DMI may also be associated with the low protein content of the LELC+Cas ration (Table 3); proteins are building blocks needed for repair of damaged tissues and egg production (van Eekeren et al. 2006). Hens fed the control diet converted feed to eggs more efficiently (2.43) compared to those on the cassava-based diet (2.55), however the difference was not statistically significant ($P = 0.076$). Glatz et al. (2013) reported an FCR of 2.4 ± 0.05 for laying hens fed LELC+Cas. These figures are comparable to the FCR of 2.34 reported by Thiele (2012) for Hyline Brown hens fed a commercial layer ration.

A×SB crossbred hens consumed significantly more feed than the SB×HB hens (117.0 vs 101.3 g/day/hen; $P < 0.01$) and laid a significantly higher number of eggs per day (5.48 vs 5.03; $P < 0.01$). The egg weights were not significantly different for both genotype and diet and there were no significant differences detected for genotype by diet interactions for all other measured variables ($P > 0.01$). HHEP was significantly higher for A×SB than SB×HB strains (91.31% vs 83.57%; $P < 0.01$). Australorps have been kept at the station for over two generations and have adapted to local conditions. Thus, these attributes could have been passed on to their crossbred progenies (A×SB) resulting in a high egg production. The HHEP for birds fed the LELC+Cas diet was slightly higher than the commercial diet (89.41% vs 85.48%) and this difference was marginally significant ($P = 0.055$). Breeding strategies to improve village egg production can further explore crossbreeding to improve utilisation of Australorp and other local chickens for market-oriented egg production.

Factors affecting feed consumption

The moisture content of feed is important for feed consumption by birds. It has been shown that dusty mash has lower palatability than wet mash (El Boushy and van der Poel 2000). The high feed intake of birds consuming the LELC+Cas diet could be due to its high moisture content—44.0% compared to 10.2% for the commercial layer ration. A 33.8% lower DM content in the LELC+Cas diet led to an 11.0% higher DMI than the commercial layer ration. This may also suggest some losses due to higher feed wastage of the pelleted commercial feed which did not however significantly affect egg production. Pottguter (2008) reported positive results when using raw materials with high fibre content in poultry diets, particularly in maintaining gut health, faecal consistency and preventing sticky droppings. Given the additional stabilisation of the gut, and the resulting improvement in nutrient absorption, an effect on the animals' performance is a logical consequence. The high intake may have also been influenced by the high crude fibre, ash content and reduced fat of the LELC+Cas diet.

Mortality

There were no mortalities observed in this study, whereas an earlier study (Glatz et al. 2013) reported mortality rates of 25.86% and 4.76% in pure Hyline Brown and Australorp crosses, respectively. Mortality rates of 7.14% and 26.18% for hens fed a LELC+Cas and a commercial diet were also reported in the same study. These high mortality rates were due to deaths from cannibalism, particularly in the commercial Hyline strain. Beak trimming is normally practised with commercial hybrids to control cannibalism but this was not done in this feeding trial.

Feed costs

The feed cost of the commercial layer diet (3.16 kina/kg DM) was 7.28% higher than the LELC+Cas diet (2.76 kina/kg DM) (Table 5). Glatz et al. (2013) reported feed costs of 2.64 kina/kg DM and 1.55 kina/kg DM for the commercial layer diet and LELC+Cas, respectively. The lower feed cost reported by Glatz et al. (2013) is mainly due to that experiment being carried out on the PNG mainland, close to the commercial feed manufacturers and where freight costs are much lower compared to the island provinces. It cost 4.18 kina to produce a dozen eggs when hens were fed LELC+Cas compared to 4.62 kina to produce a dozen eggs on the commercial layer diet. Based on unit costs that differed by only 0.03 kina (Table 5), it was cheaper (by 0.44 kina) to produce a dozen eggs through feeding crossbred hens with LELC+Cas diet compared to the commercial layer ration. This incremental saving in

Table 4. Feed intake (as dry matter), feed conversion ratio, egg production, egg weight and hen-housed egg production of crossbred hens fed either a local or a commercial layer diet.

		DMI (g/day/hen)	FCR (kg feed/kg egg)	Eggs laid/day*	Egg weight (g)	HHEP (%)
Genotype	A×SB (n = 24)	117.0[a]	2.42[a]	5.48[a]	57.59[a]	91.31[a]
	SB×HB (n = 24)	101.3[b]	2.56[a]	5.03[b]	56.24[a]	83.57[b]
Diet	LELC+Cas	115.2[a]	2.55[a]	5.34[a]	56.77[a]	89.41[a]
	Commercial	103.1[b]	2.43[a]	5.17[a]	57.07[a]	85.48[a]
SE		2.33	0.03	0.08	0.68	1.46
Significance						
	Genotype	$P = 0.003$	$P = 0.076$	$P = 0.007$	$P = 0.236$	$P = 0.006$
	Diet	$P = 0.006$	$P = 0.102$	$P = 0.116$	$P = 0.780$	$P = 0.055$
	G×D	$P = 0.227$	$P = 0.441$	$P = 0.460$	$P = 0.230$	$P = 0.599$
	CV (%)	3.0	3.2	2.4	2.4	2.4

* Eggs laid are the number of eggs produced by six hens.
DMI = dry matter intake; FCR = feed conversion ratio; HHEP = hen-housed egg production; A×SB = Australorp × Hyline Brown hens; SB×HB = Shaver Brown × Hyline Brown hens; LELC+Cas = low-energy layer concentrate + cassava; SE = standard error; G×D = genotype × diet interaction; CV = coefficient of variance.
Means within columns with different superscripts are significantly different at $P < 0.01$.

Table 5. Cost of production and projected profit margin, based on feed intake, feed costs and average selling price of 12.10 kina per dozen eggs.

Diet	Total feed intake (kg)	Total feed cost (kina)	Cost/kg (kina)	Total eggs produced	Cost/egg (kina)	Selling price/egg (kina)	Selling price/ dozen (kina)	Gross revenue (kina)	Profit margin (kina)
LELC+Cas	193.57	533.51	2.76	1,532	0.35	1.01	12.10	1, 544.76	1,011.25
Commercial	182.94	578.09	3.16	1,502	0.38	1.01	12.10	1, 514.51	936.42

feed costs supported the higher margins gained during consecutive egg production cycles.

Gross revenues of 1,545 and 1,514 kina were generated through the sale of eggs from crossbred hens fed the LELC+Cas and the commercial diets, respectively. Irrespective of genotype, crossbred hens fed the LELC+Cas diet produced more eggs and generated more revenue than birds fed the commercial layer diet based on the selling price of 12.10 kina per dozen (1.01 kina per egg). Since it costs 0.35 kina to produce a table-size egg, an increased profit margin of 7.9% (74.83 kina) was generated from eggs produced by birds fed the LELC+Cas ration. These calculations were based solely on the costs of the test diets and exclude costs associated with growing cassava, harvesting and preparation, transportation of concentrates and commercial feed as well as capital costs. A more thorough on-farm evaluation examining all the costs would be required to determine overall cost and profit.

CONCLUSION

The A×SB and SB×HB crossbred hens on both diets had FCRs that were comparable to the standard FCR for Hyline layers on commercial layer ration. Favourable HHEP and egg production were observed in the A×SB genotype and for crossbred hens fed the LELC+Cas diet. The cassava-based ration was generally cheaper than the commercial layer feed and an increase in profit margin of 7.9% was observed. Feeding hens with LELC+Cas offers a suitable lower cost feed option for small-scale egg production in the islands region, provided farmers are able to grow their own cassava. The A×SB cross is suitable for small-scale egg production enterprises. Further on-farm evaluation that examines all associated costs over a full laying cycle is needed in all regions for farmers to realise the potential of the layer concentrate blended with cassava as a more affordable feeding alternative for small-scale egg production.

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5 Local feed resources for broiler production

Evaluation of the performance of broiler chickens fed mashed or milled formulations of sweetpotato-based finisher diets in an on-station trial in Papua New Guinea

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Abstract

In Papua New Guinea (PNG) it is not known if smallholder broiler farmers should feed their meat birds diets based on dry milled or boiled and mashed sweetpotato. To resolve this question, sweetpotato-based finisher diets were fed to Ross strain broiler chickens as wet mash or dry milled, and growth performance was measured. Birds were fed a standard broiler starter diet until 21 days of age before they were switched to the experimental diets. There were four sweetpotato-based test diets, and a standard commercial broiler finisher diet was used as the control; there were two blocks, two replicates and 12 birds in each replicate. The test diets comprised 50% and 70% boiled and mashed formulations and 50% and 70% dried and milled formulations, each blended with low-energy protein concentrate to make a complete broiler finisher diet with metabolisable energy 15.0 MJ/kg and crude protein 22.7%. Feed intake and weekly live body weight were recorded up to seven weeks of age, and feed conversion ratio (FCR) was calculated on a weekly basis. Dry matter feed intake was variable between diets, as well as weeks, but the variation was not consistent. Live body weights varied significantly between the diets from five to seven weeks of age, with birds fed the control diet performing best followed by birds fed the milled and mashed 50% diet ($P < 0.001$). FCRs were significantly different ($P < 0.001$) for birds fed the diets from five to six weeks of age, with the standard control (FCR = 2.01 and 2.68, respectively) and mashed 50% diet (FCR = 3.00 and 2.25, respectively) performing best, and slight differences between the wet mash and dry milled formulations of the diets. Overall, growth of birds was similar on mashed and milled formulations of the sweetpotato diets. The high moisture content of mashed diets did not affect average feed intake and FCR. It was therefore concluded that both milled and mashed formulations can be promoted, milled formulations through the mini-mills and the mashed formulations for preparation by individual smallholder farmers. Importantly, farmers will not lose out in terms of growth and FCR when they use mashed formulations.

INTRODUCTION

Besides a small number of smallholder contract (out-grower) broiler farmers who supply directly to the country's two big broiler companies for processing, there are an estimated 50,000–60,000 smallholder broiler growers in PNG who are directly involved in market-oriented broiler farming using commercial broiler chickens and stock feed (Kohun et al. 2006; Ayalew 2013). The viability of this smallholder broiler production has been threatened by rising costs of commercial feeds. These feeds, which use imported ingredients, are vulnerable to price fluctuations in major grains on the global market. This is compounded by high transport and other associated costs, and has led to a more than doubling of retail prices for commercial stock feed in the country in recent years (Ayalew 2013). As a result, not only have

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the costs of broiler production increased dramatically but the profit margins of smallholder farmers have been reduced, exerting greater pressure on the smallholder broiler industry.

Improving the profitability of village broiler farming through the use of locally available feedstuffs has been a high priority research area for the National Agricultural Research Institute (NARI) in Papua New Guinea (PNG) and its partners, with funding provided by the Australian Centre for International Agricultural Research (ACIAR) since 2001. The initial ACIAR project 'Poultry feeding systems in PNG' (LPS/2001/077) laid a solid foundation in the development of the smallholder poultry sector in PNG. This project placed a strong focus on the delivery of feeding strategies to village farmers (Glatz et al. 2010, 2013).

It is with this background that the ACIAR project 'Improving the profitability of village broiler production in Papua New Guinea' (ASEM/2005/094) has been implemented since 2005, with the aim of developing lower cost broiler feeding strategies.

High feed intake is as important as nutrient digestibility for rapid growth of commercial broilers (Klasing 2007), and feed intake is perhaps the single most important factor determining feed efficiency for broilers (Bao and Choct 2010). Physical feed quality is considered to have a very significant effect on broiler growth (Jafarnejad et al. 2010) and the costs associated with feed processing represent a significant portion of feed costs (Behnke and Beyer 2002).

Apart from pellets, broiler diets can take the form of dry or wet mash or crumble. Dry mash is a finely ground and mixed feed. Due to its dustiness, its palatability is poor. Wet mash is made by mixing high-moisture ingredients, such as boiled sweetpotato and cassava tubers, with protein concentrates. Crumble feed results from crushing pelleted feed to a consistency coarser than mash. It is generally accepted that the feeding of pellets improves broiler growth rate compared to mash (Choi et al. 1986; Nir et al. 1994). Reasons for this may include decreased ingredient segregation, increased digestibility, reduced energy during prehension, thermal modification of starch and protein, and increased palatability (Behnke 1994, 1998).

This experiment was conducted as part of the ACIAR project ASEM/2005/094 to develop lower cost broiler feeding options using sweetpotato and cassava as energy sources and a substitute for imported grains. Both sweetpotato and cassava are among the staple crops in PNG and are usually readily available from food gardens. Processes involved in the preparation of tubers for feed include washing, peeling (cassava only), chopping or grating, and boiling. After cooling, the boiled tubers are either used directly as mash or dried and milled before being mixed with matching protein concentrates at the right ratio to make up the complete diet.

In the context of smallholder broiler farmers, who find it practical to prepare smaller quantities of the feed, diets can be prepared in both wet mash and dried milled forms. Wet mash is straightforward and convenient to feed fresh on a daily basis. Converting the boiled tubers into a milled or even a pelleted product is less straightforward, and requires a desiccator or oven, a hammer milling machine and (if pelleting) a pelleting machine. However, wet mash is perishable and liable to spoilage, whereas dried milled products can be kept longer without spoilage and are convenient for industrial-scale processing. Smallholder broiler farmers are more likely to use the boiled sweetpotato tuber as a wet mash than converting it into a dried and milled product.

The performance of broilers fed diets based on dry milled or boiled mashed sweetpotato was investigated. This experiment tested the hypothesis that the form of presentation for the main starch ingredient in the balanced broiler finisher does not affect bird growth performance.

MATERIALS AND METHODS

Location

This study was conducted during April and May 2009 at NARI's Livestock Research Station at Labu (6°40′27″ S, 146°54′33″ E), which is located about 16 km north of the city of Lae. The climate is typically warm and wet with an average daily temperature of about 30°C and 84% relative humidity.

Housing and husbandry

The experiment was conducted in an open-sided poultry house with a deep litter floor and 20 feeding pens, each 4 × 2.5 m. Wood shavings were provided as bedding for the birds and florescent tubes were used for lighting at night. Each pen was provided with one hopper feeder and one bell drinker for a total of six female and six male birds. Average stocking density was 1.2 m^2 per bird. The broiler chicks were randomly allocated to the experimental pens and raised on a local standard commercial starter diet (Flame) from 0 to 21 days of age (end of week 3) before they were introduced to the experimental diets. Feeding of treatment diets was terminated on day 49 (end of week 7).

Experimental birds and diets

A total of 240 sexed day-old Ross strain commercial broiler chickens supplied by Niugini Tablebirds Ltd. were used in a randomised complete block design with five treatments, two blocks (sides of the experimental shed) and two replicates. Each replicate comprised a separate pen housing six female and six male birds. Feed and town drinking water were offered ad libitum. The treatment diets were as follows:

- 50% milled sweetpotato mixed with low-energy concentrate (LEC);
- 50% mashed sweetpotato mixed with LEC;
- 70% milled sweetpotato mixed with LEC;
- 70% mashed sweetpotato mixed with LEC;
- a local standard commercial broiler finisher (Flame) as control.

The LEC was designed to provide a balanced broiler finisher diet with metabolisable energy 15.0 MJ/kg and crude protein 22.7% when mixed at the recommended ratio with sweetpotato.

Data collection and analysis

Live body weights were recorded at the start and end of the experiment and at the end of each week. An inventory of birds was taken on a weekly basis. Feed intake per pen was calculated on a dry matter basis as the difference between feed offered and feed refused. Feed conversion ratio (FCR) was calculated weekly for each replicate using the current inventory. The data were fitted to the following statistical model (equation 1) to partition observed variance into treatment, block and random effects.

$$Y = T_i + B_j + e_{ij} \quad (1)$$

where Y is the dependent variable (feed intake, body weight, or feed conversion ratio), T is the effect of the ith treatment ($i = 1, 2, 3, 4, 5$), B is the effect of the jth block ($j = 1, 2$), and e is the random error.

Data were analysed using a one-way analysis of variance of GenStat Release 7.22 (VSN International Ltd. (2008).

RESULTS

Mortality during the experiment was 3.75% overall, with birds fed the control diet having a mortality of 8.3% and birds fed the wet mash having a mortality of 6.3%. No birds from the groups fed on the milled feed formulations died.

Birds fed the control diet had higher weekly dry matter feed intake during weeks 5 and 6 but feed intake dropped in week 7 (Table 1). Birds fed on the mashed diets tended to catch up to the feed intake of birds fed the other diets during weeks 6 and 7. For the milled diets, birds fed the 50% diet maintained a better feed intake than birds fed the 70% sweetpotato diet.

The body weights of birds fed the control versus milled and wet mash diets showed significant differences from week 5, with birds fed the standard finisher diet performing the best, as expected, followed by the birds fed the 50% milled and mashed formulations ($P < 0.001$; Table 2). Weekly body weights were similar for the birds fed the 50% mashed and 50% milled diets ($P > 0.05$). The same was true for birds fed the 70% mashed and 70% milled diets during week 5 and week 6 but not during week 7 (Table 2).

During week 5, birds fed the standard finisher had a better FCR (Table 3) followed by birds fed the 50% mashed and then birds fed the 50% milled diet ($P < 0.001$). Birds fed on both of the 70% formulations performed poorly. During week 6, birds fed the 50% mashed formulation had superior FCR than birds fed the other diets, even better than the birds fed the standard diet.

Overall, growth performance of birds was similar when fed the sweetpotato mashed and milled formulations. Birds were fed ad libitum but the mashed formulation had to be processed twice a day to avoid spoilage and spillage. Under these circumstances, the high moisture content of mashed diets did not affect average feed intake and FCR of birds.

Table 1. Weekly feed intake (kg dry matter basis, per pen) for birds fed the different diets (mashed or dried and milled sweetpotato 50% or 70%, mixed with low-energy concentrate, or control).

	Week 4 (day 28)	Week 5 (day 35)	Week 6 (day 42)	Week 7 (day 49)
P value	0.875	<0.001	<0.001	<0.001
Overall mean	9.58	12.12	14.30	14.27
Milled 50% + LEC	9.57	13.84b	16.97c	15.28b
Mashed 50% + LEC	9.50	11.31a	13.34a	17.69c
Milled 70% + LEC	9.51	11.54a	13.55a	11.84a
Mashed 70% + LEC	9.68	10.51a	12.71a	15.63b
Standard broiler grower	9.62	13.41b	14.92b	10.92a
LSD 5%	ns	0.86	1.27	1.13
CV %	2.8	4.7	5.8	5.2

Means followed by the same letter within a week are not significantly different ($P > 0.05$). LEC = low-energy concentrate; LSD = least significant difference; CV = coefficient of variation; ns = not significant.

Table 2. Body weights (kg) of birds fed the different diets (mashed or dried and milled sweetpotato 50% or 70%, mixed with low-energy concentrate, or control).

	Week 4 (day 28)	Week 5 (day 35)	Week 6 (day 42)	Week 7 (day 49)
P value	0.22	<0.001	<0.001	<0.001
Overall mean	1.24	1.58	2.03	2.45
Milled 50% + LEC	1.25	1.61b	2.11b	2.54c
Mashed 50% + LEC	1.24	1.56b	2.08b	2.63c
Milled 70% + LEC	1.24	1.44a	1.77a	2.08a
Mashed 70% + LEC	1.25	1.46a	1.82a	2.23b
Standard broiler grower	1.24	1.81c	2.36c	2.77d
LSD 5%	ns	0.08	0.12	0.13
CV %	0.8	3.3	4	3.6

Means followed by the same letter within a week are not significantly different ($P > 0.05$). LEC = low-energy concentrate; LSD = least significant difference; CV = coefficient of variation; ns = not significant.

Table 3. Feed conversion ratio (dry matter basis) for birds fed the different diets (mashed or dried and milled sweetpotato, 50% or 70%, mixed with low-energy concentrate, or control).

	Week 4 (day 28)	Week 5 (day 35)	Week 6 (day 42)	Week 7 (day 49)
P value	0.2	<0.001	<0.001	0.911
Overall mean	1.90	3.46	2.84	3.32
Milled 50% + LEC	1.85	3.19b	2.85b	2.99
Mashed 50% + LEC	1.90	3.00b	2.25c	3.23
Milled 70% + LEC	1.94	4.88a	3.47a	3.14
Mashed 70% + LEC	1.85	4.21a	2.95b	3.68
Standard broiler grower	1.93	2.01c	2.68b	3.58
LSD 5%	NS	0.70	0.40	ns
CV %	3.3	13.3	9.3	36

Means followed by the same letter within a week are not significantly different ($P > 0.05$). LEC = low-energy concentrate; LSD = least significant difference; CV = coefficient of variation; NS = not significant.

DISCUSSION

The higher feed intake and body weight observed during weeks 5 and 6 for birds fed on the standard pellet diet is expected for the high genetic potential broiler birds (Behnke 1994; Behnke and Beyer 2002; Jahan et al. 2006). The improved feed intake of birds fed on the mashed diet during weeks 6 and 7 can be explained by better adaptability of the birds to this form of feed presentation. Dry milled diets are known to have problems with dustiness, which can be managed by splashing some water on the food and reducing the size of offerings.

In another study that compared the effect of pellet and mash on growth performance and carcass characteristics of commercial broilers, live body weight, weight gain, feed intake and FCR were not affected ($P > 0.05$) by the different forms of diet (Ahmed and Abbas 2012). This was attributed to similarities in growth response between mash, mixed and pellet-fed birds. Parsons et al. (2006) also reported similar comparable levels of feed intake between pellet and mash diets and indicated that the mash diet was associated with excessive feed waste. Jahan et al. (2006) compared performance of broiler chickens fed on mash and crumble and found that body weight gain was higher in crumble diets. Higher FCR value was observed for the mash group, which indicated lower feed conversion efficiency.

The advantages of pellet feeds over mash diets include non-selective feeding and high nutrient density. The added cost of pelleting is a disadvantage. Pellets are also known to increase water consumption and droppings become wetter. The mash formulation is relatively cheap to prepare at the household level, and the lower cost of production can appeal to broiler farmers, especially when the broiler chickens are sold on a body weight basis.

CONCLUSION

Overall, growth performance of birds was similar on mashed and milled formulations of the sweetpotato diets. The high moisture content of the mashed diets did not affect average intake and FCR. It was therefore concluded that both milled and mashed formulations can be promoted, milled formulation through mini-mills and the mashed formulation for preparation by individual smallholder farmers. Importantly, farmers will not lose out in terms of growth and FCR when they use mashed formulations.

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Evaluation of the growth performance of broiler chickens fed a rice bran-based finisher diet in an on-station trial in Papua New Guinea

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Abstract

Rice bran can substitute for wheat and maize as an alternative energy source in a poultry diet. This study in Papua New Guinea examined the growth performance and associated costs of finishing Ross 308 broiler chickens on a rice bran-based ration included at 27% of the diet compared to a standard commercial finisher diet. Birds fed the commercial finisher ration from three to seven weeks of age performed better, with significantly higher weekly body weights and higher body weight gain in weeks 4 and 5 ($P < 0.05$). Birds fed on the control diet also had a higher feed intake and better feed conversion ratio (FCR) in weeks 4, 5 and 6 compared to birds fed on the rice bran diet. However, body weight gains during week 6 were not statistically different (0.411 vs 0.487 kg/bird, $P > 0.05$). Birds fed the rice bran diets had a significantly higher body weight gain by week 7 (0.487 vs 0.236 kg/bird, $P < 0.05$) and a better FCR (2.88 vs 4.25, $P > 0.05$) compared to birds fed the commercial diet. Despite reaching market weight a week earlier, birds fed the commercial finisher diet had a significantly higher weekly feed cost. Birds fed on the rice bran diet had a 9.2% reduction in feed cost and a 15.9% increase in returns on feed cost (69.30 kina). It was concluded that rice bran can be included at 27% of the diet in commercial broiler finisher rations and improve farm profitability. Hence, this is a suitable low cost feeding option for small-scale broiler farmers.

INTRODUCTION

In the poultry industry in Papua New Guinea (PNG), the rise in feed cost has become a major impediment for informal broiler production on village farms. The reason for rising feed cost is that the major sources of energy in poultry diets, such as sorghum, maize, wheat or soybean, are imported (Kohun et al. 2006). One way of addressing this is to develop alternative diets using local and less expensive ingredients. There are many alternative energy and protein sources that are available locally, either fresh or as industrial by-products (Glatz 2012).

Rice bran, a by-product of milled rice, can be used as an energy source for feeding broiler chickens. Rice bran is the most nutritious part of the rice grain, and has high levels of protein, lipids, vitamins B and E, and trace minerals such as iron, potassium, calcium, chlorine, magnesium and manganese (Gallinger et al. 2004; Warren and Farrell 1990). It also contains a high percentage of oil (14–18%) with a high level of linoleic acid, which is particularly important in diets for laying hens. The in vitro nutritive value of rice bran is comparable with other cereals and their by-products (Gallinger et al. 2004).

In recent studies, rice bran has been used in many forms (roasted and fermented, included with enzymes, and supplemented with microbial phytase amongst others) and at different levels (5–40%) to feed meat or layer birds (Khin et al. 2011; Safamehr and Attarhoseini 2011; Abubakar et al. 2007; Deniz et al. 2007; Oladunjoye and Ojebiyi 2010). Rice bran was

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also found to be promising when substituted for other ingredients (Dafwang and Shwarmen 1996; Khalil et al. 1997). Substituting defatted rice bran at 7–21% in a basal diet improved growth and feed conversion ratio (FCR) of broilers at 3 to 13 days of age and feed intake did not decline significantly until the defatted rice bran content of the diet exceeded 20% (Warren and Farrell 1990). When enzyme (Roxazyme G2G) was added to a 20% rice bran diet, live weight and nutrient utilisation were improved and it also had no effect on feed intake and mortality (Oladunjoye and Ojebiyi 2010). No significant differences in body weight gain, feed intake and FCR were detected with addition of 10% untreated rice bran and fermented rice bran to corn–soybean meal diet, compared with the corn–soybean meal diet (Khin et al. 2011). A regular supply of rice bran and knowledge of how to feed such by-products would benefit smallholder farmers.

Based on these known positive results of using rice bran in poultry diets, this study was conducted to evaluate growth performance of broiler chickens when fed diets containing rice bran, and the associated costs compared with a commercially available broiler finisher diet.

MATERIALS AND METHODS

Location

The experimental work was conducted at the National Agricultural Research Institute (NARI)'s Livestock Research Station at Labu, outside Lae (6°40′27″S, 146°54′33″ E) in Morobe Province, PNG. The climate is typically warm and wet with an average temperature of 32°C and relative humidity of 88–90%.

Birds, housing and management

The trial was conducted over a seven-week period from 12 November to 31 December 2012. One hundred and sixty Ross 308 day-old chicks supplied by Niugini Tablebirds Ltd were obtained from Farmset Limited, feather sexed, and raised in separate spot brooders. The trial was conducted in an open-sided naturally ventilated broiler grow-out facility. The 20 experimental pens in the facility had dimensions 3.9 × 2.5 m (9.75 m^2) and concrete flooring. Wood shavings were provided as bedding for the birds. The birds were provided with fluorescent light at night (giving about 22 hours of light a day). The birds were raised on the Flame commercial starter crumble to 20 days of age. At three weeks of age, birds from each gender group were weighed and randomly allocated into experimental pens based on the group's average weight of about 200 g. There were eight experimental units, each having a total of 20 birds with an equal number of male and female birds. The birds were then introduced to the experimental diets (standard commercial finisher or the rice bran-based diet). Feed and water were offered ad libitum. The experiment was carried out using a completely randomised design with two diet treatments and four replicates per treatment. The feeding trial was terminated when birds were seven weeks of age.

Experimental diets

The control diet was purchased in 40 kg bags from Farmset Limited in Lae. The test diet was prepared on-station using rice bran obtained from a Taiwanese miller (Taiwan Technical Mission in Papua New Guinea) located at the study area (Bubia). Other ingredients were sourced locally (Table 1). The test diet was prepared in mash form. Local lowland varieties of sweetpotato were processed using mini-mill facilities. The fresh tubers were purchased from the local market and grated, sun dried and milled into flour. The milled sweetpotato was then mixed with the other ingredients to produce the rice bran diet.

Nutritional compositions of the test diet and the commercial diet are given in Table 2. Protein, calcium, phosphorus, sodium and ash were measured in the commercial diet at the PNG University of Technology, National Analytical Laboratory Ltd (Lae, PNG) by AOAC official methods (AOAC 2012) (Table 2). Moisture was determined by drying 2 g samples for 2 hours at 135°C in a forced-air oven (Thermoline Scientific). Dry matter (DM) was calculated as:

DM % = 100 – moisture %

Protein was estimated as:

Crude protein (CP) = N × 6.25
(or 5.70 for wheat-based feeds)

Table 1. Ingredients of the rice bran diet, with calculated nutrient values.

Ingredient	%	Protein (%)	ME (MJ/kg)	Fat (%)	Fibre (%)	Ca (%)	Total P (%)	Na (%)
Rice bran*	27	3.5	1.8	3.3	2.9	0.02	0	0
Sweetpotato tubers	16.8	0.7	2.5	0.1	0.5	0.03	0.03	0.04
Copra meal	10	2.1	1.7	0.6	1.7	0.03	0.07	0.002
Fishmeal	10	6.6	1.2	1.2	0.1	0.5	0.28	0.05
Soybean meal	9.4	4.2	1.0	0.3	0.3	0.02	0.08	0.01
Cooking oil	1.5	0	0.5	1.5	0	0	0	0
Millrun	23	3.5	3.7	0.9	2.1	0.04	0.25	0.01
NaCl	0.1	0	0	0	0	0	0	0.04
Methionine	0.1	0.1	0	0	0	0	0	0
Limestone	2	0	0	0	0	0	0	0
Total	100	20.74	12.51	7.92	7.68	0.64	0.71	0.15

* Source: Thomson (2012).
ME = metabolisable energy; Ca = calcium; P = phosphorus; Na = sodium; NaCl = sodium chloride.

Table 2. Proximate analysis of the rice bran diet and the commercial diet.

Diet	Protein (%)	Dry matter (%)	Fat (%)	Fibre (%)	Calcium (%)	Phosphorus (%)	Ash (%)
Rice bran diet*	20.7	84.0	7.9	7.7	0.6	0.7	NA
Commercial finisher	20.7	91.0	6.1	6.2	NA	NA	6.0

* Source: Thomson (2012).

Nitrogen was determined as total Kjeldahl nitrogen by digestion of 0.5–1.0 g samples in concentrated sulphuric acid (FOSS Tecator™) and subsequent nitrogen determination on a Kjeltec™ 8200 distiller (FOSS). Crude fibre was determined as the weighed residue on a frittered-glass crucible, after sulphuric acid digestion and ashing at 500°C. Ash was determined by weighing the resulting inorganic residue from a dried, ground sample ignited in a muffle furnace (SEM SA Pty Ltd). Calcium was determined by ashing, acid digestion and testing aliquot solutions by flame spectrophotometry (AAS240FS). The calculated values reported in Table 2 for protein, fat, fibre, calcium and phosphorus for the rice bran diet were calculated using the UNE form and a feed formulation spreadsheet (Thomson 2012).

Measurements and data analysis

Body weight, body weight gain and feed intake were measured/calculated weekly. Calculations were as follows:

$$\text{Feed intake (kg dry matter) per bird} = \frac{\text{total feed intake}}{\text{no. of chickens}} \times \text{moisture content}$$

$$\text{Body weight (kg) per bird} = \frac{\text{total body weight}}{\text{no. of chickens}}$$

$$\text{FCR} = \frac{\text{total feed intake}}{\text{total body weight}}$$

$$\text{Cost of feed (kina/kg)} = \text{feed intake} \times \text{kina per kilogram of diet}$$

The raw data were sorted in MS Excel (2007), and GenStat Discovery 4th edition (GenStat 2007) statistical software package was used for analysis of variance on the measured parameters.

RESULTS

Growth performance

Birds on the commercial diet, as expected, had significantly heavier weekly body weight compared to birds fed the rice bran diet ($P < 0.05$) and reached the market weight of 2 kg a week earlier (Table 3). In terms of body weight gain, birds fed the commercial diet had significantly higher gains during weeks 4 and 5 ($P < 0.05$). However, during week 6 there was no significant difference in body weight gain for the two diets. Birds on the rice bran diet had a numerically higher but statistically non-significant body weight gain during week 7 compared to birds on the commercial diet. Birds fed the commercial diet had significantly higher weekly feed intake compared to the birds fed the rice bran diet throughout the trial ($P < 0.05$). In terms of FCR, birds fed the commercial diet had significantly better FCR during weeks 4, 5 and 6 compared to birds fed the rice bran diets ($P < 0.05$). During week 7, birds fed the commercial diet had numerically poorer FCR value compared to birds fed the rice bran diet but the difference was not statistically significant.

Costs

The cost per kg of feed was 2.03 kina for the commercial diet and 1.54 kina for the rice bran ration. As shown in Table 4, the weekly feed cost of the rice bran diet was significantly lower throughout the experimental period compared to the commercial diet ($P < 0.05$). Birds fed on the commercial diet had a total feed cost of 6.76 kina/bird while those fed on the rice bran diet cost only 6.19 kina/bird, after accounting for bird mortalities during the experiment (Table 5). Gross revenues of 1,500 kina and 1,460 kina were calculated to be potentially generated through the sale of live chickens fed the rice bran and the control diets, respectively (Table 5).

Table 3. Weekly body weight, body weight gain, feed intake and feed conversion ratio for birds fed a rice bran or a commercial finisher diet.

Variable	Week	Grand mean	Rice bran diet	Commercial diet	CV%	SEM	*P* value
Body weight (kg)	3	0.78	0.78	0.77	3.60	0.014	0.511
	4	1.22	1.08b	1.35a	3.10	0.02	<0.001
	5	1.64	1.43a	1.86b	2.60	0.02	<0.001
	6	2.15	1.88a	2.43b	3.40	0.04	<0.001
	7	2.51	2.22a	2.81b	4.60	0.06	<0.001
Weight gain (kg)	4	0.42	0.28a	0.56b	6.60	0.01	<0.001
	5	0.39	0.32b	0.45a	10.40	0.02	0.003
	6	0.45	0.41	0.49	16.30	0.04	0.189
	7	0.28	0.49b	0.24a	43.30	0.06	0.367
Feed intake (kg)	4	0.79	0.70a	0.87b	4.80	0.02	<0.001
	5	0.89	0.83b	0.94a	3.90	0.02	0.003
	6	1.05	0.98b	1.11a	3.70	0.02	0.003
	7	0.95	0.87b	1.04b	7.10	0.04	0.024
FCR	4	2.05	2.54a	1.56b	7.10	0.07	<0.001
	5	2.38	2.63a	2.09b	8.10	0.1	0.007
	6	2.38	2.41	2.35	15.40	0.18	0.817
	7	3.56	2.88	4.25	58.70	1.26	0.076

Means in a row followed by different letters differ significantly ($P < 0.05$).

Table 4. Weekly cost of feed per bird.

	Week	Overall mean	Rice bran diet	Commercial diet	CV%	SEM	*P* value
Weekly cost of feed intake per bird (kina/kg)	4	1.59	1.26a	1.92b	5.0	0.0398	<0.001
	5	1.71	1.44a	1.99b	4.0	0.0346	<0.001
	6	1.96	1.67a	2.26	6.9	0.0674	<0.001
	7	1.72	1.44a	2.0b	9.1	0.078	<0.001

Means in a row followed by different letters differ significantly ($P < 0.05$).

Table 5. Costs of production and projected profit margins for birds on the rice bran or the commercial diet, based on selling price of 20 kina per bird upon reaching market weight (2 kg), in Lae, Morobe Province, PNG.

	Rice bran diet	Commercial diet
Initial no. of birds	80	80
Final no. of birds available to sell	75	73
Estimated cost to week 3 (starter phase) (kina)	600*	600*
Total feed intake during finishing phase (kg)	301.52**	243.17**
Cost of feed during finishing (kina)	464.34	493.64
Total cost (kina)	1,064.34	1,093.64
Sum of weekly feed cost per bird (kina)	6.19	6.76
Gross revenue @20 kina/bird (kina)	1,500	1,460
Profit margin on total birds for sale (kina)	435.66	366.36

* Estimated cost of birds to week 3 is 7.50 kina/bird × 80 birds in each treatment. The cost per bird to week 3 includes the feed cost during the starter phase.

** Feed intake was calculated based on the age at which market weight was reached for each treatment, i.e. week 6 for birds fed on the commercial diet and week 7 for birds fed on the rice bran diet.

DISCUSSION

The weights of broiler chickens fed on the rice bran diet in this study were comparable with earlier results with rice bran at 20% and 40% and with balanced amino acids (Piyaratne et al. 2009); with rice bran at 40% and supplemented with phytase (Atapattu and Gamage 2007); and with rice bran at 30% (Gallinger et al. 2004). Oladunjoye and Ojebiyi (2010) reported a 10% decrease in weight gain when rice bran was increased from 10% to 20% of the diet. However, weight gain in this study was better than that recorded by Piyaratne et al. (2009) while feed intake was similar to that recorded by Atapattu and Gamage (2007) but was higher than that reported by Oladunjoye and Ojebiyi (2010), Piyaratne et al. (2009) and Gallinger et al. (2004).

FCR of birds in this study was not superior to that recorded by Oladunjoye and Ojebiyi (2010) and Atapattu and Gamage (2007) for birds fed a rice bran diet. Towards the end of the grow-out period, FCR for birds fed the control commercial diet in the current trial was affected due to mortality and reduced weight gain. The mortality during the latter phase of the trial appeared to have resulted from obesity, as indicated by autopsy.

The poorer performance (feed intake, body weight gain and FCR) of the birds fed the rice bran diet could be attributed to the rancidity of the lipid fraction, and other constituents in rice bran, such as high fibre, phytates and anti-proteolytic substances (Safamehr and Attarhoseini 2011; Oladunjoye and Ojebiyi 2010; Samli et al. 2006). A rancid smell from the rice bran was noticed before it was mixed with other ingredients. This could be because there was no oil extraction from the rice bran used and it was kept for seven weeks after milling (Mujahid et al. 2003). Piyaratne et al. (2009) discussed that the adverse effects of feeding high levels of rice bran may diminish as the birds age, because older broilers may have better capability to cope with anti-nutrients in the rice bran. This appeared to be the case in this study during weeks 6 and 7 when the birds fed on the rice bran diet improved their weight gain.

Feed cost was analysed by comparing the retail price of commercial feed against the calculated total cost of making the rice bran diet, i.e. by aggregating costs of the ingredients used to formulate the rice bran diet. These costs relate entirely to feed and exclude labour and capital costs. The unit feed cost for the commercial diet (2.03 kina/kg) was 24.1% higher than that of the rice bran-based diet (1.54 kina/kg). Even though the birds fed the rice bran-based diet reached market weight of 2 kg a week later, the total feed cost of production was 9.2% lower and the return on feed cost was 15.9% higher. The reduction in feed cost of production is comparable to that recorded by Besari et al. (2017) when cassava (as a complementary energy source) was combined with other local ingredients to make a lower cost broiler finisher.

CONCLUSION

Ross 308 broiler birds fed the standard commercial finisher ration performed better than birds fed the rice bran-based diet. Despite birds fed the rice bran diet reaching market weight a week later, feed costs were lower and the return on feed cost was higher for birds fed the rice bran-based diet. The rice bran-based ration is a suitable lower cost feeding option for small-scale broiler farmers. Commercial finisher feed can be substituted with a rice bran-based diet during the finishing phase without adverse effect and can improve farm profitability. Rice bran can be used as an alternative ingredient in diets for finishing broiler chickens but also for other poultry, such as village chickens and ducks. Further research on feeding poultry with a combination of other local ingredients with rice bran is needed to realise its full potential.

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Evaluation of the performance of broiler chickens fed diets containing 50% cassava or sweetpotato in farmer trials in Papua New Guinea

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Abstract

As part of a project to develop an alternative broiler finisher feeding system using local feed resources, two best-bet diet formulations were trialled. The on-farm trials were conducted at four locations in Papua New Guinea (PNG) and compared growth performance of broilers on the two test diets—50% boiled sweetpotato blended with 50% low-energy concentrate (SP50L) and 50% boiled cassava blended with 50% high-energy concentrate (CAS50H)—against a commercial control. The hypothesis was that growth performance of broilers during the finishing period would not be adversely affected when the commercial broiler finisher was replaced with the alternative diets. The results showed that at all the sites, overall growth performance of broilers on test and control diets was not significantly different, and overall growth performance of broilers fed on the CAS50H and SP50L diets was very good, with birds attaining target market weight of over 2 kg from week 5. It is therefore recommended that the alternative feeding options of boiled sweetpotato and cassava blended with their respective concentrates be promoted as finishing rations for broilers. It is also recommended that further farmer trials, with minimal external input or supervision, be encouraged to consolidate evaluation of this technology and confirm the appropriateness and validity of the technology for extensive use. Further research on the digestibility of sweetpotato cultivars for feeding broilers also needs to be carried out, as well as research into the best way to present cassava roots to broilers.

INTRODUCTION

In Papua New Guinea (PNG) the commercial livestock sector is dominated by broiler chicken production due to the high demand for poultry meat (Gwaiseuk 2001). The chicken industry has grown since the early 1980s under the protection of an import ban and more recently, a high import tariff. Under this scenario, the industry has gained a high level of self-sufficiency. Moat (2001) reported a high demand for live chickens and fresh eggs in both urban and rural areas, and that live broiler chickens in particular command very high prices. The small-scale broiler chicken market operates independently from the vertically integrated commercial frozen broiler industry, and currently produces about six million birds per year for sale in informal local markets. The sale of chickens is the major source of income from the livestock sector of traditional smallholder farming systems, with an estimated 50,000 families currently producing broilers (Glatz 2007).

The carcass weight of live broiler chicken sales is estimated at 7,000 tonnes per year (Kohun et al. 2006). Assuming an average sale price of 25 kina/bird, the subsector has a value of 125 million kina. While this subsector has grown steadily over the years it also faces constraints, the major ones being access to, and the high and rising cost of, day-old chicks and commercial feeds. The high cost is due to the industry using imported hybrid chickens and formulated high-density stock feeds made from imported ingredients. In

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recent years, this problem has become more profound due to major development projects in the country, such as the Liquefied Natural Gas project, which have resulted in a greater demand for chicken meat and more smallholders entering the market.

Recommendations following a survey conducted by the National Agricultural Research Institute (NARI) in 2004 of current feeding practices and attitudes to broiler chicken production include: (1) provision of information and training on use of local feed resources in broiler diets; (2) information and training on on-farm feed mixing; and (3) broiler feeding demonstrations in different rural areas depending on need and cost effectiveness.

The strategy for this trial was to take best-bet diet options that use local feed resources and test them on village farms in a range of locations. A total of 39 farmers were selected from across the country to evaluate the diets and monitor broiler performance, and to provide information on costs, in order to assess the acceptability and profitability of the feeding options. The two experimental diets selected for this evaluation had previously been shown to have promising results based on broiler performance in grow-out trials carried out by NGO partners near to selected farm sites. The NGOs were Christian Leaders' Training College (CLTC) in Banz, Western Highlands Province; Lutheran Development Services (LDS) in Morobe Province; and the OK Tedi Mining Limited (OTML) in Tabubil, Western Province. Grow-out experiments on these partner sites commenced late in 2008 and aimed to establish if selected feeding options were viable for on-farm testing. Based on the results, it was recommended that these two feeding options be tested on-farm.

In the trials conducted at the NGO sites, milled sweetpotato and cassava were used. The sweetpotato or cassava was peeled, chopped, dried and hammer milled, and then mixed with concentrate. The dry form of sweetpotato and cassava was not considered suitable for farmers, as they do not have mills and driers available. To make it more convenient for farmers, it was decided to use boiled and mashed sweetpotato or cassava instead. A grow-out trial on-station at NARI-Labu demonstrated that broiler performance was not affected by the form of presentation of the sweetpotato/cassava component of the diet (Ayalew et al. 2017).

MATERIALS AND METHODS

Sites

The on-farm trials were conducted in the Eastern Highlands, Morobe, Western Highlands and Western provinces of PNG (Figure 1). In Morobe Province, the site was in the Finschaffen District, which is located at the eastern end of the Huon Peninsula and has a population of 36,000 (NSO 2002). Altitude ranges from 0 to 3,000 m above sea level and average annual rainfall is 2,400–3,700 mm. Generally, people in this district are extremely disadvantaged due to relatively high population density on land of limited agricultural potential, poor access to services and low cash income.

In the Eastern Highlands Province, the on-farm trials were conducted in the Obura-Wonenara District. The altitude of the district ranges from 1,400 to 1,800 m above sea level and average annual rainfall is 1,800–4,000 mm. Based on the 2000 census, the population is around 45,000. Generally, the land has low agricultural potential and access to services is moderate. Cash income is also moderate and child malnutrition is a concern.

Trials were also conducted in North Waghi District in the Western Highlands. This district is located in the central east of the province and has a population of 44,000. Altitude ranges from 1,400 to 3,000 m above sea level and average rainfall is 2,300–2,600 mm. Overall, people in this district are not disadvantaged as there is little agriculture pressure and land potential is very high. Access to services is good and cash income is high.

Western Province covers 99,300 km^2 and is the largest province in PNG. The trials here were conducted with 10 famers located along the Kiunga–Tabubil highway, in Sisimakam, Wangbin, Migalsim, Kwiroknai and Tabubil villages. The villages are located in the North Fly district, which has an area of 13,138 km^2 and an average annual rainfall of 8,000 mm. Most of the economy of the district revolves around the Ok Tedi Mine, which is the largest economic entity in the Western Province, accounting for over half of the entire province's economy. There is also a productive rubber industry situated around Kiunga–Tabubil highway.

This paper does not include results from follow-on trials which were conducted at Nawae (Morobe Province), Kainantu Rural (Eastern Highlands Province) and Tambul-Nebliyer (Western Highlands Province).

Housing

The trials were carried out on farms close to where the NGO project partners operated. Housing for the chickens was mostly built from local materials. The houses in the highland sites (Banz and Kainantu) were grass-thatched. The walls were a combination of chicken mesh and a single layer of woven pit-pit mat. The same material was used for flooring. The birds were raised on a slightly elevated position above the floor level. The broiler houses near the coast, particularly in Finschhafen and in Western Province, were made of sago palm thatches and chicken wire mesh was used as walls giving natural ventilation. In sites where sawdust or wood chips were available, these were used as litter.

Where available, drinkers and feeders were purchased; otherwise they were made from bamboo. Most farmers used plastic pan drinkers and feeders. The drinkers were refilled twice daily with clean water, and where boiled mashed feed was used, this was made twice daily as well, usually in the mornings and evenings. In Western Province, where milled cassava was used, feeders were refilled with a certain amount of weighed feed as and when necessary. Farmers were advised to make sure their birds had unrestricted access to feed and clean, cool water throughout the experimental period.

Experimental diets and birds

The birds were distributed to the participating farmers as day-old chicks. Depending on the locality, brooding of these day-old chicks was from day 0 to day 7 in coastal sites, and continued for an additional week in highland sites.

The two experimental diets comprised low- and high-energy concentrates blended with sweetpotato and cassava, respectively. The first diet (SP50L) comprised the low-energy concentrate (metabolisable energy (ME) 15.0 MJ/kg and crude protein (CP) 22.7%) mixed with boiled and mashed sweetpotato at a ratio of about 1:3 on an as-fed basis, which is equivalent to a ratio of about 1:1 on a dry matter basis. The second diet (CAS50H) comprised the high-energy concentrate (ME 16.2 MJ/kg and CP 22.8%)

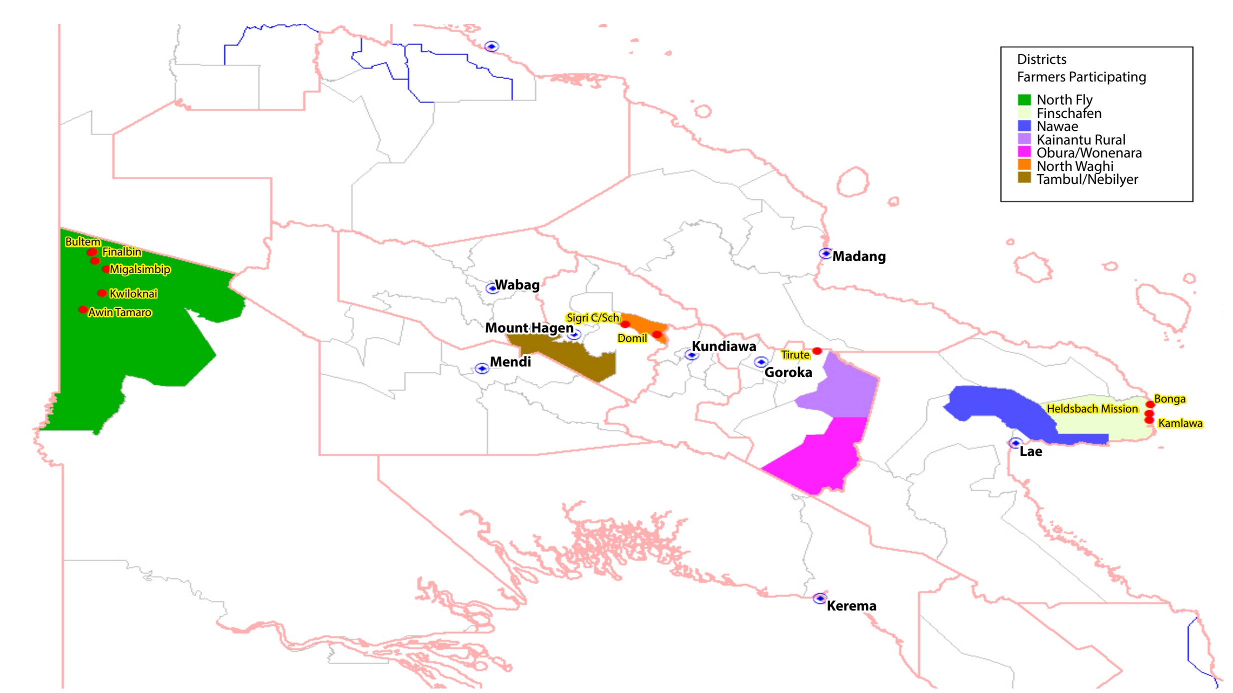

Figure 1. Location of sites where on-farm trials were conducted. Source: NARI-GIS Section.

mixed with boiled and mashed cassava at a ratio of 1:3 on an as-fed basis to give an equivalent ratio of 1:1 on a dry matter basis. Nutrient compositions of the diets, as well as the commercial diets used in the trials, are given in Table 1.

Farmers in the lowlands tested the CAS50H diet and farmers in the highlands tested the SP50L diet, due to the low cost and high availability of these two major staples in the respective locations. Farmers in Western Province tested both the cassava and the sweetpotato diets, however their data for the sweetpotato diet were not included in the analysis due to the fact that sweetpotato is not a staple in the area and is not easily available.

Ross 308 broiler day-old chicks were used in the trials. Participating farmers were selected by the project partner NGOs. These farmers were assisted to buy a box of day-old chicks, two 40 kg bags of commercial broiler starter crumble supplied by New Guinea Table Birds (NGTB), and 60–80 kg of the relevant NARI broiler concentrate bulked up with the respective energy source (sweetpotato or cassava).

From day 1 to day 20, the birds were raised together on commercial broiler starter crumble (Flame). On day 21, birds were weighed and distributed evenly into two separate pens based on their weights. Birds in one pen were fed the NGTB commercial finisher pellets and birds in the other were fed the experimental diet. The experimental phase began on day 21 and ended on day 42. After day 42, the farmers were able to sell their birds.

Data and statistical analysis

Parameters measured were weekly body weights of groups of birds (to calculate average individual weights) and feed intake, which was calculated from the total amount of feed distributed and the feed remaining in bags. There were occasional issues with unreliable recording of leftover feed by the farmers; hence it was not possible to get accurate measurements of feed intake.

A one-way analysis of variance was performed using GenStat® (Lawes Agricultural Trust 2005) to determine whether there were significant differences between the treatment diets in the weekly body weights of birds. Data were managed and analysed separately for the four sites.

RESULTS

Birds fed the cassava diet (CAS50H) in Western Province had lower weekly body weights in weeks 5 and 6 compared to birds fed the commercial finisher feed, as expected, but the weight differences were not statistically significant ($P > 0.05$; Table 2). The birds on the test diet reached market weight of 1.8 kg by week 5 and 2.4 kg by week 6. The coefficient of variation (CV) as shown in Table 2 was above 10% in week 4, 12% in week 5 and 14% in week 6. These large variations may be an indication of variable feed intake of birds due to attributes of the feeds or the feeding practice.

Table 1. Proximate nutrient compositions of the commercial and experimental diets used in the trials.

Nutrient	Commercial diets		Experimental diets	
	Flame	NGTB	SP50L	CAS50H
Protein (%)	24.4	26.2	22.7	22.8
ME (MJ/kg)	*	*	15.0	16.2
Fat (%)	7.7	5.8	2.85	4.95
Fibre (%)	6.8	3.2	1.50	3.95

* Not available.
Composition of the commercial stock feed was obtained from Ayalew and Pandi (unpublished report for Trukai Industries).
NGTB = New Guinea Table Birds; SP50L = boiled and mashed sweetpotato blended with low-energy concentrate (1:1 on a dry matter basis); CAS50H = boiled and mashed cassava blended with high-energy concentrate (1:1 on a dry matter basis); ME = metabolisable energy.

During weeks 5 and 6, birds fed the CAS50H diet in Morobe Province appeared to have lower weekly weights compared to birds fed the control diet, however these differences were not statistically significant ($P > 0.05$; Table 3). In this trial the CV was again quite high, reflecting high variability in the growth of individual birds. We observed farmers who properly mixed the cassava with the high-energy concentrate and had better average broiler performance, but in some cases the cassava was not cooked properly and not mixed well with the concentrate and this may have affected the results.

Results of the trial at Kainantu in Eastern Highlands Province showed no differences between weights of birds fed the sweetpotato test diet and the control diet. Birds fed the SP50L diet had slightly higher body weights during weeks 5 and 6 compared to birds fed the control diet, but these differences were not statistically significant ($P > 0.05$; Table 4). The cooler temperatures and wetter conditions at this site may have contributed to the good end weights; these could also reflect good management of experimental animals, which was supervised by researchers.

In the trials conducted at Banz in the Western Highlands Province, which were supervised by CLTC staff, the birds fed the SP50L diet had lower body weights in weeks 5 and 6 compared with birds fed the control diet, however these differences were not statistically significant ($P > 0.05$; Table 5). Judging by the higher overall end weights, the experimental birds at this site performed better than those at the other sites. This may be due to the farmers' experience—the farmers engaged in the trial had years of experience growing broiler chickens with support from the extension services of CLTC.

Table 2. Weekly end weights of broilers fed the cassava* test diet vs the commercial diet in Western Province ($N = 10$).

Age	Diet	Weekly average bird weight (kg)	Grand mean	LSD	CV (%)	*P* value
Week 4	CAS50H	1.449	1.453	0.145	10.6	0.914
	NGTB control	1.457				
Week 5	CAS50H	1.872	1.961	0.23	12.1	0.112
	NGTB control	2.05				
Week 6	CAS50H	2.411	2.538	0.338	14.2	0.132
	NGTB control	2.665				

* Unlike in the other trials, farmers in this trial were provided with milled cassava meal to mix with the concentrate.
N = number of birds in the group; LSD = least significant difference; CV = coefficient of variance; CAS50H = cassava blended with high-energy concentrate (1:1 on a dry matter basis); NGTB = New Guinea Table Birds.

Table 3. Weekly end weights of broilers fed the cassava test diet vs the commercial diet in Finschhafen, Morobe Province ($N = 8$).

Age	Diet	Weekly average bird weight (kg)	Grand mean	LSD	CV (%)	*P* value
Week 4	CAS50H	1.147	1.148	0.307	24.9	0.995
	NGTB control	1.148				
Week 5	CAS50H	1.511	1.582	0.352	20.8	0.402
	NGTB control	1.652				
Week 6	CAS50H	1.76	1.94	0.488	23.4	0.141
	NGTB control	2.12				

N = number of birds in the group; LSD = least significant difference; CV = coefficient of variance; CAS50H = boiled and mashed cassava blended with high-energy concentrate (1:1 on a dry matter basis); NGTB = New Guinea Table Birds.

Table 4. Weekly end weights of broilers fed the sweetpotato test diet vs the commercial diet in Kainantu, Eastern Highlands Province (*N* = 9).

Age	Diets	Weekly average bird weight (kg)	Grand mean	LSD	CV (%)	*P* value
Week 4	SP50L	1.277	1.29	0.126	9.8	0.665
	NGTB control	1.303				
Week 5	SP50L	1.793	1.727	0.321	18.6	0.398
	NGTB control	1.661				
Week 6	SP50L	2.422	2.408	0.239	9.9	0.814
	NGTB control	2.395				

N = number of birds in the group; LSD = least significant difference; CV = coefficient of variance; SP50L = boiled and mashed sweetpotato blended with low-energy concentrate (1:1 on a dry matter basis); NGTB = New Guinea Table Birds.

Table 5. Weekly end weights of broilers fed the sweetpotato test diet vs the commercial diet in Banz, Western Highlands Province (*N* = 12).

Age	Diet	Weekly average bird weight (kg)	Grand mean	LSD	CV (%)	*P* value
Week 4	SP50L	1.507	1.51	0.117	8.2	0.895
	NGTB control	1.514				
Week 5	SP50L	2.172	2.237	0.133	6.3	0.057
	NGTB control	2.301				
Week 6	SP50L	2.738	2.83	0.203	7.6	0.073
	NGTB control	2.922				

N = number of birds in the group; LSD = least significant difference; CV = coefficient of variance; SP50L = boiled and mashed sweetpotato blended with low-energy concentrate (1:1 on a dry matter basis); NGTB = New Guinea Table Birds.

DISCUSSION

The on-farm trials were conducted with the objective of assessing the acceptability and profitability of the various feeding options. The two feeding options used in this assessment were selected based on previous experiments (Glatz 2013). The results confirmed that these diets based on local ingredients were successful, as the final body weights of birds on the test diets were comparable to those fed the standard broiler finisher feed.

Many studies have been conducted to assess the growth of broilers fed sweetpotato diets at various sweetpotato levels. This study may be the first with 50% sweetpotato to report final body weights that are comparable to birds fed standard commercial diets. Studies by Agwunobi (1999) and Afolayan et al. (2012) showed significantly lower final body weights of broilers fed 50% sweetpotato diets. These differences may be due to diets not being adjusted for protein and energy or the breed of chicken used.

Some studies have evaluated the replacement of cereals with cassava products in poultry diets, and have reported varying results due to differences in the variety used, plant maturity at harvest, ecological conditions of plant growth and processing methods (Chauynarong et al. 2009). The authors of this review on the use of cassava in poultry diets noted that as long as ME, amino acid, mineral and vitamin requirements of poultry are met, a maximum inclusion of cassava at 70% can be achieved, provided the cassava is processed appropriately.

Feed intake is affected by feed form, which in turn affects weight gains and final body weights. The best feed intake occurs on good quality crumble or pelleted feeds, with an even particle size (Aviagen 2014). This could explain the high variation in the weights of birds fed the boiled cassava root. One of the main attributes of boiled cassava roots is friability (Padonou et al. 2005) (friability or mealiness is defined as being easy to crumble or pulverise). We observed that if cassava roots were harvested late, and if they were not boiled long enough, the roots were not friable. Instead the boiled roots were lumpy, which made it difficult to mix thoroughly with the concentrate, leading to uneven particle size of these diets. Beleia et al. (2006) noted that while cooking times of up to 30 minutes are generally accepted, better quality roots require between 10 and 20 minutes cooking. The authors studied the influence of root maturity and cultivar type on the cooking of cassava roots over two planting periods and concluded that age of roots was an important factor, with cooking time being at least double for 25-month-old samples compared to 12-month-old samples. In our trials with the sweetpotato-based diet, the results generally had a lower CV than trials with the cassava-based diet, and this may be because boiled mashed sweetpotato root is easier to prepare as an even mix than boiled mashed cassava roots.

Another factor which may have contributed to the variation in bird weights is inadequate feeding space for birds. High stocking densities and lack of adequate feeders or drinkers may not allow all birds to obtain their equal share of feed. This problem may be overcome by observing the birds feeding and providing more feeders if some birds are missing out.

Another overarching factor that would have affected the performance of broilers at all sites is farmer experience. The greater experience farmers have in raising broilers, the more able they would be in resolving problems with bird management. These include issues such as ensuring adequate feeding space, proper ventilation during warmer temperatures, and litter management. These factors can have a major effect on broiler growth and quality (Aviagen 2014).

CONCLUSION

Overall, performance of broilers on the cassava and sweetpotato diets was very good, and birds attained the target market weight of over 2 kg from week 5. The SP50L diet compared very well with the NGTB commercial diet in terms of body weight. Based on the results of these trials, the alternative feeding options of boiled mashed sweetpotato and cassava, blended with their respective concentrates, can be promoted as a technology for broiler farmers in PNG. However farmer participation to assess broiler performance under their own conditions and management, with minimal input or supervision from NARI, must be encouraged to further evaluate the appropriateness of this technology at the farmer level. The results in this trial on bird performance varied depending on locality and farmer experience, management and attitude. Information on general basic management practices—such as adequate feeding space, litter management, importance of proper ventilation and record keeping—must be made available to farmers in order to realise the full potential of these hybrid birds and improve efficiency and profitability at the farm level. Digestibility of sweetpotato cultivars that are used for feeding broilers also needs to be assessed, as well as the best way to present cassava roots to broilers.

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Evaluation of the performance of broiler chickens fed diets containing different proportions of cassava or sweetpotato in an on-station trial in Papua New Guinea

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Abstract

Currently, all commercial stock feeds in Papua New Guinea (PNG) are manufactured using imported grains, and research endeavours are focused on investigating ways of substituting such grains with local resources. The objective of this experiment was to evaluate the performance of broilers fed cassava or sweetpotato blended in different proportions with a high- or a low-energy protein concentrate. Ross 308 chickens were fed either milled cassava or sweetpotato at dietary levels of 0%, 50% and 70%, combined with the corresponding concentrate. The birds were fed a commercial broiler starter diet from hatch to day 20, and experimental diets were introduced at day 21. Body weight gain and feed conversion ratio (FCR) of birds fed the control (0%) diet were significantly superior only in the first 2 weeks. In weeks 6 and 7, birds fed the 50% cassava (CAS50H) and the 50% sweetpotato (SP50L) diets had higher gains and better FCRs compared to the control diet. During the experiment the environmental temperature ranged between 24°C and 31°C and humidity ranged from 75% to 80%; during the latter stages of the trial birds fed the control diets reached a high body weight and were unable to cope with the high temperature and humidity. The FCR of the birds on the test diets improved significantly over time and they reached a market weight of 2 kg by day 49, which is economical for PNG village farmers. It is suggested that 50% cassava and sweetpotato, blended with their respective energy concentrates, can be used to finish off broilers without any deleterious effects on the birds. Greater utilisation of root crops such as cassava and sweetpotato in livestock feed will not only add value to these crops but also improve profit margins for famers and diversify income earning opportunities.

INTRODUCTION

Papua New Guinea (PNG), like other developing nations in the Pacific region, imports large quantities of grains such as sorghum and wheat for the manufacture of commercial livestock feed, especially for the pig and poultry industries. This means that retail prices of feed produced by local commercial feed companies are high, and are considered a constraint by smallholder poultry and pig producers. Based on global trends, in the future there may not be sufficient amounts of feed ingredients such as maize, soybean meal, fishmeal and meat meal to make enough feed to meet the demand from semi-commercial farmers and traditional smallholder farmers (Ravindran 2012).

Demand for poultry products is increasing in PNG, largely due to the many oil and gas development projects in the country. To meet this demand via the village production system, alternative feeding strategies must be found. Farrell (2005) suggested matching poultry production in developing countries with the available feed resources as a way forward to combat rising feed prices. In addition, using poultry production performance indicators (such as feed conversion efficiency and growth rates) from developed countries

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as a benchmark for poultry in developing nations should be avoided as these will be unattainable.

The three major criteria determining the regular use of non-conventional feed resources in poultry diets are: availability of the resources in sufficient quantities; their nutritional value, which must be suitable for poultry; and price, which must be competitive compared to traditional feeds (Ravindran 2012). One of the strategies employed in PNG in the last decade has been to blend a protein concentrate mix with local feed ingredients, such as cassava or sweetpotato, to finish off broiler birds. Different feeding strategies have been trialled, and depending on cost and growth rates, the best options have been recommended for smallholder broiler farmers. The data presented here are from one of these trials. The objective of this experiment was to assess the performance of broiler chickens when fed diets comprising different proportions of cassava and sweetpotato mixed with high- and low-energy protein concentrates, respectively.

MATERIALS AND METHODS

Location

The study was conducted at the National Agricultural Research Institute (NARI)'s Livestock Research Station at Labu (6°40′27″ S, 146°54′33″ E), which is located about 16 km north of the city of Lae. The climate is typically warm and wet with an average daily temperature of about 30°C and 84% relative humidity.

Experimental diets

Four test diets were produced on-site at the same time. The control diet, which was the commercial finisher pellet from New Guinea Table Birds (NGTB), was purchased around the same time from a retail outlet.

The cassava and sweetpotato roots were dried and milled prior to blending with their respective concentrates. The fresh clean roots (peeled in the case of cassava) were processed into flakes using a flake machine. The flakes were then sun dried over 2–3 days until approximately 70% of the moisture had been removed. The dried flakes were then put through a grinding machine or a hammer mill to obtain milled product. The milled meal was stored in storage bins until used.

The milled cassava and sweetpotato were blended with a high-energy (11.8 MJ/kg; 41.9% crude protein (CP)) or a low-energy protein concentrate (9.4 MJ/kg; 41.8% CP), respectively. The four experimental diets were:

- 50% high-energy protein concentrate + 50% cassava (CAS50H);
- 30% high-energy protein concentrate + 70% cassava (CAS70H);
- 50% low-energy protein concentrate + 50% sweetpotato (SP50L);
- 30% low-energy protein concentrate + 70% sweetpotato (SP70L).

The calculated proximate chemical compositions of the diets are summarised in Table 1.

Table 1. Proximate chemical analysis of the experimental diets and the commercial diet used in the trial.

	Diet				
	NGTB finisher (control)	CAS50H	CAS70H	SP50L	SP70L
Energy (MJ/kg)	12.50	15.12	15.11	14.16	14.65
Protein (%)	23.90	22.45	14.63	23.05	15.67
Fat (%)	6.40	5.30	3.46	3.11	2.39
Fibre (%)	4.20	3.13	3.44	3.32	3.11
Lysine (%)	0.80	3.59	3.72	3.45	3.51
Methionine (%)	0.35	1.67	1.64	1.50	1.38
Calcium (%)	1.20	2.23	2.02	1.61	1.05
Avail. phosphorus (%)	0.55	0.47	0.28	0.62	0.41
Sodium (%)	0.05	0.33	0.32	1.14	1.44

NGTB = New Guinea Table Birds; CAS50H = 50% cassava + 50% high-energy concentrate; CAS70H = 70% cassava+ 30% high-energy concentrate; SP50L = 50% sweetpotato + 50% low-energy concentrate; SP70L = 70% sweetpotato + 30% low-energy concentrate.

The trial

The broiler chickens used in the trial were Ross 308 strain purchased from a commercial retail outlet. A total of about 520 day-old chicks were purchased, feather-sexed, weighed and allocated to two separate brooding pens, depending on gender. The chicks were kept in the brooding pens with kerosene lamp heaters during the night and fed on starter feed for 7 days. On day 7, the brooders were removed and the chicks were raised on litter until the experiment began on day 21.

The trial was carried out in a naturally ventilated broiler grow-out shed, with side and partition walls made of chicken wire. The two sides of the shed received either the morning or afternoon sun, and these sides were treated as blocks in the design. Each treatment (diet) was replicated twice on both sides (blocks) of the shed. A total of 20 pens were used, each with dimensions 4 × 2.5 m, and each pen treated as an experimental unit. The experimental design used was a 5 × 4 × 2 randomised complete block design with one treatment factor (i.e. diet).

On day 21, the chickens were weighed and randomly allocated to experimental pens, with 10 males and 10 females in each pen and overall weight of the group in each pen roughly equal. The experimental diets were then randomly allocated to the pens. The birds were introduced to the experimental diets and the feeding continued for 4 weeks. The experiment was terminated on day 49. During the experimental period, all birds had unlimited access to clean and cool water.

At the start of each week during the experiment, body weights of chickens were measured and recorded during the early morning. Feed residues and spillage, if any, were collected, weighed and discarded. All cases of mortalities were recorded and birds were examined for signs of ill health. Ambient room temperature of the broiler shed was recorded at 8 am, 10 am, 12 pm, 2 pm and 4 pm as well as the daily minimum and maximum temperatures.

Data analysis

Data were collected, cross-checked and entered into an Excel® database. Average weekly values for feed intake, weight gain and feed conversion rates were calculated. Statistical analysis was performed using GenStat®, Release 4.2, Discovery Edition (Lawes Agricultural Trust 2005).

RESULTS

Body weight

As expected, the birds fed the control diet had significantly higher weekly weights compared to birds fed the experimental diets ($P < 0.001$; Table 2). In terms of end weights at 49 days, birds on the SP50L diet had the second highest end weight after the control diet, followed by the birds on the CAS50H and SP70L diets. The birds fed the CAS70H diet had significantly lower end weights compared to the other diets ($P < 0.001$). Birds on the experimental diets SP50L, CAS50H and SP70L reached a market weight of 2 kg by the end of week 7.

Body weight gain

The weekly average body weight gains of birds on the control diet were significantly higher in weeks 4 and 5 compared to birds on the experimental diets ($P < 0.001$; Table 2). However in week 6, birds on the CAS50H diet had significantly higher gains compared to birds on the other diets ($P < 0.002$). In week 7 birds on the SP50L diet had significantly higher weight gains compared to birds on the other experimental diets ($P < 0.001$). Birds on the SP70L diet had the second highest weight gain, followed by the birds on the CAS50H ration. The birds on the control and the CAS70H diets had significantly lower ($P < 0.001$) weight gains at the end of week 7.

Feed intake

In terms of average weekly feed intake, in weeks 4, 5, 6 and 7 birds on the CAS70H diet had significantly lower intake compared to those on the other experimental diets ($P < 0.001$). Overall, higher intakes were observed for the sweetpotato diets (SP50L and SP70L) than the cassava diets (Table 2).

Feed conversion ratio

As shown in Table 2, the average feed conversion ratio (FCR) values of broilers on experimental diets were significantly different between the different diets throughout the experiment. In weeks 4 and 5, the birds on the control diet had better FCRs than those on the other diets. In week 7, birds on the SP50L diet had lower feed conversion compared to birds on the other

Table 2. Weekly average body weight, weight gain, feed intake and feed conversion ratio of broilers on the cassava and sweetpotato experimental diets and the control diet.

Age (weeks)	Overall mean	Diet					LSD 5%	*P* value
		NGTB finisher (control)	SP50L	CAS50H	SP70L	CAS70H		
Body weight (kg)								
3	0.906	0.904a	0.906a	0.907a	0.903a	0.909a	0.012	0.838
4	1.177	1.269a	1.219b	1.236ab	1.075c	1.086c	0.041	<0.001
5	1.54	1.855a	1.587b	1.531c	1.488c	1.238d	0.055	<0.001
6	1.892	2.558a	1.810b	1.875b	1.719b	1.500c	0.214	<0.001
7	2.321	2.709a	2.473ab	2.384b	2.231b	1.809c	0.241	<0.001
Weight gain (kg)								
4	0.271	0.365a	0.313b	0.330ab	0.172c	0.177c	0.038	<0.001
5	0.363	0.586a	0.368b	0.295c	0.413d	0.152e	0.03	<0.001
6	0.258	0.269b	0.212bc	0.344a	0.201c	0.263bc	0.062	0.002
7	0.443	0.223c	0.663a	0.509b	0.512b	0.309c	0.115	<0.001
Feed intake (kg)								
4	0.717	0.733a	0.750a	0.704a	0.750a	0.648b	0.048	0.002
5	0.86	1.153a	0.894b	0.763c	0.897b	0.593d	0.041	<0.001
6	0.911	1.445a	0.814b	0.694b	0.991b	0.612b	0.364	0.002
7	0.858	0.924b	1.069a	0.797c	0.969b	0.530d	0.088	<0.001
FCR								
4	2.935	2.017c	2.410c	2.147c	4.404a	3.699b	0.485	<0.001
5	2.644	1.969c	2.433bc	2.587b	2.173bc	4.059a	0.564	<0.001
6	3.74	5.491a	3.854b	2.077c	4.944ab	2.345c	1.45	<0.001
7	2.47	5.483a	1.620b	1.625b	1.907b	1.713b	2.814	0.042

Means followed by the same letter in a row are not significantly different ($P > 0.05$).
NGTB = New Guinea Table Birds; CAS50H = 50% cassava + 50% high-energy concentrate; CAS70H = 70% cassava + 30% high-energy concentrate; SP50L = 50% sweetpotato + 50% low-energy concentrate; SP70L = 70% sweetpotato + 30% low-energy concentrate; LSD = least significant difference.
Source: Glatz (2013).

diets ($P < 0.042$); this figure was significantly different to the FCR of birds on the control diet, but was not significantly different to birds on the CAS50H, SP70L and CAS70H diets. The FCR of birds on the CAS70H diet improved from 3.699 at week 4 to 1.713 at the end of week 7, while FCR on the SP70L diet improved from 4.404 at week 4 to 1.907 at the end of week 7. The birds fed the control diet had significantly higher FCR at the end of week 7 compared to those on the other diets ($P < 0.042$).

DISCUSSION

The results for body weight, weight gain and FCR of birds obtained in this trial are comparable to birds fed commercial stock feed under PNG local conditions. Both cassava mixed with the high-energy concentrate and sweetpotato mixed with the low-energy concentrate showed promising results. Birds fed the experimental diets were able to reach a market weight of 1.8–2.5 kg by 49 days. Birds fed the CAS70H diet had low feed intake throughout the experiment, which may be associated with higher energy values in the feed; the birds had good weight gains, and good FCR at the end of week 7. The results show that these roots can be fed to broilers and can improve profit margins for farmers.

According to the International Society for Tropical Root Crops (http://www.istrc.org/about-the-istrc), the current challenge is for appropriate processing technologies and business enterprise models to be developed for these crops, as unlike grains, root and tuber crops are bulky, have high water content and have a relatively short shelf-life.

Using cassava and sweetpotato as animal feed not only adds value to these crops but also diversifies income earning opportunities for farmers growing these crops. Cassava and sweetpotato are two of the major traditional root crops grown throughout PNG and are important to the livelihoods of many rural farmers. Therefore, any advances in product development for these crops will have a direct impact on improving food security and income generation.

As shown in this paper, these two crops can supply the majority of the carbohydrate in livestock diets provided they are supplemented with other nutrients, such as protein and essential amino acids. The implications of using these local ingredients to feed livestock are huge, especially for smallholder producers who need to maximise farm productivity and increase efficiency.

CONCLUSION

The results in this paper show that it is feasible to feed broiler chickens in PNG on a protein concentrate blended with a local root crop. The two best feeding options based on growth performance appear to be 50% sweetpotato mixed with 50% low-energy concentrate and 50% cassava mixed with 50% high-energy concentrate. More research is needed into appropriate processing technologies for these crops so that their full potential can be realised, for chickens and other livestock. Developing business models for small feed mill operators, incorporating these feeding options, will pave the way for potential investors to fully exploit these crops.

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Evaluation of growth performance of broiler chickens fed a locally manufactured protein concentrate prepared at a mini-mill in Papua New Guinea

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Abstract

Feed ingredients in Papua New Guinea are generally imported and very expensive. There has been emphasis on producing a balanced diet from local feed ingredients, making it more affordable and convenient for smallholder broiler chicken farmers. This trial was designed to evaluate a mini-mill-manufactured broiler concentrate (MMBC) containing local ingredients. The MMBC was blended with sweetpotato at 50% (MMBC50) and 60% (MMBC60, i.e. 40% sweetpotato) and these were tested against National Agricultural Research Institute low-energy broiler concentrate blended with 50% sweetpotato (NLEBC50) and a commercial broiler finisher diet (as control). The MMBC contained fishmeal, soybean meal, cassava leaves, milled corn, limestone, copra meal, cassava meal and kikuyu leaves, as well as table salt, methionine, palm oil and broiler pre-mix. Its nutrient specifications were 29.05% protein, 6.84% crude fibre, 4.66% crude fat, 6.33% calcium and 0.89% phosphorus. The trial was carried out at the NARI Livestock Research Station near Lae. The four treatment diets were fed to birds from 21 to 42 days of age, and monitoring was done until the end of week 6. Birds fed on the MMBC60 diet performed similarly to the NLEBC50 diet in terms of body end weight. The lowest body weight gain was for birds fed the MMBC50 diet while birds fed the commercial diet had the highest body weight gain. Birds fed the NLEBC50 and the MMBC60 diets attained weights above 2 kg in week 6. The lower costs of the MMBC60 diet (5.23 kina/kg) and the NLEBC50 diet (6.46 kina/kg) mean they are viable alternatives to the commercial diet (7.20 kina/kg). In isolated areas of PNG, where commercial or NARI-produced diets may not be readily available, the production of effective and affordable diets in mini-mills will be of great benefit to chicken farmers.

INTRODUCTION

The smallholder village broiler sector in Papua New Guinea (PNG) depends primarily on expensive commercial feeds made largely from imported ingredients. The National Agricultural Research Institute (NARI) in PNG has been collaborating with the South Australian Research and Development Institute (SARDI) and the PNG University of Technology (Unitech) in an Australian Centre for International Agricultural Research (ACIAR)-funded project titled 'Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea' (ASEM/2010/053). One of the project objectives is to formulate a range of low-cost diets for fish, pigs and poultry using local feed resources that can be produced by mini-mills. The study reported in this paper aimed to develop a low-cost broiler concentrate from local feed ingredients and test the diet in an on-station trial

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to determine if the diet was suitable to recommend for use by smallholder broiler enterprises.

Informal broiler enterprises have extended widely throughout PNG, except in areas accessible only by plane. Even though there has been a rapid increase in the cost of feed and day-old chicks, and a similar increase in the sale price of live birds and frozen meat products, the broiler industry sector continues to expand (Bourke and Harwood 2009). Smallholder broiler farmers have entered the market chain selling live birds at village markets. Farmers can obtain regular cash flow from this enterprise due to the short production cycle of six weeks to produce a meat bird.

Pandi (2005) examined the growth rate of village broilers fed a commercial finisher feed mixed with 20–80% of copra meal. Mixing with 20–40% copra meal resulted in similar growth as the control diet and significant reduction in feed cost. This approach is currently recommended and used in smallholder farms in the Momase and Islands regions of PNG where copra meal is abundant. The financial viability of this approach depends on the availability and cost of copra meal. Other studies have also demonstrated acceptable growth at 6–7 weeks on diets comprising 50% NARI low-energy broiler concentrate blended with 50% boiled and mashed sweetpotato and NARI high-energy broiler concentrate blended with 50% boiled and mashed cassava tubers (Ayalew et al. 2017; Pandi and Glatz 2017; Pandi et al. 2017).

The main issue has been the availability of broiler protein concentrate, that is also affordable for smallholder broiler farmers. This can be a challenge in parts of PNG where road infrastructure is limited and transport cost is correspondingly high. Other advantages of producing feed at mini-mills using local resources include allowing broiler production all year round, and also creating additional market opportunities for local farmers engaged in crop production. Mini-mills can play an important role of maintaining cash flow throughout the year through constant demand for crops that are major components of mini-mill broiler concentrate.

The mini-mill broiler concentrate in this trial comprised nearly half local ingredients, mixed with sweetpotato at ratios of 50:50 and 60:40. These diets were tested against NARI low-energy broiler concentrate blended 50:50 with sweetpotato (NLEBC50) and a commercial broiler finisher diet as control.

MATERIALS AND METHODS

Location

The trial was conducted at the National Agricultural Research Institute (NARI) Livestock Station at Labu (6°40′27″ S, 146°54′33″ E) on the Wau-Bulolo road near Lae from 12 February to 4 March 2013. The climate is warm and wet and the temperature averaged 28–33°C during the experimental period.

The trial

Ross 308 day-old broiler chicks from Zenag hatchery were bought from Farmset distributors in Lae. The birds were raised in a round brooder made from cardboard. Woodchips were used as litter to a depth of 4 cm over the concrete floor and the top was covered with copra bags. Newspaper was placed over the woodchips and starter crumble feed (apparent metabolisable energy (AME) 12.13 MJ/kg; 21% crude protein) was broadcast for the first week. Tube feeders (20 cm in diameter) were used for the remaining trial period. Water drinkers were refilled twice daily to provide clean water. A hurricane kerosene lamp was provided in the brooder 24 hours a day during the first week, and at night during the second and third weeks.

After the third week birds were weighed and allocated to experimental pens. The average weight per bird was 0.95 ± 0.02 kg for males and 0.93 ± 0.10 kg for females.

The trial was carried out in a shed (30 × 6 m) with an iron roof, masonite and chicken wire walls and a concrete floor. The shed faced in a northeast direction. The shed had a total of 20 pens with each pen 3 × 2.5 m; eight pens were used in the trial. Woodchips were used as deep litter material on the concrete floor of each pen to 5 cm depth. A 30 cm diameter feeder and 28 cm diameter drinker were used for each pen providing 3.9 cm/bird linear feeding space and 3.4 cm/bird linear drinking space. Light was provided for 24 hours: 11 hours of natural light and 13 hours of artificial light from 5 pm to 6 am.

Birds were fed the experimental diets from 22 to 42 days of age. Healthy chickens (five male and five female) were randomly allocated to each of the treatment pens. Fresh feed (2 kg) was provided twice daily (morning and afternoon) and clean water from a nearby reservoir tank was provided daily. Feed and water were monitored closely. The birds were weighed at the end of each week.

The trial compared growth and feed cost for broiler chickens from 3 to 6 weeks of age fed pelleted (0.5 mm) treatment diets 50% and 60% MMBC blended with cooked sweetpotato (MMBC50 and MMBC60, respectively) compared with 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato (NLEBC50) and a commercial broiler finisher diet (control). The NARI low-energy broiler concentrate (NLEBC) was the same concentrate used in previous trials (Glatz et al. 2010; Ayalew et al. 2017; Pandi et al. 2017), with nutrient specifications 9.87 MJ/kg metabolisable energy, 39.99% crude protein, 4.81% crude fat, 4.67% crude fibre, 3.34% calcium and 1.50% available phosphorus.

A randomised design was used with the four treatments replicated twice. Each treatment unit had 10 broiler chickens starting at 3 weeks of age. Table 1 shows the treatment allocations.

Experimental diets

The mini-mill broiler concentrate (MMBC) was formulated from commonly available local feed ingredients (Table 2). These included sweetpotato, fishmeal, cassava leaves, maize, limestone, copra meal, cassava meal and kikuyu leaves. The MMBC diet contained 60% local ingredients and was manufactured at the NARI mini-mill facility. Methionine, soybean meal and pre-mix (containing minerals such as iron, magnesium, manganese and zinc) were the only ingredients not made in PNG.

Soybean meal is a significant component of the MMBC, and like fishmeal, is used to enhance the level of protein and energy. Powdered fishmeal, copra meal and soybean meal are agro-industrial by-products. Cassava and sweetpotato are widely grown on

Table 1. Treatment allocation of diets for the eight pens.

Replicate I	Replicate II
Pen 1: NLEBC50	Pen 8: MMBC60
Pen 2: Control	Pen 7: MMBC50
Pen 3: MMBC60	Pen 6: NLEBC50
Pen 4: MMBC50	Pen 5: Control

NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato;
MMBC50 = 50% mini-mill broiler concentrate blended with cooked sweetpotato;
MMBC60 = 60% mini-mill broiler concentrate blended with cooked sweetpotato.

Table 2. Ingredients of the mini-mill broiler concentrate, and costs.

Ingredient	Amount (kg/103.76 kg)	Unit cost (kina)	Total cost (kina)
Fishmeal	26.8	2.15	57.26
Milled corn	14.46	2.00	28.92
Soybean meal	32.15	1.90	61.09
Copra meal	3	1.50	4.50
Cassava meal	0.1	0.77	0.08
Kikuyu leaves (fresh)	2.26	0.50	1.13
Cassava leaves (fresh)	15.76	0.50	7.88
Palm oil	0.26	5.00	1.30
Limestone	4.94	1.32	6.52
Salt (NaCl)	2.28	2.00	4.56
DL-methionine	1.26	13.20	16.63
Pre-mix	0.49	5.55	2.72
Total	103.76		192.52

smallholder farms. Milled corn was obtained from Rumion farm in the Markham Valley.

The sweetpotato and cassava tubers were peeled and grated on a manual grater machine into fine chips, sun dried for 2 days to reduce moisture content by 65–70%, and processed into a fine powder. The fresh cassava leaves and kikuyu leaves were chopped into fine pieces and mixed with the powdered ingredients, including soybean, corn, copra and fishmeal, and a blend of methionine, salt, pre-mix and limestone (mixed previously) was mixed in, along with palm oil. Once the mix was uniform, the MMBC was packed and stored.

The MMBC formulation was uniformly mixed with boiled and mashed sweetpotato at 50:50 and 60:40 ratios and these test diets were pelletised in an animal feed pellet machine (Model Victor 210), dried in the sun until 10% moisture was reached, and stored under room conditions. The NLEBC diet was blended with boiled and mashed sweetpotato at a ratio of 50:50 and pelletised. The unit costs of the diets are shown in Table 3. The nutrient specifications of the diets were predicted using feed formulation software (Table 4).

Table 3. Unit costs of the experimental diets and the control diet.

Feed constituent	Unit cost	Sweetpotato component cost	Total unit cost (kina/kg)
Sweetpotato	0.68	–	0.68
MMBC	1.86	–	1.86
MMBC50	0.93	0.34	1.27
MMBC60	1.11	0.27	1.38
NLEBC50	1.25	0.34	1.59
Control	2.18	–	2.18

MMBC = mini-mill broiler concentrate; MMBC50 = 50% mini-mill boiler concentrate blended with cooked sweetpotato; MMBC60 = 60% mini-mill boiler concentrate blended with cooked sweetpotato; NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato.

Chemical analysis

Feed samples were randomly taken each week from each treatment, ground-up and stored in the fridge at 5°C. Samples from each collection were mixed together and analysed for crude protein, crude fat, crude fibre, calcium and phosphorus at the Analytical Service Laboratory of the PNG University of Technology using the methods of AOAC (1990).

Measurements and statistical analyses

Live body weights, feed weights, feed refusal weights, temperature and humidity were monitored over the

Table 4. Diet composition and nutrient specification of the local diet predicted using the University of New England feed formulation software and the nutrient specification of Goodman Fielder International (manufacturer of the control diet).

Diet/component	ME (MJ/kg)	CP (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Avail. P (%)
Sweetpotato	14.9	4.2	0.7			
MMBC	9.84	39.98	5.36	3.64	3.25	0.83
NLEBC	9.87	39.99	4.81	4.67	3.34	1.50
MMBC50	12.37	22.09	3.03	1.82	1.63	0.42
MMBC60	11.86	25.67	3.50	2.18	1.95	0.50
NLEBC50	12.39	22.10	2.75	2.33	1.67	0.75
Control	12.2	19	7.5	4	1.28	0.71
Requirements*	13.39	19.5	3.0	3.0	0.79	0.395

* Finisher feed requirement of broilers (Thomson, 2012).
ME = metabolisable energy; CP = crude protein; Avail. P = available phosphorus; MMBC = mini-mill broiler concentrate; NLEBC = NARI low-energy broiler concentrate; NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato; MMBC50 = 50% mini-mill boiler concentrate blended with cooked sweetpotato; MMBC60 = 60% mini-mill boiler concentrate blended with cooked sweetpotato.

experimental period. Feed intake, feed conversion ratio (FCR) and weight gains were calculated as follows:

Feed intake = average feed offered – average feed refused

Weight gain = end of week body weight – start of week body weight

Feed conversion ratio = weekly feed intake/weekly body weight gain

The data were entered into Microsoft Excel, aggregated and subjected to one-way ANOVA in SPSS version 17.

Model $Y = T_j + B_i + e_{ij}$

where

Y is the response variable, T is the effect of the ith treatment (i = 1, 2, 3, 4, 5), B is the effect of the jth block (j = 1, 2), and e is the random error.

RESULTS

The protein level of the MMBC diet (29.05%) was lower than that of the NLEBC diet (39.9%); crude fat and calcium were higher (6.84% and 6.33%) than the NLEBC diet (4.81%, 3.34%); while crude fibre and phosphorus were comparable. The MMBC60 formulation had similar nutrient values to the control diet while the MMBC50 diet formulation was considerably lower in protein, fibre, calcium and phosphorus (Table 5). The energy level of each diet was not analysed as the instrument to measure this was not available.

Prediction of nutrient specifications using feed formulation software (Table 4) was different from the values measured using chemical analysis (Table 5).

One bird from the control diet group died during week 6 of the trial. Figure 1 shows the birds' weekly body weight gain from week 3 to week 6. The birds fed the control diet were heavier and had a higher weight gain throughout the experiment compared to birds fed the test diets. Birds fed the MMBC60 diet were marginally heavier than birds fed the NLEBC50 diet while birds fed the MMBC50 diet had the lowest body weight gain (1.77 ± 0.054 kg) by week 6.

At the commencement of the trial (week 3) birds in all groups had a similar average body weight. In week 4, bird body weights were significantly different (Table 6); birds fed the control diet had the highest body weight (1.45 ± 0.035 kg) as expected, compared to birds fed the MMBC50 diet (1.22 ± 0.01 kg). Birds fed the NLEBC50 diet (1.38 ± 0.00 kg) and the MMBC60 diet (1.32 ± 0.03 kg) had statistically similar weights. This trend in body weight continued to week 5. At the finishing weight in week 6, birds fed the control standard diet were significantly heavier (2.42 ± 0.12 kg) than birds fed the NLEBC50 diet (2.10 ± 0.01 kg; $P < 0.05$) and the MMBC60 diet (2.01 ± 0.03 kg; $P < 0.05$), while birds fed the MMBC50 diet had significantly lower body weight (1.77 ± 0.05 kg; $P < 0.05$) compared with the other diets.

In week 4, feed consumption of birds varied between the treatment diets with a significantly higher intake for birds fed the control diet (0.12 ± 0.0 kg)

Table 5. Nutritional profile of the test diets and the commercial broiler finisher diet.

Diet	Protein (%)	Crude fat (%)	Crude fibre (%)	Calcium (%)	Phosphorus (%)
MMBC	29.05	6.84	4.66	6.33	0.89
MMBC50	15.55	6.06	2.77	3.33	1.42
MMBC60	20.2	7.95	3.00	4.25	2.41
NLEBC50	21.5	4.81	4.67	3.34	0.6
Control	20.7	9.0	6.2	–	–

MMBC = mini-mill broiler concentrate; MMBC50 = 50% mini-mill boiler concentrate blended with cooked sweetpotato; MMBC60 = 60% mini-mill boiler concentrate blended with cooked sweetpotato; NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato; Control = commercial broiler finisher standard diet.

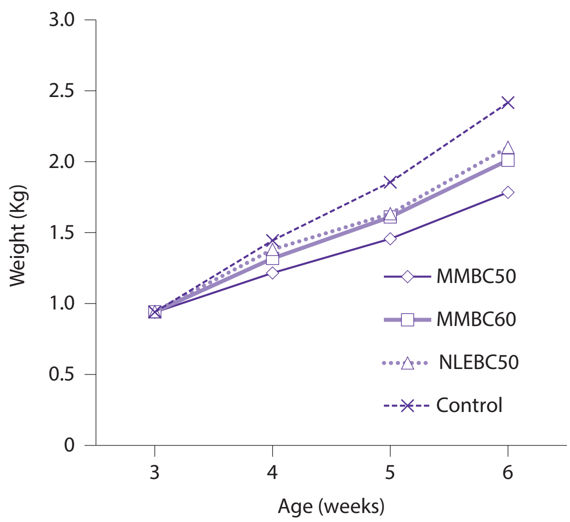

Figure 1. Average weekly body weights of birds fed on the four test diets. MMBC50 = 50% mini-mill boiler concentrate blended with cooked sweetpotato; MMBC60 = 60% mini-mill boiler concentrate blended with cooked sweetpotato; NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato; Control = commercial broiler finisher standard diet.

compared to the NLEBC50 diet (0.09 ± 0.00 kg), the MMBC60 diet (0.08 ± 0.01 kg) and the MMBC50 diet (0.08 ± 0.00 kg), which had statistically similar feed consumption ($P < 0.05$; Table 6). In week 5 a similar result was noted with birds fed the control diet having a significantly higher intake (0.13 ± 0.00 kg) than birds fed the MMBC60 diet (0.11 ± 0.00 kg; $P < 0.013$), while birds fed the MMBC50 (0.09 ± 0.01 kg) and NLEBC50 (0.09 ± 0.01 kg) diets had similar feed consumption.

The FCRs of birds fed the different treatment diets throughout the experiment were similar (Table 6). The weight gain in week 4 was significantly higher ($P < 0.007$) for birds fed the control diet (0.50 kg) compared to birds fed the NLEBC50 diet (0.44 kg), the MMBC60 diet (0.38 kg) and the MMBC50 diet (0.28 kg). Similar results for weight gain were also noted in week 5 for birds fed the different diets, however there was a slight drop in weight gain for birds fed NLEBC50 between weeks 4 and 5. There was no significant difference in weight gain in week 6 (Table 6).

Feed costs per bird from weeks 3 to 6 for birds fed the MMBC60 diet (5.23 kina) were lower than those on the NLEBC50 diet (6.46 kina), the control standard diet (7.20 kina) and the MMBC50 diet (7.78 kina) (Table 6).

DISCUSSION AND CONCLUSION

The use of local ingredients in a broiler finisher formulation is physically and economically viable. The broiler concentrate formulated at the mini-mill facilities in PNG using up to 60% local feed ingredients had a nutrient composition similar to the NARI low energy concentrate. Mixing with cooked sweetpotato enhanced the nutrient quality of the mini-mill concentrate, providing a complete finisher diet.

Moreover, the birds fed on 60% mini-mill broiler concentrate mixed with 40% cooked sweetpotato performed exceptionally well in terms of growth performance from week 4 to week 6. These birds finished well ahead of those fed on the 50% blend, and their growth performance was similar to birds fed the standard commercial diet and the % NARI low-energy broiler concentrate mixed with sweetpotato in terms of feed intake, feed conversion ratio, body weight and weight gain from week 5 to week 6.

The use of 50% NARI low-energy broiler concentrate mixed with 50% boiled and mashed sweetpotato was also reported in the paper by Glatz et al. (2010), which indicated that a 50:50 low-energy concentrate:sweetpotato (SP50LEC) formulation was promising for broiler finisher feed in terms of optimum growth performances and cost reduction. The average body weights in week 5 were 1.59 kg and 1.86 kg for the SP50LEC and commercial diets, respectively (Glatz et al. 2010).

Feed form and nutrient composition of feed also determine growth performance. It was reported that feeding pellets can improve the performance of broilers compared with mashed feeds (Choi et al. 1986; Nir et al. 1994; Ayalew et al. 2017). Similarly, birds fed on pelletised 50% NARI low-energy broiler concentrate with 50% sweetpotato achieved body weight of 1.64 kg in week 5 compared to 1.59 kg on a similar diet in boiled mashed form (Glatz et al. 2010).

Table 6. Bird numbers, feed intake (kg/day), feed conversion ratio (FCR) (feed/g weight), body weight and weight gain of birds from week 3 to week 6 by treatment diet (means ± standard errors of means).

Week	Variable	MMBC50	MMBC60	NLEBC50	Control diet	*P* value (0.05)
3	Bird numbers	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0	–
	Body weight (kg)	0.94 ± 0.0	0.94 ± 0.0	0.94 ± 0.0	0.94 ± 0.0	0.49
4	Bird numbers	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0	–
	Feed intake (kg)	0.08^{a} ± 0.0	0.08^{a} ± 0.01	0.09^{a} ± 0.0	0.12^{b} ± 0.0	0.001
	FCR	2.05 ± 0.15	1.65 ± 0.05	1.45 ± 0.05	1.6 ± 0.10	0.05
	Body weight (kg)	1.22^{a} ± 0.01	1.32^{b} ± 0.03	1.38^{b} ± 0.0	1.45^{c} ± 0.04	0.01
	Weight gain (kg)	0.28^{a} ± 0.01	0.38^{b} ± 0.03	0.44^{b} ± 0.0	0.5^{c} ± 0.03	0.007
5	Bird numbers	10 ± 0.00	10 ± 0.00	10 ± 0.0	10 ± 0.0	–
	Feed intake (kg)	0.09^{a} ± 0.01	0.11^{b} ± 0.01	0.09^{a} ± 0.01	0.13^{c} ± 0.0	0.013
	FCR	2.75 ± 0.05	2.55 ± 0.35	2.77 ± 0.20	2.2 ± 0.0	0.34
	Body weight (kg)	1.46^{a} ± 0.03	1.62^{b} ± 0.02	1.64^{b} ± 0.01	1.86^{c} ± 0.03	0.001
	Weight gain (kg)	0.24^{a} ± 0.01	0.29^{b} ± 0.44	0.25^{a} ± 0.00	0.41^{c} ± 0.0	0.017
6	Bird numbers	10^{a} ± 0.0	10^{a} ± 0.0	10^{a} ± 0.0	9.89^{b} ± 0.01	0.03
	Feed intake (kg)	0.15 ± 0.01	0.17 ± 0.02	0.17 ± 0.0	0.16 ± 0.0	0.22
	FCR	3.15 ± 0.15	2.85 ± 0.05	2.55 ± 0.05	2.2 ± 0.30	0.06
	Body weight (kg)	1.77^{a} ± 0.05	2.01^{b} ± 0.03	2.10^{b} ± 0.01	2.42^{c} ± 0.12	0.01
	Weight gain (kg)	0.33 ± 0.02	0.40 ± 0.05	0.47 ± 0.00	0.56 ± 0.09	0.12
Feed cost/kg feed/bird (kina)		7.78	5.23	6.46	7.20	

Means with the same superscript letter within a week are not significantly different ($P > 0.05$).
MMBC50 = 50% mini-mill boiler concentrate blended with cooked sweetpotato; MMBC60 = 60% mini-mill boiler concentrate blended with cooked sweetpotato; NLEBC50 = 50% NARI low-energy broiler concentrate mixed with cooked sweetpotato.

The results in this paper indicate that it is more economical to raise birds on 60% mini-mill broiler concentrate mixed with 40% cooked sweetpotato up to the market weight (2 kg) in week 6. This is despite the fact that the unit cost of the MMBC60 formulation is higher than the MMBC50 formulation, and reflects the MMBC60 diet being more efficiently converted into the birds' body mass.

Farmers who participate in the informal broiler market need to reduce the cost of production by using local feed ingredients. The findings suggest that the 60% mini-mill manufactured broiler concentrate and 40% sweetpotato can reduce costs by 27% compared to commercial feed. In addition, the birds achieved growth similar to those fed on a 50%NARI low-energy broiler concentrate diet and a commercial diet. The local ingredients are readily available and accessible to mini-feed mill operators, while the micro-ingredients and premix can be obtained from commercial mills or as imports. Further work is needed to refine the concentrate formulations from local ingredients.

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6

Local feed resources for fish production

Growth performance of juvenile genetically improved farmed tilapia (GIFT) fed on broiler concentrate mixed with sweetpotato or cassava meal

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Abstract

A feeding experiment was conducted with juvenile genetically improved farmed tilapia (GIFT) to evaluate three different feeds. Two feeds were made by combining National Agricultural Research Institute (NARI) broiler concentrates with sweetpotato or cassava. A high-energy concentrate was combined with cooked cassava meal (HEC) and a low-energy concentrate was combined with cooked sweetpotato (LESP). Concentrate and sweetpotato or cassava were combined in the diet at 75% and 20%, respectively, and palm oil (5%) was used to balance each diet. Performance on the blended diets was compared to performance of GIFT fed a fish standard diet as control (FishSTD). Growth performance was assessed by measuring changes in feed intake, body weight and feed conversion ratio (FCR) over 12 weeks. Each dietary treatment was replicated in four research tanks and each tank was stocked with four fingerlings (≈ 6.65 g individual body weight). Fish were reared in rainwater and each of the feeds was offered at a rate of 7% of bodyweight of fish twice daily, adjusted by weekly weighing procedures. The results showed no significant difference between the harvest weight, feed intake or FCR for the different dietary treatments. However, fish reared under the HEC and LESP regimes had higher numerical feed intakes (20.8 and 20.7 g/fish/week, respectively) than fish offered the FishSTD diet (16.5 g/fish/week). The individual harvest weight of fish reared on the HEC and LESP diets was also higher (46.8 and 46.5 g, respectively) than fish offered the FishSTD diet (36.5 g). Weekly FCR values fluctuated from a low of 1.84 in week 1 to more than 5.1 at the end of the experiment, possibly due to the low stocking density. The use of the NARI broiler concentrates blended with either cooked cassava or sweetpotato meals appears promising, and new trials should be conducted to determine if this technology can be used in farm-based ponds and cages.

INTRODUCTION

There are more than 11,000 fish farmers in Papua New Guinea (PNG) (Smith et al. 2009). The major constraints faced by these farmers are non-availability of fish feed, non-availability of fingerlings, lack of training and lack of access to information and extension services. Most PNG fish farmers are subsistence farmers, and produce carp (*Cyprinus carpio*) and genetically improved farmed tilapia (GIFT), a strain of Nile tilapia (*Oreochromis nilotica*). GIFT have many desirable traits, including high growth rate, ability to feed on natural aquatic food and supplemental feeds, and tolerance to diseases and adverse environmental conditions (Rakocy 1989). For these reasons, GIFT were imported from the Philippines to PNG by the National Fisheries Authority (NFA) and the Eastern Highlands Aquaculture Development Centre as a highly suitable species for inland aquaculture. More recently, farmers have also begun farming trout (*Oncorhynchus mykiss*).

Despite the lack of feed availability and technical knowledge required to formulate simple farm-based

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feeds, interest in inland aquaculture in PNG has increased due to household protein demand and prospects for income generation (Smith et al. 2009). The NFA has supported this interest by providing funding to small cooperative farmer groups to venture into inland fish farming. This support has significantly increased the number of fish farmers in highland and coastal regions of PNG (Booth et al. 2006). As a result of increases in fish farming activity the demand for fish feed has increased, but supply and availability remain limited. This has forced farmers to investigate making their own fish feeds from locally available ingredients.

The major ingredients in prepared fish feeds are protein and energy sources derived from by-products of processed plants and animals (Gatlin 2010). At present, there is an exciting opportunity for fish farmers in PNG to utilise the recently released broiler concentrate technology developed by the National Agricultural Research Institute (NARI). The broiler concentrates, which are readily available in bulk to poultry farmers from all NARI centres around PNG, may prove to be an invaluable protein source for fish farmers wishing to formulate and make their own feeds. The broiler concentrate has a high protein level (41% crude protein (CP)) and is available as a high-energy (HE) and a low-energy (LE) concentrate. Ideally, these concentrates should be mixed with readily available, lower value energy sources in order to obtain higher feed volume of lower protein density. This approach is likely to be very successful in species such as GIFT, which have low to moderate protein requirements (Mjoun et al. 2010).

Two of the most abundant low-value energy sources available in the highland and lowland areas of PNG are cassava and sweetpotato. Cassava and sweetpotato are good sources of energy that can be used in fish feed formulation, however the presence of anti-nutrient inhibitors, such as trypsin in sweetpotato and cyanide in cassava, affects their digestibility. These anti-nutrient inhibitors can be reduced by boiling, sun-drying and processing into dried milled product. Treated in this way, these ingredients have been successfully blended with broiler concentrates and fed to poultry, and there is potential to use this technology in other monogastric species, such as fish and swine. Therefore, the aim of this study was to evaluate the use of the NARI broiler concentrates in farm-made feeds for juvenile GIFT.

The objective of this trial was to evaluate growth performance of juvenile GIFT fed on three different diets. The primary diets of interest were those made from the high-energy and low-energy broiler concentrates blended with cassava (HEC) or sweetpotato (LESP), respectively. A third diet, known as Fish Standard (FishSTD), was also included in the trial to benchmark the performance of the concentrate-based feeds. The hypothesis was that there would be no significant difference between the performances of juvenile GIFT fed on the HEC, LESP or FishSTD diets.

MATERIALS AND METHODS

Site location

The experiment was conducted at the Inland Aquaculture Research Facility, at Labu Livestock Research Station of NARI in Lae, PNG. The facility is located at latitude 6°41´ S and longitude 146°04´ E and is about 16 m above sea level. The average annual rainfall ranges from 2,000 to 2,400 mm and the average daily temperature is 27°C (NARI Bubia weather records).

Experimental facilities

The experiment was conducted in a shed that allowed limited control of most environmental variables. Twelve experiment tanks were assembled in rows of three and four columns. The fibreglass tanks were uniform in cylindrical shape and size and held up to 100 L of water at a depth of 70 cm. All experiment tanks were filled with fresh rainwater (constant depth) using buckets. The rainwater was collected from the roof and stored in a 9,000 L tank. Once every week, water from the storage tank was used to replace the water in the 12 experiment tanks. The experiment tanks had an outlet valve that allowed the used water to flow out easily. Each experiment tank had a single dissolved oxygen aerator that supplied constant oxygen to the fish.

Fish

A total of 48 mixed-sex juvenile GIFT fingerlings were used in the experiment. The fingerlings were taken from a pond at the integrated fish and duck farming facility at the research station where they had naturally spawned. Groups of four fish were randomly selected and allocated to each of the 12 experimental tanks, with group body weight balanced between the tanks (≈26.6 g body weight).

Dietary treatments

The benchmark feed used in the experiment was supplied by the NFA mini-mill in Goroka, PNG, which is the only mini-mill supplier of fish feed in the country. The ingredients and nutrient compositions of the HEC and LESP dietary treatments are presented in Table 1. The percent dry matter, crude protein and gross energy compositions of all three diets are presented in Table 2.

Diet preparation, feeding and experimental procedures

Ten kilograms each of sweetpotato and cassava tubers were grated, boiled, sun-dried, oven-dried and hammer milled to produce the final meal. Root tubers of cassava and sweetpotato were harvested or purchased from local markets, washed to remove decayed or pest-ridden material, and chopped or grated with a kitchen grater or a chipper machine. The chips were boiled for 15 minutes, and then sun-dried (at 30°C) and oven-dried (at 55°C) consecutively for 5 days and 2 days, respectively. The dried chips were milled using an electric hammer mill into cassava and sweetpotato flour. The dry-milled flour ingredients were then mixed with the appropriate broiler concentrate (low energy with sweetpotato and high energy with cassava) in proportions according to Table 1, and the palm oil was added. The diets were then made into pellets (Gonzales and Allan 2007) using a manual hand mincing machine (4 mm pellet size), and the pellets were sun-dried for a further 5 days at 28–32°C, or alternatively oven-dried at 55°C for 2 days.

All fish were given the FishSTD diet for 14 days for adaptation. The three diets (i.e. HEC, LESP and FishSTD) were then randomly allocated to the 12 experiment tanks, giving four replicates for each diet treatment. Each group of fish (i.e. the fish in each

Table 1. Ingredient and nutrient composition of the treatment diets.

Diet	Ingredient	Content (%)	Dry matter (%)	Crude protein (%)	Gross energy (MJ/kg)
HEC	HE concentrate	75.0	90.0	42.0	15.1
	Cassava*	20.0	86.5	2.1	14.7
	Palm oil	5.0	90.3	0	16.4
LESP	LE concentrate	75.0	90.0	41.5	13.0
	Sweetpotato*	20.0	88.0	4.2	14.9
	Palm oil	5.0	90.3	0	16.4

* Data for sweetpotato and cassava dried meal from Tacon (1990).
HEC = high-energy broiler concentrate blended with cassava; LESP = low-energy broiler concentrate blended with sweetpotato.

Table 2. Nutrient and energy composition of the experimental diets and the control diet.

Diet	Dry matter (%)	Crude protein (%)	Gross energy (MJ/kg)
FishSTD	92.4	36.8	17.6
HEC	89.3	35.5	16.9
LESP	89.6	35.5	15.1

FishSTD = fish standard diet from National Fisheries Authority mill;
HEC = high-energy broiler concentrate blended with cassava; LESP = low-energy broiler concentrate blended with sweetpotato.

tank) was weighed using an ACS-3H electronic scale at the end of each week and the feed delivered in the following week was adjusted based on this. The feed was calculated and given at 7% of body weight daily. Half the feed was fed to the fish in the morning between 9 am and 10 am, and the other half in the afternoon between 4 pm and 5 pm. Daily procedures included checking temperature and dissolved oxygen (DO) levels using a YSI 550A DO meter (mg/L). Water in the experiment tanks was replaced once a week with all faeces and waste feed washed out. All data from both daily and weekly procedures were recorded and entered into Microsoft Excel for analysis. The trial lasted for 12 weeks.

Statistical analysis

Data from each dietary treatment (HEC, LESP or FishSTD) were statistically analysed using one-way ANOVA based on a completely randomised design with four replicates per diet group. Performance variables analysed included weekly feed intake, body weight and feed conversion ratio (FCR = feed intake/weight gain). Analysis of raw data was done using the GenStat software (Lawes Agricultural Trust 2005) with alpha set at 0.05. Where ANOVA indicated significant differences among treatment means, means were separated using Fisher's LSD post-hoc test.

RESULTS

One-way ANOVA indicated there was no significant difference between weekly feed intake, mean body weight or FCR of juvenile GIFT fed the HEC, LESP or FishSTD diets. However, while not significant, there was some variation in feed intake, body weight and FCR among the three diets which became more pronounced after six weeks of feeding. Coefficient of variation (CV) within treatments also became larger as the trial progressed, which may be attributable to the low stocking density in this study (Tables 3–5).

Feed intake

Juvenile GIFT fed the HEC treatment recorded the highest feed intake from week 1 to week 6 (Figure 1). From week 7 through to harvest, feed intake tended to be higher in GIFT juveniles fed the HEC and LESP diets compared to fish fed the FishSTD diet. At the conclusion of the trial, weekly feed intake of fish fed the HEC and LESP diets was about 25% higher than those fed the FishSTD diet (Figure 1).

Table 3. Weekly *P* value and coefficient of variation of feed intake, body weight and feed conversion ratio for fish fed the three test diets.

Week	Feed intake		Body weight		FCR	
	P	CV (%)	*P*	CV (%)	*P*	CV (%)
1	0.661	5.9	0.569	6.1	0.728	23.1
2	0.103	4.0	0.103	4.0	0.774	23.6
3	0.340	5.1	0.334	5.2	0.142	27.4
4	0.175	9.3	0.241	8.9	0.198	37.2
5	0.382	12.8	0.382	12.8	0.586	48.5
6	0.611	16.6	0.611	16.6	0.379	36.6
7	0.968	25.2	0.531	19.4	0.355	32.1
8	0.560	21.8	0.449	21.3	0.049	31.0
9	0.423	23.3	0.371	22.6	0.468	15.6
10	0.853	27.1	0.331	22.4	0.175	23.2
11	0.274	26.0	0.328	23.0	0.708	46.5
12	0.297	21.8	0.297	21.8	0.886	25.4

CV = coefficient of variation; FCR = feed conversion ratio.

Table 4. Overall summary (means) of total feed intake, total body weight and feed conversion ratio for fish fed the three test diets.

	Total feed intake (g)	Total body weight (g)	FCR
FishSTD	110.90	30.00	3.274
HEC	129.06	40.00	2.973
LESP	129.31	39.86	2.860
Grand mean	123.39	36.62	3.036
SEM	0.829	1.790	0.158
P	0.360	0.191	0.167
CV (%)	55.90	56.30	36.20

FCR = feed conversion ratio; FishSTD = fish standard diet from National Fisheries Authority mill; HEC = high-energy broiler concentrate blended with cassava; LESP = low-energy broiler concentrate blended with sweetpotato; SEM = standard error of the mean; CV = coefficient of variation.

Table 5. Results from Fisher's LSD post-hoc testing of means.

Treatment	Intake	Body weight	FCR
HEC vs FishSTD	1.41[a]	4.0[a]	0.301[a]
LESP vs FishSTD	1.47[a]	3.9[a]	0.414[a]
LESP vs HEC	0.06[a]	0.1[a]	0.113[a]
Fisher's LSD	2.32	4.92	0.444

FishSTD = fish standard diet from National Fisheries Authority mill; HEC = high-energy broiler concentrate blended with cassava; LESP = low-energy broiler concentrate blended with sweetpotato.
Means with the same superscript in the same column are not significantly different ($P > 0.05$).

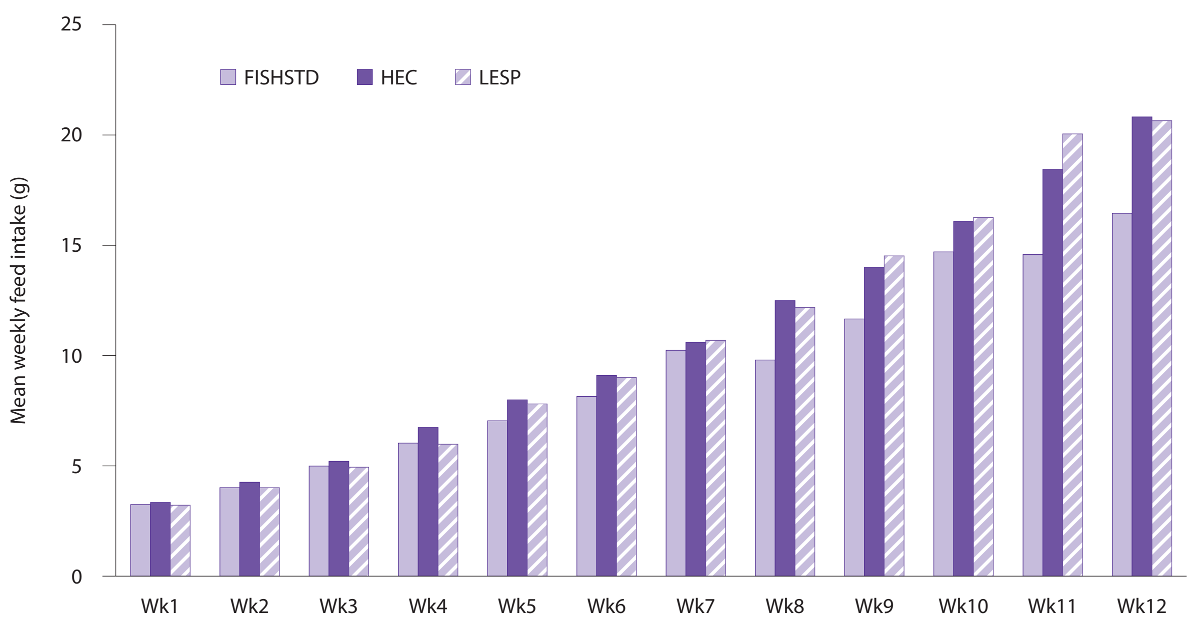

Figure 1. Mean weekly feed intake (g) of GIFT juveniles fed the three test diets over 12 weeks.

Body weight

GIFT grew from a stocked body weight of approximately 6.7 g to an average body weight of 36.5 g, 46.8 g and 46.5 g when fed the FishSTD, HEC and LESP diets, respectively (Figure 2). Although there was no significant difference in average body weight throughout the 12-week trial (Table 4), GIFT fed the HEC and LESP dietary treatments were approximately 27% heavier than fish fed the FishSTD at harvest.

Feed conversion ratio

Weekly fluctuations in FCR among diets are presented in Figure 3. FCR ratios ranged between 1.84 and 2.10 at week 1 and tended to increase as the trial progressed. In the last week of the trial FishSTD had the highest (worst) FCR compared to HEC and LESP.

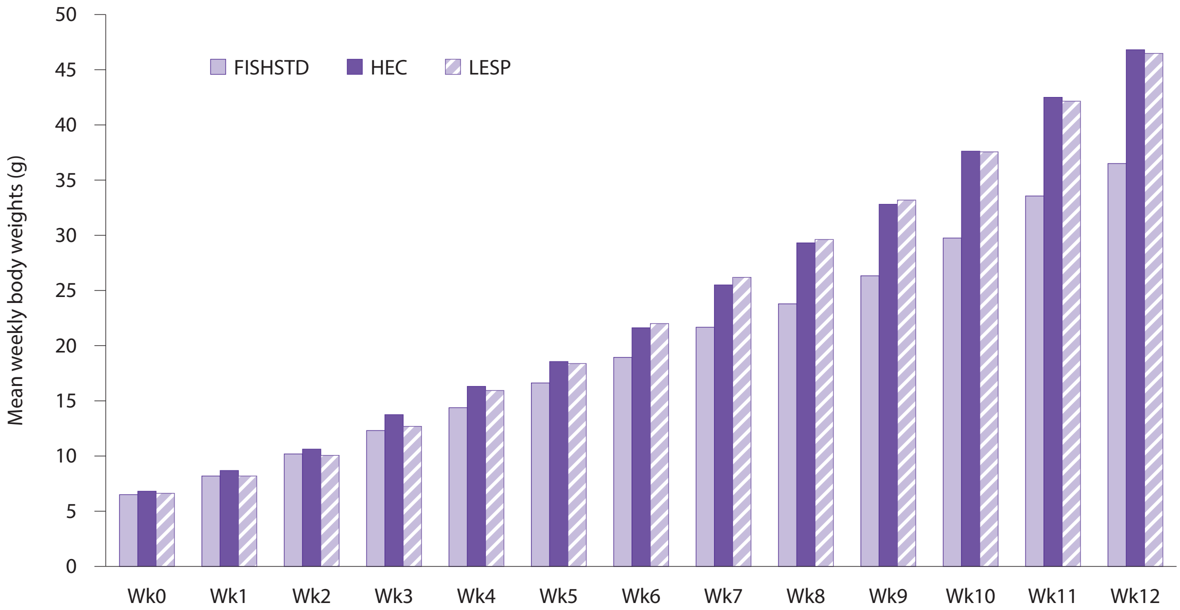

Figure 2. Mean weekly body weights (g) of GIFT juveniles fed the three test diets over 12 weeks.

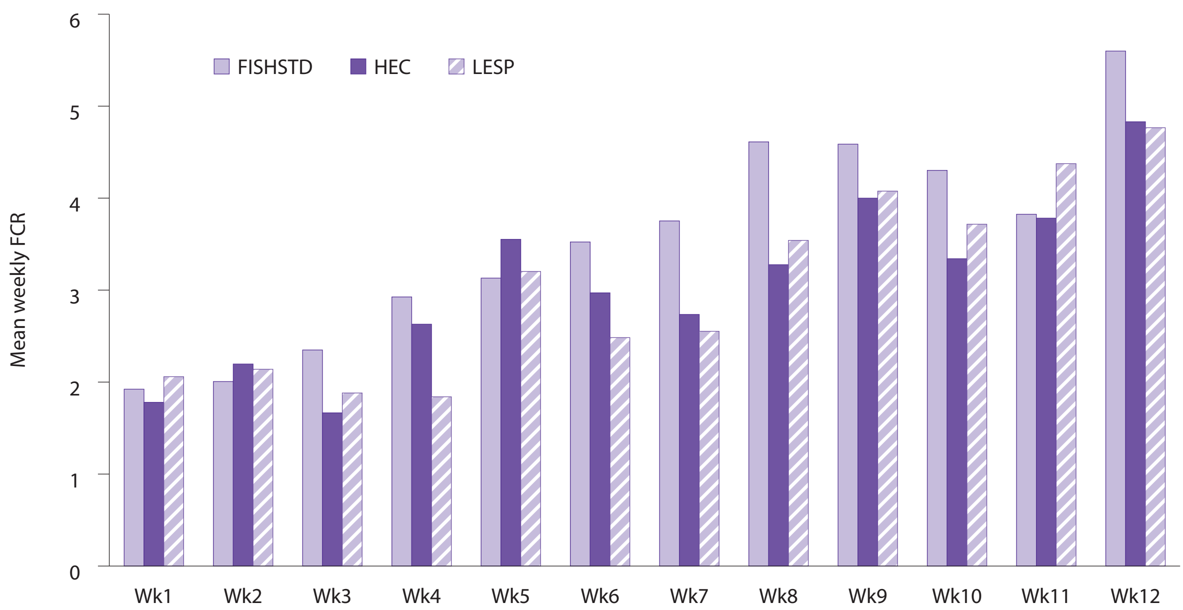

Figure 3. Mean weekly feed conversion ratio of GIFT juveniles fed the three test diets over 12 weeks.

DISCUSSION

The experiment was conducted under optimum environmental conditions to minimise factors that may influence fish growth, such as dissolved oxygen (DO), temperature and light intensity. The normal DO level required for GIFT is above 1 mg/L (Popma and Masser 1999); thus in this experiment DO level was maintained at 5 mg/L and above.

GIFT have a monogastric digestive system and poultry feed can be effectively utilised. Chiayvareesajja et al. (1988) determined that chicken pellets (19.9% crude protein) were a suitable supplemental feed for cage culture in Thailand.

In this study, the diets containing a mixture of 75% broiler concentrate and 20% cassava or sweetpotato meal were found to support a higher growth of GIFT juveniles than fish fed the FishSTD diet. At the end of the experimental period, the mean values for feed intake, body weight and FCR of juvenile GIFT fed HEC and LESP were not significantly different from those for fish on the control diet ($P > 0.05$). Although not significant, the results support the findings of Cao Thang Binh et al. (1996) who reported that a diet containing 20% crude protein formulated from concentrated poultry feed (40% crude protein) and cassava meal gave best growth of Nile tilapia.

The higher intake and bodyweight gain of fish fed on HEC and LESP diets compared to the FishSTD diet may have been due to the processing of the cassava and sweetpotato prior to pelleting, which reduced the anti-nutrients in cassava and sweetpotato making them more palatable. This hypothesis is supported by a report from Glatz et al. (2009).

Under good growth conditions and fish care, cultured tilapia in nursery ponds can grow from about 1 g to 20–40 g in 5–8 weeks (Popma and Masser 1999). The body weight of the mixed GIFT fed the HEC and LESP diets in this trial reached approximately 30 g after 8 weeks (Figure 2). This value is in the middle of the range suggested by Popma and Masser (1999); higher values might be realised with fish reared in ponds where other feed organisms are available.

The micronutrients present in the broiler concentrates may have contributed to the better intake and body weight gain by the fish fed on the test diets. A report by Cao Thang Binh et al. (1996) stated that adding micronutrients to concentrated chicken feeds led to faster growth rates. Fast growth rates are common when fish are grown in tanks and are fed diets containing CP levels of 35–40% (Chapman 2009).

CONCLUSION

The results of this study show that a diet of 75% low-energy broiler concentrate combined with 20% cooked sweetpotato and a diet of 75% high-energy broiler concentrate combined with 20% cooked cassava can support an acceptable growth rate in juvenile GIFT when reared in tanks. According to statistical analysis, there was no difference between the performances of fish reared on the different treatment diets and the standard fish diet, and this supports the stated null hypothesis. The blended diets appear promising and new trials should be conducted to determine if this technology can be used in farm-based ponds and cages. If the technology is successful, it could go a long way towards meeting the growing demand for locally made low-protein fish feeds amongst village farmers in PNG.

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Growth performance of juvenile genetically improved farmed tilapia (GIFT) fed diets with two levels of rice bran or a high-energy broiler concentrate mixed with cassava meal

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Abstract

This paper examines the use of rice bran and cassava meal in feeds for genetically improved farmed tilapia (GIFT). Two isoproteic (28% crude protein) and isoenergetic (17 MJ/kg) feeds were formulated using fishmeal, cassava meal and millrun to contain either 20% rice bran (RB20) or 40% rice bran (RB40). These diets were compared to a diet formed by blending high-energy universal feed concentrate suitable for use with broilers, layers or pigs with 31% cassava meal (HEC+CAS; 24% crude protein, 17 MJ/kg). The three feeds were fed to mixed-sex juvenile GIFT (3.80 ± 1 g) for 12 weeks. Fish were reared in 100 L freshwater tanks at a temperature of 29°C and each dietary treatment was randomised to four replicate tanks. Each tank contained four fish. After 12 weeks there was no significant difference in the weight gain or feed conversion ratio (FCR) of tilapia fed the different diets ($P < 0.05$). However, fish fed the HEC+CAS diet were heavier (36.7 g) than fish fed the RB40 (29.1 g) and RB20 (27.9 g) diets and had a better FCR. The protein efficiency ratio (PER) of fish fed HEC+CAS was significantly better (1.85) than fish fed the RB20 (1.15) and RB40 diets (1.17). The slight increase in weight gain and improvement in FCR and PER of GIFT fed the HEC+CAS diet might be a function of the lower protein:energy ratio of this diet or the additional micronutrients contained in the universal concentrate. Nonetheless, the fish fed on diets RB20 and RB40 achieved similar weight gains, FCR and PER, suggesting rice bran is as useful an energy source as cassava meal for this species. Further research on the performance and economics of using rice bran in grow-out diets for GIFT in Papua New Guinea is recommended. Moreover, the research should focus on larger scale trials that formulate test feeds on a digestible nutrient and energy basis and that apply satiation feeding strategies.

INTRODUCTION

The rapidly increasing population of Papua New Guinea (PNG) is requiring more food from the agriculture, livestock and fisheries sectors, creating economic opportunities for rural farmers. Aquaculture is currently growing at an unprecedented rate, with tilapia emerging as an important food fish for more than 11,000 farmers throughout PNG who rely on production of this and other species for their livelihood (Smith 2007). Fish farming in PNG is practised mostly at a subsistence level and is characterised by low investment resulting in low production. The main species farmed are *Tilapia mossambica*, *Tilapia rendalli* and *Oreochromis niloticus*, as well as the common carp (*Cyprinus carpio*). Tilapia is well suited to subsistence or small-scale farming because it grows quickly, is a prolific breeder, survives in poor water conditions and eats a wide range of foods (Smith 2007). Adult tilapia prefer vegetarian diets, varying from macrophytic to

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phytoplanktivorous, which can be attained through pond fertilisation (Powell 2003). The ability of tilapia (a filter feeder) to utilise additional nutrients from increases in primary or secondary pond production stimulated by fertilisation can offset feeding costs.

One of the greatest challenges facing PNG fish farmers is the ability to purchase, manufacture or otherwise provide nutritious cost-effective feeds for their fish. At present, commercial fish feeds cannot be obtained. As an alternative, fish farmers can use manufactured feeds formulated for poultry and pigs. These too can be expensive and hard to obtain. Options to reduce costs and improve flexibility include blending commercial feeds with locally available ingredients. Alternatively, farmers with knowledge of nutrition can make their own feeds using a suitable source of protein mixed with local ingredients.

Leftover food from the kitchen and termites are major sources of fish feed for most PNG farmers, according to a survey conducted by the Australian Centre for International Agriculture Research (Smith 2007). Aquaculture production in PNG is generally low compared to other developing countries and this is attributed to poor feeding and management practices and lack of technical knowledge. Tilapia performance primarily depends on its nutrition (Mjoun and Rosentrater 2010). In its normal growth and reproduction, tilapia must consume and utilise proteins, carbohydrates, fats, vitamins and minerals, hence commercial fish diets contain all these major nutrients. Ideally, low-cost tilapia feeds using local ingredients should be nutritionally comparable to good quality commercial tilapia feed, however farm-manufactured feeds are unlikely to contain a full complement of vitamins and minerals (Lovell 1980, in Ovie et al. 2005). Low-cost, farm-manufactured feeds usually consist of readily available agriculture by-products (e.g. rice bran, copra meal, cassava meal, sweetpotato and millrun) which are inexpensive but are usually high in carbohydrates and low in other nutrients.

Commercial feeds for pigs and poultry may also provide sufficient nutrition to tilapia and support adequate growth rates. For example, pig finisher feed improved tilapia growth more than rice bran diets (Lochmann 2002). Similarly, commercial chicken feed provided better growth performance to tilapia; however, proprietary feeds are more costly than diets containing rice bran and maize (Cao et al. 2001, in Liti et al. 2001).

Cereal by-products—such as rice bran, a product of rice milling—have been successfully used in formulated diets for fish, poultry and pig production in Asia and elsewhere (Choct 1997). One advantage of rice bran compared to ingredients such as cassava meal is that it contains high levels of energy as well as relatively high levels of protein (12%). Rice bran is a by-product of processed rice and usually contains a significant amount of oil (14–18%) as well as being a good source of B vitamins. This can lead to rancidity if the rice bran is not stored correctly and used relatively quickly. The high oil content includes advantageous levels of linolenic acid. Rice bran consists of the pericarp, seed coat nucleus and aleurone layers surrounding the endosperm of the rice kernel but generally not the outer husk. For this reason, rice bran is high in dietary fibres such as beta-glucan, pectin and gum.

The aim of this study was to evaluate the growth of genetically improved farmed tilapia (GIFT; *Oreochromis niloticus*) juveniles on formulated diets containing high levels of rice bran or a blended diet composed of a high-energy broiler concentrate mixed with dried cassava meal.

MATERIALS AND METHODS

Location and experimental facility

The study was conducted at the aquaculture research facility of the National Agricultural Research Institute (NARI) at Labu, near Lae, latitude 06°41´ S and longitude 146°04´ E. The facility is about 20 m above sea level with an average annual rainfall of 2,000–2,400 mm. The climate is typically warm and wet with an average temperature of 32°C and relative humidity of 85–90%.

The facility contained 12 independent 100 L circular fibreglass tanks arranged in two rows of six. Rainwater collected in a 9,000 L holding tank was used to fill the experimental tanks at the start of the study as well as to exchange the tank water on a weekly basis as the experiment progressed. Each tank was stocked with four fish, equivalent to a stocking density of 100 fish/m^2 (Yakubu et al. 2012). Ambient air temperature within the tank room ranged between 20°C and 32°C.

Feeds and feeding

Three experimental feeds were prepared according to specifications presented by Thomas (2006). Two isoproteic (28% crude protein) and isoenergetic (17 MJ/kg) feeds were formulated using fishmeal, cassava meal and millrun to contain either 20% or 40% rice bran (RB20 and RB40). The third diet was a high-energy universal concentrate (NARI broiler concentrate) blended with 31% cassava meal (HEC+CAS; 24% crude protein, 17 MJ/kg). The nutrient profile of the HEC is given in Pandi et al. (2017). Estimates of the nutrient and energy composition of ingredients are presented in Table 1, compositions of the diets are shown in Table 2, and calculated nutrient contents of the diets are given in Table 3. Slight variations were noted in the protein:energy ratio of the rice bran diets, with the ratio of the HEC+CAS being lower (Table 3).

The ingredients were purchased locally and ground to a flour-like consistency using a hammer mill. Formulated mixtures were then placed on a canvas sheet and thoroughly mixed by hand before the addition of wet ingredients. Tallow was warmed to 60–65°C and added to the RB20 and RB40 mixtures as an energy source and binding agent. Commonly used vegetable cooking oil was also warmed to 60–65°C and used in the HEC+CAS mixture instead of tallow. Warm water (65–70°C) was then added to each mash and the resulting dough was passed through a 4 mm mincing machine to form pellets. The pellets were sun-dried in the middle of the day (11 am to 4 pm) at temperatures of 27–34°C for 3 days (total of 15 hours of sun drying). Prior to use in the experiment, the 4 mm pellets were ground to a small crumble size of less than 2 mm.

Table 1. Estimated as-fed nutrient and energy content of ingredients used in the test diets.

Ingredient	Dry matter (%)	Crude protein (%)	Gross energy (kJ/kg)	Fat (%)	Ash (%)
Fishmeal (FAQ)	91.8	65.3	19.0	7.1	15.0
Rice bran (Guimaraes et al. 2008)	91.0	12.8	17.1	16.8	9.81
Cassava meal	86.5	2.1	12.7	0.6	3.4
Wheat millrun (NRC 2011)	89.0	16.6	16.5	4.0	4.5
Tallow	99.0	0.0	38.0	99.0	1.0
Cooking oil	99.0	0.0	38.0	99.0	1.0
Universal concentrate*	95.0	35.8	17.1	8.7	8.2

* Based on Carey Universal Concentrate for broiler, pig and layer 26/04/2014; single mix formulation.
FAQ = fair average quality.

Table 2. Composition of the test diets (%).

Ingredient	Diet		
	RB20	RB40	HEC*+CAS
Fishmeal (FAQ)	32.0	30.0	–
Rice bran	20.0	40.0	–
Cassava meal	23.0	5.0	30.8
Wheat millrun	23.0	23.0	–
Tallow	2.0	2.0	–
Cooking oil	–	–	5.0
Universal concentrate*	–	–	64.2

* Based on Carey Universal Concentrate for broiler, pig and layer 26/04/2014; single mix formulation.
RB20 = 20% rice bran diet; RB40 = 40% rice bran diet; HEC+CAS = high-energy concentrate + cassava diet; FAQ = fair average quality.

Table 3. Calculated nutrient contents of the diets.

Nutrient	Diet		
	RB20	RB40	HEC+CAS
Crude protein (%)	27.8	28.6	23.6
Gross energy (MJ/kg)	16.9	17.7	16.8
Fat (%)	8.7	11.8	10.7
Ash (%)	8.6	9.6	6.4
NFE (%)	45.0	40.9	49.2
Crude protein/gross energy ratio (g/MJ)	16.4	16.2	14.0

RB20 = 20% rice bran diet; RB40 = 40% rice bran diet; HEC+CAS = high-energy concentrate + cassava diet.

All fish were fed according to a restrictive feeding regime. Fish were hand-fed during the first week at a rate of 12% live body weight per day (i.e. 2 g feed/tank/day). Feeding rations were increased in absolute terms from 2 g/tank/day to 3 g/tank/day (week 2 and week 3) and then to 4 g/tank/day (week 4) as the experiment progressed. Feed was delivered by carefully broadcasting 50% of the ration in the morning (8 am to 9 am) and 50% of the ration in the evening (4 pm to 5 pm), except the day preceding weighing of fish when feeding was delayed until sampling was completed.

Fish stocking and sampling

Mixed-sex, unpaired juvenile GIFT (*Oreochromis niloticus*) of F_1 generation were sourced locally from Potsi Inland Fish Farming Ltd located 16 km from Lae. The fish were initially kept for 1 week in a large tank for acclimatisation and to ensure they were healthy before stocking. During this time, they were fed HEC+CAS. After acclimatisation, healthy fish with body weights around 3.8 g were selected and four fish were randomly assigned to each of the 12 experimental tanks. The fish were allowed to acclimatise to tank conditions for 7 days before test feeds were introduced. No mortality was observed during this period. The average biomass and individual weight of fish across all tanks were 15.21 ± 1 g and 3.80 ± 1 g, respectively. Weight assessment was done on a weekly basis, allowing the tanks to be drained, cleaned and refilled with fresh rainwater. At this time, fish from each tank were bulk weighed without anaesthetic being applied. A standard digital top-loading balance (Constant®) was used throughout the period. Dead fish were not replaced during the study.

Water quality monitoring

Water temperature was measured with a YSI Environment meter and dissolved oxygen was measured using a Lutron electronic DO meter. The temperature range was between 28.10°C and 29.77°C while the dissolved oxygen level in the experimental tanks was 4.48–8.04 mg/L throughout the study period. The concentration of dissolved oxygen and water temperature in all tanks were maintained within published guidelines for best practice culture of tilapia juveniles (Masser et al. 1999). The pH and ammonia levels were measured on a weekly basis over 3 weeks with Aqua One aquarium test kits.

Performance metrics

Survival, feed intake, weight gain and biological feed conversion ratio (bFCR) were calculated using the following formulae:

$$\text{Survival }\% = \frac{\text{number of fish stocked in a tank}}{\text{number of fish in the tank at harvest}} \times 100\%$$

$$\text{Feed intake (g/fish)} = \frac{\text{as-fed feed weight (g)}}{\text{number of fish in the tank}}$$

$$\text{Weight gain (g/fish)} = \text{final weight of fish (g)} - \text{initial weight of fish (g)}$$

$$\text{Specific growth rate (SGR) (\%/day)} = \frac{\ln\left(\text{final weight}\right) - \ln\left(\text{initial weight}\right)}{84 \text{ days}} \times 100$$

$$\text{Biological feed conversion ratio (bFCR)} = \frac{\text{as-fed feed intake (g)}}{\text{biomass gain in the tank (g)}}$$

$$\text{Protein efficiency ratio (PER)} = \frac{\text{weight gain (g)}}{\text{protein intake (g)}}$$

Statistical analysis

Data were analysed using one-way ANOVA using GenStat software® (Lawes Agricultural Trust 2013) after checking data for normality and homogeneity of variances. Upon detection of statistically significant differences ($P < 0.05$), a Duncan's multiple range test was used to rank the test diets (Duncan 1955). The average metric value for each tank was considered as the unit of replication (i.e. average performance metric of four fish/tank). A one-way ANOVA was run to check whether there was a difference in the initial weight of fish allocated to different treatments at the start of the trial ($F_{2,9} = 0.15$, $P = 0.86$).

RESULTS

A 100% survival rate was recorded in five of the 12 experiment tanks (i.e. two allocated to RB20 and three allocated to RB40). Seventy-five percent of fish survived in six of the 12 experiment tanks (i.e. one allocated to RB20, one allocated to RB40 and four allocated to HEC+CAS) while only 25% of fish survived in one tank allocated to RB20. Mortality was not related to dietary treatment.

Weight gain was consistent throughout the trial, with the SGR of fish fed HEC+CAS, RB40 and RB20 being 2.68%, 2.40% and 2.36% per day, respectively (Figure 1 and Table 4). One-way ANOVA found no difference between the final body weights of fish fed RB20, RB40 or HEC+CAS ($F_{2,9} = 2.78$, $P = 0.11$). However, fish fed HEC+CAS were approximately 25–30% heavier (36.65 g) than fish fed RB20 (27.88 g) and RB40 (29.11 g) by the end of the study (Table 4).

Biological FCRs of fish on the different test diets were not significantly different after 84 days feeding

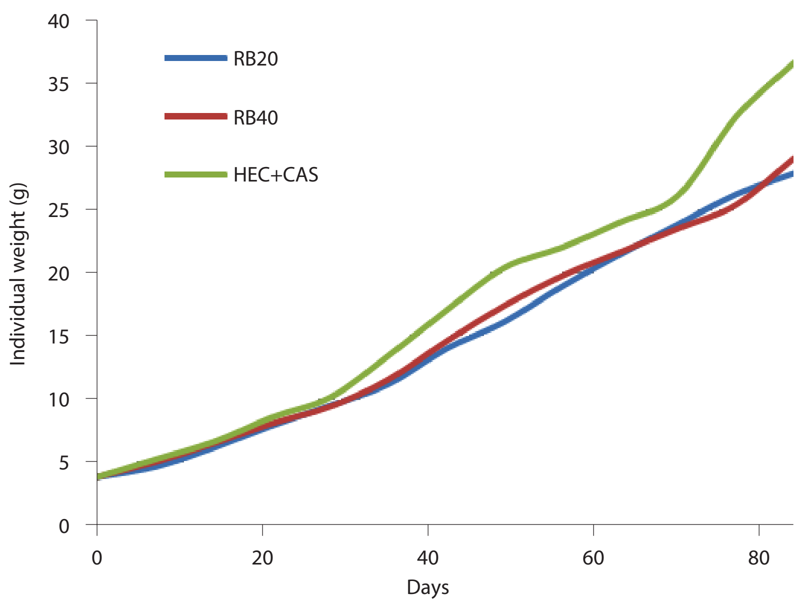

Figure 1. Average weight gain of juvenile tilapia on the three experimental feeds for 84 days. RB20 = 20% rice bran diet; RB40 = 40% rice bran diet; HEC+CAS = high-energy concentrate + cassava diet.

($F_{2,9}$ = 1.98, P = 0.19; Table 4). However FCR was lowest (i.e. best) for fish fed HEC+CAS (2.80 ± 0.58), compared with fish fed RB40 (3.10 ± 0.77) and RB20 (3.67 ± 0.51).

Fish were fed according to a restricted feeding regime commencing at about 12% tank biomass/day. This resulted in all tanks of fish being offered the same absolute amount of feed over the course of the trial (i.e. 301 g feed/tank) with the exception of the replicate tank from treatment RB20 that contained only one surviving fish. When feed input is calculated in terms of the average weekly biomass of experimental tanks, fish fed HEC+CAS tended to receive less feed on a per biomass basis than the other two treatments (Figure 2).

Table 4. Growth performance of juvenile tilapia fed the three test diets for 84 days (means ± standard error of the mean).

Growth parameter	Diet			*P* value
	RB20	RB40	HEC+CAS	
Initial weight (g)	3.79 ± 0.02	3.81 ± 0.01	3.81 ± 0.02	0.8654
Final weight (g)	27.88 ± 2.08	29.11 ± 3.01	36.65 ± 3.29	0.1149
Weight gain (g)	24.08 ± 2.09	25.32 ± 3.00	32.83 ± 3.32	0.1165
SGR (%/day)	2.36 ± 0.08	2.40 ± 0.12	2.68 ± 0.12	0.1563
FCR	3.67 ± 0.26	3.10 ± 0.38	2.80 ± 0.29	0.1932
Energy intake (kJ/tank)	5,087	5,327	5,056	–
Protein intake (g/tank)	83.7	86.1	71.0	–
PER	1.15 ± 0.09[a]	1.17 ± 0.14[a]	1.85 ± 0.18[b]	0.0127
Survival rate (%)	75.00 ± 17.67	93.75 ± 6.25	75.00 ± 0.00	0.4053

Means in the same row with different superscripts are significantly different ($P < 0.05$). Means separated by Duncan's multiple range test. RB20 = 20% rice bran diet; RB40 = 40% rice bran diet; HEC+CAS = high-energy concentrate + cassava diet; SGR = specific growth rate; FCR = feed conversion ratio; PER = protein efficiency ratio.

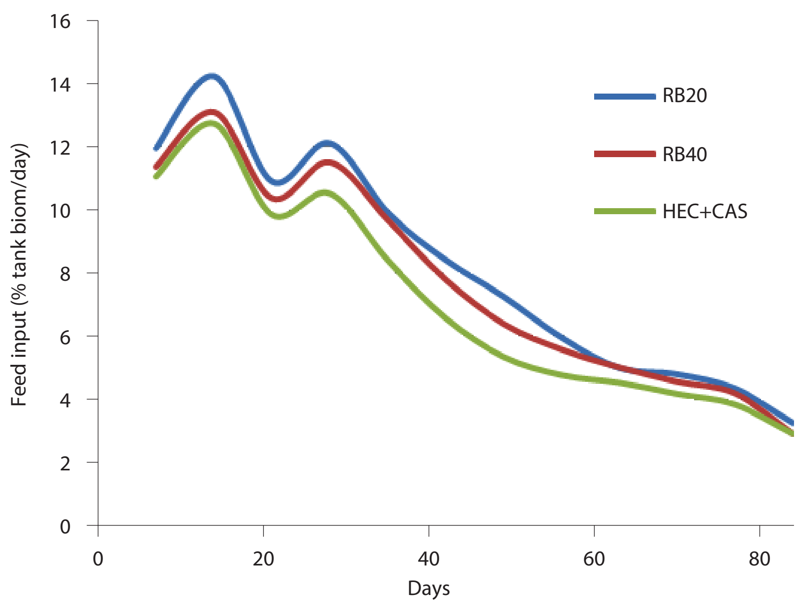

Figure 2. Average feed input presented as % tank biomass/day (n = 4 tanks). RB20 = 20% rice bran diet; RB40 = 40% rice bran diet; HEC+CAS = high-energy concentrate + cassava diet.

The lower relative feed intake coupled with a higher weight gain indicates the HEC+CAS diet was superior to the RB20 and RB40 diets under the feeding strategy employed in this experiment. A satiation feeding strategy, where fish are free to consume as much feed as they desire at each meal, may result in different outcomes to those observed in this trial.

Fish fed the HEC+CAS diet had a significantly higher PER than fish on the two rice bran diets; there was no difference between the PER of fish fed the RB20 and RB40 diets ($F_{2,9}$ = 7.36, P = 0.0127; Table 4).

DISCUSSION

This experiment was designed to evaluate the performance of GIFT reared on diets containing 20% (RB20) and 40% rice bran (RB40). Both diets had similar levels of crude protein (28%), gross energy (17 MJ/kg), fishmeal, tallow and millrun. The lower amount of rice bran in RB20 was balanced by the inclusion of 23% cassava meal; RB40 contained only 5% cassava meal. The performance of tilapia on these diets was compared against fish fed a high-energy universal concentrate suitable for broilers, pigs and layers that was mixed with a high level of cassava meal (31%) and cooking oil. The estimated crude protein content of this diet was about 4.4% lower than RB20 and RB40 but gross energy content was similar. Therefore, the estimated crude protein: gross energy ratio of this diet was considerably lower than the rice bran diets.

Survival of fish was problematic in this study but was not related to dietary treatment. Experimental tanks were stocked with only four juveniles and dead fish were not replaced. Fish were fed under a restricted feeding regime, meaning all tanks of fish were offered a similar amount of dry matter. This paired feeding strategy is useful for evaluating the nutritional potential of a feed on a gram for gram basis as it prevents fish from increasing their feed intake to overcome any nutritional deficits or variations in energy. However, if diets are not reasonably identical then paired feeding can favour animals receiving diets with greater nutrient or energy density or where protein: energy ratio is closer to optimal levels.

In the present work, the gross energy content of diets was fairly similar (on a calculated basis) but there was a clear difference in the crude protein content of the feeds. This resulted in fish fed the HEC+CAS diet receiving about 71 g protein per tank while fish fed the RB20 and RB40 diets received 83.7 g and 86.1 g protein per tank, respectively (Table 4). A decrease in protein: energy ratio resulting from decreases in dietary protein content has been shown to favour increases in protein utilisation and decreased nitrogenous losses in many fish studies. Increasing the proportional amount of lipid or carbohydrate supplying dietary non-protein energy may also spare various amino acids from being catabolised for energy, which also leads to improved protein utilisation (NRC 2011). Tilapia is a species with a better ability to utilise carbohydrate than most other fish, therefore the improvement in FCR and protein efficiency of fish fed the HEC+CAS diet might be due to the elevated nitrogen-free extract content of the mixture due to the addition of cassava meal (primarily starch). Besides vitamin and mineral supplements, the universal concentrate also contains meat meal, blood meal, fishmeal and soybean meal. This probably provided a superior amino acid mixture for tilapia fingerlings, as well as increased levels of phosphorus. Such additives, which may have marginally enhanced the growth rate of tilapia, are absent from RB20 and RB40. As the trial was run in rainwater, any dietary deficiency in minerals, such as phosphorus, might negatively affect growth of fish. A phosphorus requirement (as KH_2PO_4) of 8.6 g/kg for GIFT reared in fresh water was recently determined by Yao et al. (2014).

Diets formulated for this trial were based on crude nutrient and energy values of ingredients, and the digestible protein and digestible energy density of each diet may be quite different and may have influenced the results. It would be enlightening to determine the digestible nutrient value of each diet and reappraise the data. Maximum daily weight gain of tilapia in this trial was about 0.4 g per day with an SGR of 2.68% per day. This was similar to that reported by Ng and Wee (1989) for juvenile tilapia fed a fishmeal control and cassava leaf meal-based diets (i.e. 13 g to 86 g in 70 days). Masser et al. (1999) reported daily growth of tilapia to be between 0.5 and 1.0 g per day at temperatures around 28°C, while Koumi et al. (2011)

demonstrated that juvenile tilapia (11 g at stocking) kept under optimum conditions attained a growth rate of about 1.6 g per day on a fishmeal diet and about 0.71 g per day when fed a diet containing about 50% soybean meal.

Chitmanat et al. (2009) reported that rice bran included at 33.19%, 39.47% and 43.73% did not affect average weight gain, body weight and FCR in juvenile tilapia, but the performance was improved at the highest inclusion of 49.15%. In contrast, Muin et al. (2013) observed poor growth performance for tilapia fingerlings when rice bran was included at 34% but observed better performance when levels of rice bran were lower (e.g. 17%). In the current study, similar growth, FCR and PER were observed for tilapia fed diets containing 20% or 40% rice bran. RB20 and RB40 also had similar levels of fishmeal and wheat millrun. Under the feeding regime used, the level of rice bran could be increased to 40% and the level of cassava meal reduced to 5% without greatly affecting performance. This indicates that rice bran and cassava meal are almost exchangeable on a gram for gram basis in terms of the nutrients and energy they can provide to this species, at least in the formulas tested here.

CONCLUSION

This study evaluated the growth of juvenile tilapia (*Oreochromis niloticus*) on formulated diets containing high levels of rice bran (20% and 40%) and a blended diet composed of a high-energy broiler concentrate and dried cassava meal. Tilapia fed the rice bran diets and the high-energy blend exhibited statistically similar growth rates and FCR under a restricted feeding regime. However, the PER of the latter group was significantly improved and growth and FCR were numerically better. These results might be a function of the lower protein: energy ratio of the HEC+CAS diet, more digestible nutrients, or the additional micronutrients contained in the universal concentrate. Nonetheless, the fact that fish fed diets RB20 and RB40 achieved similar weight gain, FCR and PER suggests rice bran is a useful energy and protein source for this species. Further research on the performance and economics of using rice bran in grow-out diets for GIFT in PNG is recommended, particularly as this ingredient is a valuable source of secondary protein. Moreover, the research should focus on larger scale trials that formulate test feeds on a digestible nutrient and energy basis, and that apply satiation feeding strategies. The results will be used to improve fish culture in PNG and encourage optimal use of locally available agricultural by-products as major ingredients in low-cost, farm-made fish feeds.

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Growth performance of juvenile genetically improved farmed tilapia (GIFT) fed a feed concentrate blended with cassava or sweetpotato

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Abstract

The purpose of this study was to assess the growth performance of juvenile genetically improved farmed tilapia (GIFT) on diets formulated from a locally developed high-protein feed concentrate blended with cassava or sweetpotato. A total of 240 mixed-sex fingerlings were randomly assigned to four dietary treatments: (1) cassava + concentrate (CaC); (2) formulated standard diet (FSTD); (3) sweetpotato, cassava, cassava leaf + concentrate (CaLC); and (4) sweetpotato + concentrate (SPC). All diets were prepared as dry-milled products pelleted into 4 mm pellets. The fingerlings were reared for 84 days in twelve 250 L circular fibreglass tanks maintained in a recirculation aquaculture system. Each dietary treatment had three replicates with 20 fingerlings per tank. The results showed no significant differences in biomass gain among fish fed the FSTD, SPC and CaC diets, but significant differences for fish fed on CaLC ($P < 0.05$). In terms of feed intake, fish fed FSTD, SPC, CaC and CaLC show significant differences from each other ($P < 0.05$). There were significant differences in the feed conversion ratio (FCR) of fingerlings fed FSTD, SPC and CaC ($P < 0.05$), while the FCR of those fed CaLC was not significantly different from that of fish fed CaC but was significantly different from those of fish fed FSTD and SPC ($P < 0.05$). The results indicate that diets made from cassava or sweetpotato blended with feed concentrate will provide good fish yield and reduce costs.

INTRODUCTION

Inland aquaculture in Papua New Guinea (PNG) is a relatively new undertaking and most farmers involved in this sector have little or no understanding of husbandry practices. According to a review by Vira (2012), aquaculture became recognised as a mainstream activity supporting food security in the late 1990s, and by 2000 it had gained momentum throughout the highlands and some lowland areas of PNG. The majority of smallholders practising aquaculture are involved in inland freshwater fish farming, specifically genetically improved farmed tilapia (GIFT) which is a strain of Nile tilapia (*Oreochromis nilotica*) and carp (*Cyprinus carpio*), with a few involved in semi-intensive farming of trout (*Oncorhynchus mykiss*). Allen et al. (2007) identified poor quality and limited availability of supplementary feed as key constraints faced by these farmers. This, combined with the high cost of feed, whether produced locally or internationally, has led most smallholder fish farmers to use feed produced from their own farm, which is dominated by high starch ingredients such as sweetpotato and cassava. As a result, performance of fish is often suboptimal.

GIFT are sometimes called 'aquatic chicken' due to their high growth rate, adaptability to a wide range of environmental conditions, ability to grow and

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reproduce in captivity, and ability to be fed at a low tropic level (i.e. on a variety of ingredients) (Mirea et al. 2013). These advantageous characteristics, when combined with a good balanced feed and good husbandry system, can enable tilapia to achieve optimum growth. Producing a nutritionally balanced diet from local ingredients may seem easy but the challenge is to understand the nutrient limitations of ingredients and the requirements of fish in order to ensure appropriate formulation. According to Glencross et al. (2007), formulating fish feeding strategies based on key aspects of ingredients such as digestibility, palatability, utilisation and functionality will ensure that local ingredients are properly utilised.

An experiment conducted by Sine et al. (2012) using a broiler concentrate developed by the PNG National Agricultural Research Institute (NARI) combined with sweetpotato or cassava gave promising body weight gain of fish from fingerling to juvenile grower. This led to further work in developing a feed concentrate technology for fish farmers under the ACIAR project 'Enhancing role of small scale feed milling in the development of the monogastric industries in Papua New Guinea' (ASEM/2010/053). Concentrate production was initiated at NARI's Labu station in 2013 with ingredients sourced from local suppliers; ingredients included fishmeal, soybean meal, meat and bone meal, poultry offal meal, tallow, and synthetic amino acids, vitamins and minerals. The concentrate has very high protein density and is designed to be mixed with locally available carbohydrate ingredients such as cassava or sweetpotato to a ration that is nutritionally balanced to meet the requirements of fish. The concentrate is readily available to smallholder fish farmers or mini-mill operators around the country, enabling them to produce a fish feed at their farm or mini-mill site from ingredients that are readily available in the local market or in homegardens.

The purpose of this study was to assess the growth performance of juvenile GIFT fed three test diets formulated from the feed concentrate and cassava or sweetpotato, compared with a formulated standard diet. The study also looked at the costs involved in producing the fish feeds and the feed concentrate.

MATERIALS AND METHODS

The experiment was conducted at NARI's Inland Aquaculture Research Facility in Lae, PNG. The facility is located at the Livestock Research Station in Labu, at latitude 06°41´ S and longitude 146°04´ E and about 16 m above sea level. The average annual rainfall is 2,000–2,400 mm and the average daily temperature is 27°C (NARI Bubia weather records).

Experimental treatments

The high-protein feed concentrate was formulated using meat and bone meal, fishmeal, soybean meal, poultry offal, treated cassava meal (binder), methionine and vitamin premix. The ingredients were obtained from Lae Feed Mill, Niugini Tablebirds, International Food Corporation (IFC) and the local market in Lae. The ingredients were mixed according to formulation at the NARI mini-mill facility at Labu to produce the concentrate. The concentrate was then combined with cassava meal, cassava leaf meal and/or sweetpotato meal so that the finished blends met the nutritional requirements of juvenile tilapia (Tables 1 and 2). For the first two test diets, the concentrate was blended with sweetpotato (SPC) or cassava (CaC) meal at the ratio 60:40. A third diet (CaLC) was prepared with cassava leaf meal, sweetpotato meal, cassava meal and concentrate at the ratio 10:10:20:60. A standard formulated diet (FSTD) was used to benchmark the test diets.

The diet ingredients were prepared as follows. Sweetpotato, cassava tubers and leaf were purchased from the local market and prepared as dry-milled product. The process involved grating (in a manual chipper at 80 kg/hour), dehydrating (sun-drying for 3–5 days) and milling (using a hammer mill at 1.3 kg/minute). Mixing of the diets was done according to the formulation ratios (Table 1) and involved the use of a feed mixer, buckets, trays, packing plastics, an electronic digital scale and measuring jar/cup. The mixed diets were then made into pellet feed (4 mm pellets) using a mincing machine at the mini-mill. Diet samples were collected and sent to the National Analytical Laboratory (NAL) at PNG University of Technology for proximate analysis of their nutrient profile (Table 2).

Before use, the feed pellets were ground using a die plate machine, dust particles removed and the solid small particles fed to the fingerlings. The feed (100 g) was weighed on an electronic balance scale (ACS-3H electronic scale) and hand-fed to the fish twice daily from Monday to Friday, in the morning between 9 am and 10 am and in the afternoon between 3.30 pm and 4.30 pm, and once on Saturday and Sunday between 11 am and 12 noon. The feed was provided to fish to satiation and remaining feed was recorded.

Experimental fish and facility

Prior to handling, fish were sedated with lidocaine hydrochloride combined with sodium bicarbonate, as described by Carrasco et al. (1984). A total of 240 juvenile GIFT fingerlings were obtained from a pond at the integrated fish and duck farming facility at NARI Labu where they had naturally spawned. The fish were conditioned for 2 weeks prior to start of the experiment; during this period they were given a

Table 1. Formulations of the feed concentrate and the experimental diets on a dry matter basis, and the cost of producing 20 kg of the feeds.

Ingredient	Concentrate (kg)	Cassava + concentrate (CaC) (kg)	Standard (FSTD) (kg)	Cassava leaf + concentrate (CaLC) (kg)	Sweetpotato + concentrate (SPC) (kg)
Fishmeal	33.51		6.91		
Meat and bone meal	20		14.83		
Soybean meal	31.79		35		
Maize			3.1		
Rice bran			25		
Sweetpotato meal				10	40
Fish concentrate		60		60	60
Tallow	7.89		3.81		
Cassava meal (dry)	5	40	10	10	
Cassava leaf meal				19.72	
Vitamin premix	1		0.5		
Methionine 50%	0.81		0.84	0.28	
Total (kg)	100	100	100	100	100
Cost/20 kg (kina)	44.14	33.17	28.45	30.40	38.48

Diets formulated using Win Feed 2.8 Commercial Version Release 4 (Baig and Miller 1999).

Table 2. Nutrient profiles of the feed concentrate and the experimental diets (from chemical analysis at the National Analytical Laboratory at PNG University of Technology).

		Experimental diet			
	Concentrate	CaC	FSTD	CaLC	SPC
Dry matter (%)	88.9	88.3	86.8	86.9	87.1
Crude protein (%)	43.3	28.4	31.5	32.6	26.8
Fat (%)	15	9.3	10	10.6	10.2
Fibre (%)	1.2	1.8	6.7	4.3	2
Energy (MJ/kg)	19.6	16.8	18.2	18.5	17.9
Ash (%)	13.6	9.6	9.6	9.8	9.1

CaC = cassava + concentrate diet; FSTD = standard formulated diet; CaLC = cassava leaf, sweetpotato, cassava + concentrate diet; SPC = sweetpotato + concentrate diet.

formulated standard diet twice daily to satiation. The test diets were then fed for a period of 84 days. Twenty mixed-sex fingerlings with an average individual weight of 2.48 ± 0.05 g were randomly allocated to each of 12 fibreglass tanks in a recirculating aquaculture system (RAS). The circular fibreglass tanks were arranged in two rows of six tanks. Each tank had a water holding capacity of 250 L at a depth of 0.7 m. All experimental tanks were filled with fresh rainwater, which was collected as run-off rain water from the laboratory roof and stored in a 9,000 L tank. Each morning water from the storage tank was used to replenish some of the recycled water. A Hailea air pump aerator (model ACO-9601) was used in each of the experimental tanks to supply dissolved oxygen to the fish.

Water quality management

The water quality was maintained for optimum fish growth, with water flow kept constant at 1,000 mL/min in each of the experiment tanks and water recycled back into the main system for waste filtration before being pumped back into the tanks. Dissolved oxygen (DO) and temperature were checked daily using YSI 550A DO meter, and the ammonia level was monitored monthly with a Palintest Comparator. The DO level was maintained at 4–6 mg/L, temperature range was 26–30C° and ammonia level was 0.30 ppm. These water parameters are within the recommended range for fish culture, except for the ammonia level (Masser et al. 1999).

Biomass yield calculations

Growth rate was expressed as specific growth rate (SGR) and calculated as follows:

$$SGR = \frac{\ln(FBW) - \ln(IBW)}{d} \times 100$$

where FBW is final bodyweight (g), IBW is initial bodyweight (g), and d is the number of days.

Feed conversion ratio (FCR) and biomass gain were calculated for each tank as follows:

$$FCR = \frac{\text{feed intake (dry matter)}}{\text{live weight gain}}$$

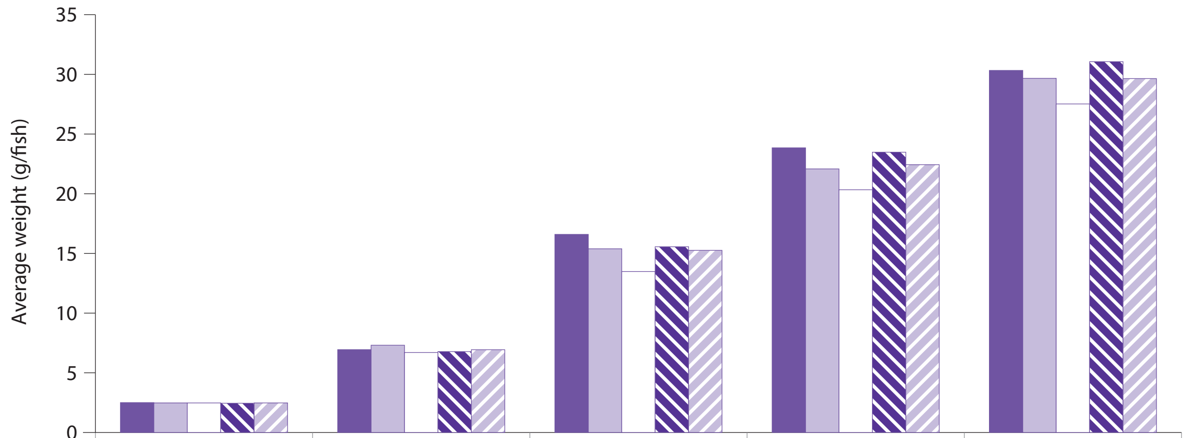
Biomass gain = FBW – IBW

Data analysis

The trial consisted of four treatments with three replicates arranged in a completely randomised design. Data were summarised in Microsoft Excel and entered into GenStat Discovery Edition 3 (Lawes Agricultural Trust 2005) and StatGraphics Plus Version 4 Software. Data were analysed using one-way ANOVA and means were separated using the Student–Newman–Keuls test. Parameters tested included: body weight gain, feed intake, FCR, SGR and body length. Effects of the treatments were considered significant at $P < 0.05$.

RESULTS

All fish survived throughout the 84 days of the experiment. The results for live body weight (Figure 1), body weight gain, feed intake, FCR and SGR are summarised in Table 3. The effect of test diets on body growth is presented in Figure 2. Overall, body weight differed significantly among treatments. Fingerlings on CaLC (27.5 g) were the least performing and this was significantly different from fish fed CaC (30.33 g), FSTD (29.67 g) and SPC (31.07 g) ($P < 0.05$). However, fish fed CaC, FSTD and SPC were not significantly different from each other in terms of body weight (Figure 2). Fish fed CaLC had the lowest body weight gain (27.5 g) compared to CaC (30.33 g), FSTD (29.67 g) and SPC (31.07 g). Fish fed CaC, FSTD and SPC were not significantly different from one another in terms of body weight gain but fish fed SPC had the highest body weight gain followed closely by CaC and FSTD. This interaction was also evident in the SGR. As shown in Table 3, fish fed SPC had the highest growth rate of 3.02% followed closely by CaC at 2.97% and FSTD at 2.95%. These growth rates were not significantly different from each other, whereas fish fed CaLC at 2.87% had the lowest growth rate and this was significantly different from all the other diets. Feed intake was significantly different in all the diets. Fish on CaC had the highest intake followed by SPC, CaLC and FSTD. FCR was lowest (1.57) in fish fed on FSTD and highest (1.87) in fish fed CaC. FCR values were not significantly different for fish fed CaC and CaLC, but for both FSTD and SPC they were significantly different (Figure 3).



	Stock	Wk3	Wk6	Wk9	Wk12
CaC	2.51	6.94	16.60	23.85	30.33
FSTD	2.48	7.31	15.39	22.08	29.67
CaLC	2.48	6.70	13.49	20.34	27.52
SPC	2.45	6.78	15.56	23.48	31.07
Mean	2.48	6.93	15.26	22.44	29.65

Sampling periods (week)

Figure 1. Mean weight increase (g) of GIFT fingerlings fed the test diets and standard diet for 12 weeks. CaC = cassava + concentrate diet; FSTD = standard formulated diet; CaLC = cassava leaf, sweetpotato, cassava + concentrate diet; SPC = sweetpotato + concentrate diet.

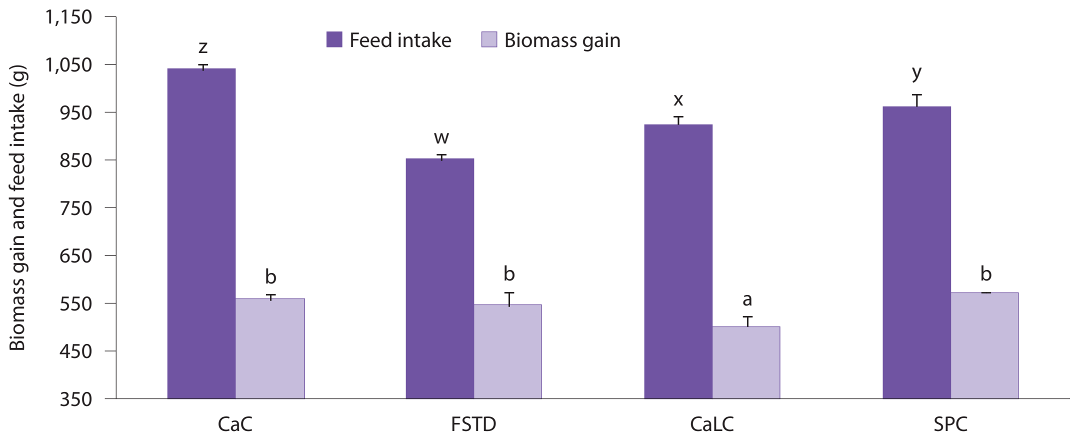


Figure 2. Total biomass gain and feed intake (g) of GIFT fingerlings fed the test diets and standard diet for 12 weeks. CaC = cassava + concentrate diet; FSTD = standard formulated diet; CaLC = cassava leaf, sweetpotato, cassava + concentrate diet; SPC = sweetpotato + concentrate diet. The letters a and b indicate significant difference in biomass gain, and w, x, y and z indicate significant difference in feed intake.

Table 3. Growth performance of juvenile GIFT fed test and standard diets for 84 days.

Parameter	Treatment				SEM	$F_{pr.}$	CV
	CaC	FSTD	CaLC	SPC			
Average IBW (g)	2.51	2.48	2.48	2.45			
Average FBW (g)	30.33^{b}	29.67^{b}	27.5^{a}	31.07^{b}	0.547	0.009	3.2
Average BWG (g)	27.82^{b}	27.19^{b}	25.04^{a}	28.62^{b}	0.545	0.009	3.5
Daily BWG (g)	0.33^{b}	0.32^{b}	0.30^{a}	0.34^{b}	0.006	0.009	3.5
Average FI (g)	51.99^{d}	42.53^{a}	46.27^{b}	48.18^{c}	10.060	0.001	1.8
Daily FI (g)	0.62^{d}	0.51^{a}	0.55^{b}	0.57^{c}	0.120	0.001	1.8
FCR	1.87^{c}	1.57^{a}	1.85^{c}	1.68^{b}	0.032	0.001	3.2
SGR (%)	2.97^{b}	2.95^{b}	2.87^{a}	3.02^{b}	0.022	0.006	1.3
Survival (%)	100.00^{a}	100.00^{a}	100.00^{a}	100.00^{a}			

Means in the same row with different superscripts are significantly different ($P < 0.05$) using Student–Newman–Keuls test.
CaC = cassava + concentrate diet; FSTD = standard formulated diet; CaLC = cassava leaf, sweetpotato, cassava + concentrate diet; SPC = sweetpotato + concentrate diet; SEM = pooled standard error of the treatment means; CV = coefficient of variation; IBW = initial body weight; FBW = final body weight; BWG = body weight gain; FI = feed intake; FCR = feed conversion ratio; SGR = specific growth rate.

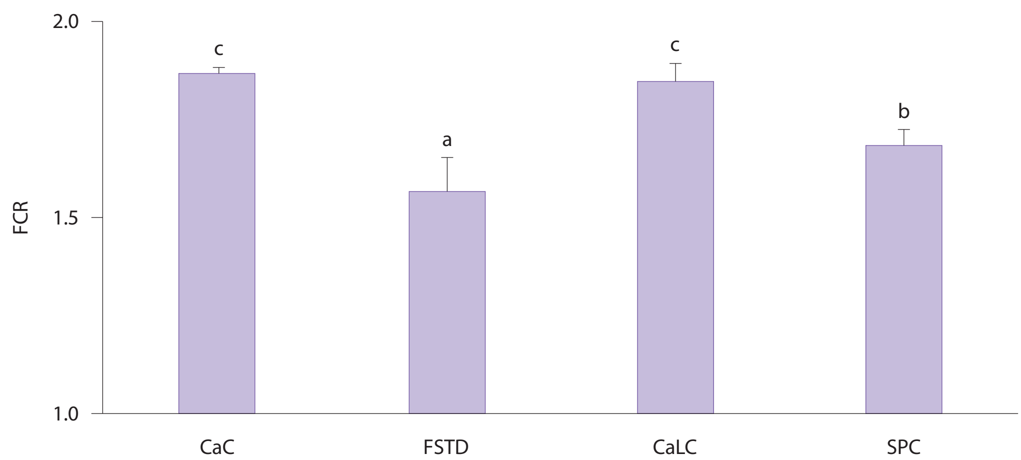


Figure 3. Feed conversion ratio (FCR) of GIFT tilapia fingerlings fed the test diets and the standard diet for 12 weeks. CaC = cassava + concentrate diet; FSTD = standard formulated diet; CaLC = cassava leaf, sweetpotato, cassava + concentrate diet; SPC = sweetpotato + concentrate diet. The letters a, b and c indicate significant difference in FCR.

DISCUSSION

The study was conducted to evaluate the growth of tilapia fingerlings fed a formulated feed concentrate blended with cassava or with sweetpotato. At the end of the study, on average, GIFT grew up to 30 g in 12 weeks with a weight gain of almost 29 g for the best performing treatment. According to Masser et al. (1999), with normal growth rates tilapia can reach 50 g in 3 months, therefore the growth rate in this trial is just less than normal, which is promising. The growth rate of 3.02% achieved in the trial is slightly less than the growth rate of 3.69% reported by Allen et al. (2007) with a diet including 32% crude protein and fish grown in an earthen pond. The lower growth rate in our study may have been due to a loss of nutrient quality due to prolonged storage of the feed concentrate in a storage area without temperature control. This was evident in the results of the chemical analysis of the diet (Table 2). The formulated concentrate was intended to have a crude protein level of 52% which when mixed with cassava or sweetpotato would give a crude protein level of 32%. However this was not case, as results from chemical analysis at the National Analytical Laboratory showed; the crude protein level was 43% for FC, and 28% and 27% for CaC and SPC, respectively. Another factor influencing growth rate may have been the water quality. The ammonia level was around 0.3 ppm which is high; according to Masser et al. (1999) the optimum control ammonia is at less than 0.05 ppm.

Results for body weight, body weight gain and SGR showed no significant differences among fish fed FSTD, SPC and CaC, but there were significant differences for fish fed on CaLC ($P < 0.05$). This result is similar to the findings of Ng and Wee (1989) who observed that increasing levels of cassava leaf meal resulted in growth depression in fish and feed not being utilised. This may be due to anti-nutrients in the cassava leaf, as explained by Ng and Wee (1989). The feed intake for fish fed FSTD, SPC, CaC and CaLC was significantly different ($P < 0.05$). The higher feed intake and body weight gain of fish on CaC and SPC compared to the FSTD diet may have been due to the processing of the cassava and sweetpotato prior to blending with the concentrate. These processing steps reduced the anti-nutrients in cassava and sweetpotato, thus increasing the palatability of these two diets (Lukuyu at al. 2014). In addition, micronutrients present in the concentrate may have enabled the fish on the test diets to have a better intake and body weight gain. Cao Thang Binh et al. (1996) stated that added micronutrients in concentrated chicken feeds give faster growth rates.

There were significant differences in the FCR of fingerlings fed FSTD, SPC and CaC diets ($P < 0.05$). The FCR for fish fed CaLC was not significantly different from that for fish fed CaC, but was significantly different from those for FSTD and SPC ($P < 0.05$). The high FCR might be due to high intake as a result of processing the cassava tubers and leaves to meal, however the feed may be less utilised because of anti-nutrients in the diet. As expected, FSTD had a good FCR compared to the other diets.

One of the aims of this study was to formulate a low-cost feed based on locally available ingredients that could be easily adopted by smallholder farmers. The positive results from this trial, where test diets performed similar to the standard diet, indicate that farmers can produce their own fish feed. The current cost of tilapia feed (Goroka Feed Mill price) is 3 kina per kilogram. Therefore, it would cost 60 kina for a 20 kg bag of feed, whereas the current fish feeds formulated from cassava or sweetpotato cost 33 kina and 38 kina, respectively, for 20 kg (Table 1). This cost can be further reduced if a farmer uses cassava or sweetpotato from their own farm.

CONCLUSION

This study has shown that the feed concentrate blended with either sweetpotato or cassava meal at a ratio of 60:40 results in a good growth rate (3.02%) for GIFT. Results suggest that cassava or sweetpotato can successfully be used as an energy source in fish feeds diets blended with feed concentrate, despite a reduction in crude protein level. The next stage is to improve on the formulation and test it on grower fish either on-station or on-farm, and assess the costs involved. The results for feed costs indicate that the feed produced for this experiment is less expensive than commercial fish feed. The feeds tested in this trial could help farmers reduce their dependence on expensive feeds.

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