Australian Government

Australian Centre for
International Agricultural Research

Final report

project	**Improved rice germplasm for Cambodia and Australia**
project number	CSE/2009/005
date published	14/04/2016
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final report number	FR2016-11
ISBN	978-1-925436-41-9
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

We thank all project staff from the Cambodian Agricultural Research and Development Institute (CARDI), General Directorate of Agriculture (GDA), Rice Research Australia Pty Ltd (RRAPL), New South Wales Department of Industry and Investment (I&I NSW), University of Queensland (UQ), and International Rice Research Institute (IRRI) for their hard work to make the project successful.

We appreciate the survey on rice germplasm needs of Cambodia conducted by Indochina Research (Cambodia) Ltd.

We acknowledge the following partners who conducted trials in Cambodia and Australia:
Tonle Bati Agriculture Development Center of Takeo Province, Cambodia
Prey Pdau Agriculture Research Station of Kampong Speu Province, Cambodia
Polors Plant Protection Research Station of Prey Veng Province, Cambodia
Provincial Department of Agriculture (PDA) of Prey Veng Province, Cambodia
PDA of Takeo Province, Cambodia
PDA of Kampot Province, Cambodia
PDA of Kampong Thom Province, Cambodia
Northern Territory Primary Industries, Australia
Western Australia Department of Agriculture and Food, Australia
Andrew Barfield – producer in Mackay, Queensland, Australia
Greg Barnett – producer in Emerald, Queensland, Australia
Garry Woolley – producer in Lismore, Northern NSW, Australia

2 Executive summary

2.1 Understanding the current and future germplasm needs of Cambodian farmers, millers, and traders through a survey

Indochina Research (Cambodia) Ltd. (IRL) was contracted by the project in October 2010 to carry out a survey on rice germplasm needs of Cambodia. The questionnaire used for the survey was developed jointly by IRL and IRRI, and was finalized in December 2010. The survey was conducted from late December 2010 to early January 2011 in the three project provinces, Takeo, Kampot, and Kampong Thom. In this survey, 12 focus group discussions (8 persons per group) with farmers and consumers and 24 in-depth interviews with 9 millers and 15 traders were conducted by IRL in the three provinces. The survey data were analysed by IRL, and a report on the survey was submitted to IRRI in February 2011. The survey result served as a guideline in varietal development for Cambodia under the project.

2.2 Evaluating existing rice germplasm to identify suitable cultivars for Cambodia

The project collected 1,551 rice lines/cultivars, of which 1,445 were from IRRI, 14 from Australia, and 92 from CARDI, for evaluation targeted at three rice systems: aerobic, lowland, and rainfed.

- For the aerobic system, 284 lines, including 175 aerobic rice lines and 109 rainfed lines with drought tolerance, were evaluated under direct-seeded aerobic soil conditions.
- For the lowland system, 1,092 lines, including 969 lowland lines and 123 rainfed lines, were evaluated under transplanted or broadcast lowland conditions.
- For the rainfed system, 197 lines were evaluated under either submergence (121) or drought (76) and lowland conditions.

Germplasm evaluation began in the first project season, that is, the wet season (WS) of 2010. Materials targeted at different systems were first evaluated at CARDI in plots to examine their adaptation. The first selection was based on agronomic traits, including plant height, plant type, growth duration, lodging and disease resistance, and yield. The second selection was based on grain quality traits, including grain shape, chalkiness, head rice, colour (milled rice), translucency, amylose content, gel consistency, and gelatinization temperature. We looked at the grain shape and chalkiness at CARDI, and sent the selections to IRRI for deeper quality analysis, especially in the early stage of the project. After the first round of selection, the number of lines to handle decreased so that we were able to further evaluate them in replicated trials at multilocations. With multilocation trials, we focused on grain yield, lodging and disease resistance, stability, genotype × environment (G × E), and preference of local farmers through participatory varietal selection (PVS). Selection was conducted after every crop season to further decrease the number of entries. When the most promising lines were identified, they were tested at more locations for a couple of seasons before some of them were promoted to On-farm Adaptive Trials (OFAT), the last testing step before possible varietal release. Besides CARDI, the testing locations included Bati, Dunkeo, and Ankor Borey in Takeo Province, Prey Pdau in Kampong Speu Province, Chamkiri in Kampot Province, Santuk in Kampong Thom Province, and Kamchay Mear in Prey Veng province. Varietal trials since the beginning of the project are listed in Table 1.

Screening for resistance to brown planthopper (BPH) was conducted every dry season since the beginning of the project. But, unfortunately, all screenings failed because of insufficient population of naturally occurring BPH. In WS 2014, 16 most promising early lines identified by the project underwent a screening in the greenhouse of CARDI to examine the reaction of these lines to infestation of the dominant BPH race in Cambodia.

Additionally, since most improved traditional varieties are susceptible to bacterial blight (BB), improvement in resistance to BB is very necessary. For this, the project imported 30 near-isogenic lines (NILs) from IRRI, and grew them at CARDI and Prey Pdau Station in Kampong Speu Province to identify the dominant BB races in Cambodia.

Table 1. Varietal trials conducted in dry (DS) and wet seasons (WS) in Cambodia in 2010-14.

Year & season	**2010 WS**	**2011 DS**	**2011 WS**	**2012 DS**	**2012 WS**	**2013 DS**	**2013 WS**	**2014 DS**	**2014 WS**
Aerobic	284 lines CARDI	63 lines CARDI Bati Polors	45 lines CARDI Bati Prey Pdau	45 lines CARDI Bati Prey Pdau	32 lines CARDI Bati Prey Pdau		8 lines CARDI Bati Prey Pdau	8 lines CARDI Bati Prey Pdau Prey Veng Kampot	
Lowland 1	577 lines + aerobic lines CARDI	30 lines (7 sites) 54 lines 64 lines CARDI	30 lines (6 sites) 40 lines (4 sites)	11 lines (9 sites) 30 lines (6 sites) 40 lines (4 sites)	15 lines (12 sites) 30 lines (6 sites) 40 lines (6 sites)	15 lines (12 sites)	6 lines Seed increase	OFAT (99 sites)	OFAT (75 sites)
Lowland 2			515 lines CARDI	200 lines CARDI	80 lines CARDI	40 lines (6 sites) 56 lines (6 sites)	15 lines (16 sites) 25 lines (6 sites) 25 lines (6 sites)	15 lines (16 sites) 25 lines (6 sites)	15 lines (transplanting + direct seeding) OFAT, 8 lines (25 sites in 5 provinces)
Lowland 3 (BPH)			45 lines CARDI	45 lines CARDI		45 lines CARDI		45 lines CARDI	16 lines, (greenhouse screening)
Rainfed 1 (submergence)	121 lines (subm.) CARDI		118 lines (lowland) CARDI		64 lines (lowland) CARDI				
Rainfed 2 (drought)		76 backcross populations (drought) CARDI	130 lines (lowland) CARDI		58 lines (lowland, aerobic) CARDI		28 lines (lowland, drought, aerobic) CARDI		26 lines (lowland, drought, aerobic) CARDI 15 lines (rainfed, drought) 4 sites
Rainfed 3 (glutinous)			4 lines OFAT (15 sites)		1 line OFAT (32 sites)		1 line OFAT (50 sites)		
Bacterial blight identification									30 NILs (CARDI, Prey Pdau)

2.3 New breeding programs at CARDI and IRRI

New breeding activities are summarized in Table 2.

Table 2. New breeding program activities in dry (DS) and wet seasons (WS) at CARDI.

Year & season	2010 WS	2011 DS	2011 WS	2012 DS	2012 WS	2013 DS	2013 WS	2014 DS	2014 WS
Aerobic & lowland (insensitive)			10 crosses	10 F_1	10 F_2 (lowland)	208 F_3 (lowland)	694 F_4 (lowland)	246 F_5 (lowland, drought)	67 F_6 in OYT (lowland, drought) 128 F_6 lines advanced
Rainfed 1 (sensitive)			4 crosses	4 F_1	4 F_2 (lowland)		99 F_3 (lowland)		99 F_4 (lowland)
Rainfed 2 (sensitive)	Backcross PRD × CAR3	$BC_{4-5}F_1$	$BC_{4-5}F_2$	$BC_{4-5}F_3$ (drought screening)			169 F_4 (lowland)		
Rainfed 3 MAS	5 BC_1F_1 IR64-Sub1	5 BC_2F_1	3 BC_3F_1 2 crosses	3BC_2F_2 2BC_1F_1				BC_1F_1 Ciherang -Sub1-AG1 (IRRI)	BC_2F_1 Damaged by typhoon but remade in 2015 at IRRI

For aerobic and lowland rice systems, 10 crosses were made in WS 2011 to breed for early and photoperiod-insensitive cultivars with good grain quality, aroma, and with/without drought tolerance. Populations or progenies had been advanced every season under lowland conditions until the end of 2013. In DS 2014, 246 F_5 lines were evaluated under both lowland and drought conditions in the field for selection on agronomic traits and drought tolerance, and in the lab for selection on grain quality traits. In the meantime, 128 F_5 plants were selected. In WS 2014, (1) 67 selected lines were evaluated in replicated trials under both lowland and drought conditions at CARDI; (2) the 67 lines were screened on aroma by running Badh 2.1 marker in CARDI's lab; (3) after harvesting, paddy samples of all 67 lines (F_7) were sent to IRRI for quality measurement; and (4) 128 F_6 lines were advanced and underwent further selection.

For the rainfed rice system, four crosses were made in WS 2011 to breed for photoperiod-sensitive cultivars combining yield with quality and drought tolerance/lodging resistance. Ninety-nine F_3 lines were advanced in WS 2013 and 99 F_4 advanced in WS 2014. Additionally, a population of $BC_{4-5}F_1$ (Phka Rumduol × CAR3) was created in WS 2010 and selfed up to F_3 before being screened in drought in 2012. From the drought screening, 169 plants were selected and advanced to F_4 in WS 2013.

For the component of introgressing the *SUB1* gene into local backgrounds to improve local cultivars in submergence tolerance, populations were well prepared at CARDI during 2010-12. However, because the Gel Documentation System (GDS) in CARDI's lab was out of order and the newly purchased GDS was not in place until September 2013, and because of the resignation of CARDI staff who were trained in marker-assisted selection (MAS), not much progress was made at CARDI. Anyway, the project is collaborating with IRRI scientists to introgress the *SUB1* gene together with the *AG1* gene (for anaerobic germination) into Pkha Rumduol (PRD) using MAS at IRRI headquarters. This work began at IRRI in 2014. BC_2F_1 has been gained.

2.4 Study on sensory quality of Cambodian rice

An F_6 population used for the study on sensory quality of Cambodian rice was derived from a cross of Phka Rumduol × Thmar Krem, two Cambodian varieties contrasting in grain quality. The cross was made in WS 2010, and the population was advanced in a dark room in the DS or in a field in the WS. The single seed descent method was used to maintain the population from F_2 to F_5. Seed of 365 F_6 RILs was finally obtained in WS 2013 at CARDI. Milled rice samples were sent to UQ for phenotyping on metabolomics in January 2014, and paddy samples were sent to IRRI for genotyping and phenotyping on other quality traits in February 2014. Both genotyping and phenotyping at IRRI have been completed, and phenotyping at UQ is ongoing.

2.5 Capacity building in Cambodia

2.5.1 Commissioning CARDI's grain quality lab and molecular lab

An Orbit Shaker used to mill small samples, a spectrophotometer used to determine amylose content, and an S21 used to measure physical grain traits were purchased, calibrated, and installed in CARDI's grain quality lab in November 2011. With all the equipment, CARDI has the capacity to evaluate rice grain quality with small samples.

A Gel Documentation System used to read gels, a PCR used to amplify DNA, an Udy Mill used to make tissue powder, an analytical balance, and a fume hood were purchased and installed in CARDI's molecular lab in September 2013. With these supplemental instruments, CARDI has a full set of instruments to run MAS.

2.5.2 Staff training

In September-November 2011, CARDI staff member Ouk Sothea was trained at IRRI in grain quality evaluation and MAS on aroma for 2.5 months.

In November 2011, four IRRI staff members travelled to Cambodia to commission the CARDI labs and train all staff in the Plant Breeding Division of CARDI in the operation of the newly installed equipment, and in MAS.

In August 2012, one IRRI staff member travelled to CARDI to settle issues on the use of the S21.

In September 2012, one IRRI staff member travelled to CARDI to further train CARDI staff in MAS and to help make a standard operating procedure of MAS in Khmer.

In September 2013, Dule Zhao provided a 3-day in-door training to CARDI and GDA staff and students in experimental design and data analysis.

Hands-on training in experiment management, data collection, and plant/line selection for CARDI staff was on a daily basis. Training on PVS for CARDI, GDA, and PDA staff was carried out at the project sites every year/season.

2.6 Rice trials in Northern Australia

Rice variety evaluation of 203 local and introduced lines across 28 trials during the life of the project was conducted across Northern Australia from Kununurra WA in the North West and Adelaide River and Katherine in the Northern Territory to Mackay and Emerald in Queensland and Lismore in Northern NSW. Most trials were managed under upland and aerobic soil conditions, but some were managed under irrigated lowland conditions.

Collaborators included Northern Territory Primary Industries, Western Australia Department of Agriculture and Food, and primary producers in both Queensland (Andrew Barfield – Mackay, Greg Barnett – Emerald) and Northern NSW (Garry Woolley – Lismore). Trials were conducted in temperate NSW at Leeton Field Station and Rice Research Australia Pty Ltd among other commercial and trial plantings.

3 Background

Wet-season issues

Rice is the staple of Cambodia, providing 68% of the calorie intake. Agriculture contributes 34% of Cambodia's GDP with 80% of the population living in rural areas and a third living below the poverty line of $1/day. Rainfed (wet-season) rice contributes 85% of the annual rice harvest of approximately 7 million tons produced on 2.4 million ha. Wet-season rice yields are low, around 2 t/ha. If this is the only crop in the year, as in most of Cambodia, poor farming families are at risk of insufficient rice to eat for the full year. Two abiotic stresses lead to yield penalties each year. The first occurs in the early part of the season, before the monsoon rains fall, but, when they arrive, submergence is the major yield reducer. Unpredictable weather patterns, such as delayed rainfall and typhoon rainfall, are currently being experienced in many countries of Southeast Asia. Insufficient rainfall delays transplanting or results in drought conditions and typhoon rainfall exacerbates submergence conditions. Varieties of rice that carry tolerance of both stresses are required, as well as adaptation to direct seeding, as diminishing farm labour resources will result in movement away from transplanting.

Despite the release of 34 varieties in CIAP time, Cambodia is currently growing only pure-line selections from traditional varieties, despite their low yield. These selections are based on aroma and eating quality. Little information exists worldwide on the basis of sensory quality or how to select for it. This project offers the opportunity to apply new science to understand sensory quality.

Dry-season issues

Cambodia has not historically grown a crop in the dry season, but new irrigation strategies are leading to a significant increase in dry-season production, all of which is exported. The varieties must be short duration, to leave enough time for the wet-season crop, which feeds the family. IR66 and IR504 are the two main varieties used in the dry season, and a major limitation to production is the susceptibility of these to BPH and viral diseases, which can result in severe yield loss. Sen Pidao, another dry-season variety, is liked for its basmati style of aroma and suitability for export to South Asia and the Middle East, but it is grown on fewer hectares because of its lower yield than IR66 and IR504. All the dry-season rice is exported, so there is a clear marketing opportunity to increase the value of the crop by increasing quality, yield, and resistance to pests and diseases. There is also significant opportunity to increase yield by changing management practices. Direct seeding will lead to higher yield and eventually lower costs since the cost is high, and increasing, of hiring transplanters from a shrinking pool of labour. Correct use of fertiliser would also produce higher yields. By creating the right package of yield and quality traits in a short-duration background, targeting the variety to a particular market, and growing it with the right management tools, Cambodian farmers growing a dry-season crop could potentially lift themselves out of poverty.

Priorities in Cambodia

In 2008, ACIAR and AusAID co-hosted a workshop attended by 95 Cambodian government officials, researchers, extensionists, and NGO and farmer representatives to discuss research priorities for future improvement of the productivity and profitability of rice-based farming systems. Development of and access to improved varieties that are better matched to the transforming agricultural systems were agreed as one of the top priorities. This was confirmed through further consultations with the Ministry of Agriculture, Forestry and Fisheries in February and April 2009, and a series of field visits conducted in May-June 2009.

Australia

In Australia, for the last 70 years, the overwhelming majority of rice production has been fully ponded temperate production in southern NSW using japonica types. The previous 8 years of drought triggered the industry to assess options in tropical and subtropical regions, where water resources are more plentiful. An alternative form of direct-seeded rice production has recently been trialled in these areas, with the prerequisite that rice is used in rotation with other high-value crops, making aerobic rice culture the preferred irrigation strategy. Despite promising commercial (4 to 6 t/ha) and trial yields (8 to 10 t/ha), there is a need to re-visit the agronomic packages used under aerobic production systems starting with a sound base of adapted germplasm. Several abiotic and biotic constraints are common to Australia's tropical north and Cambodia, most notably drought, flood, and bacterial disease. Australian production has targeted medium grain (i.e., japonica type) and speciality type (fragrant, etc.) varieties as these supply lucrative international markets. In this project, through collaboration on germplasm exchange and development with IRRI and Cambodian collaborators, Australian partners will be able to access and undertake collaborative assessment of tropical japonica and indica germplasm relevant to both the agronomic and production requirements of an evolving rice industry in tropical regions of Australia. The Australian drought has also motivated Sunrice, an Australian company owned by all Australian rice-growers, to explore production options in other countries so it can continue to supply its markets with high-quality rice. Increasing the yields of Cambodian varieties and maintaining their quality could allow Cambodian farmers to profit from a completely new rice-growing opportunity, which would benefit farmers in both Cambodia and Australia.

This project aligns with ACIAR's, IRRI's, and I&I NSW's strategic plans. It forms component 1 of ACIAR's 6-component Mekong-South Asia Food Security Research Program (MSA-FSRP). It fits within IRRI's MTP, aligning with goals of Programs 1 and 2, which address poverty alleviation in rainfed and irrigated systems, respectively. It addresses several priority areas under the NSW Department of Primary Industries Corporate Plan 2008-11 for new initiatives and innovative technologies for adapting to climate change in rural and regional NSW.

4 Objectives

The aims of this project are (1) to improve food security and incomes of Cambodian farmers by enabling CARDI to develop improved germplasm with high yield and tolerance of specific abiotic stresses and that carries desired traits of quality, and (2) to enable the Australian rice industry to adapt to new environments.

Objective 1: Identify the current and future germplasm needs of Cambodian farmers and traders to determine the priorities and strategies for new germplasm development and dissemination

- Activity 1: Conduct an ex ante assessment of the germplasm requirements of farmers and traders to determine the priority traits, strategies, and target markets for introducing stress tolerance and quality.

- Activity 2: Analyze the survey data (including secondary survey data) to determine whether existing IRRI germplasm with tolerance traits is useful or whether an introgression program maintaining Cambodian types is required. The analysis will be submitted to the Cambodian Journal of Agriculture.

- Activity 3: Through workshops involving government, industry, and researchers, identify priorities for germplasm dissemination and design a detailed strategy.

- Activity 4: Empower PDA staff to conduct appropriate varietal extension activities.

- Activity 5: Train CARDI, GDA, and PDA in conducting on-farm participatory advanced rice germplasm trials.

Objective 2: Strategic development and dissemination of improved rice germplasm for different agro-ecological rice systems in Cambodia

The direction that rice breeding will take will be based on data generated by the survey. For introducing abiotic stress tolerance, two approaches are possible: release an existing variety carrying *SUB1* and drought QTLs or introgress those traits into popular high-quality Cambodian varieties. For resistance to biotic stresses, early duration, and high quality, advanced generation materials from IRRI and other centres will be evaluated and promising lines selected. The gene controlling aroma could be introgressed into promising material.

- Activity 1: Development and dissemination of suitable improved germplasm for rainfed lowlands either by introgression programs or evaluation of existing germplasm.

- Activity 2: Development and dissemination of suitable improved germplasm with short duration.

- Activity 3: Development and dissemination of suitable improved germplasm with desired quality and submergence tolerance.

Objective 3: Understand the scientific basis of sensory quality of Cambodian rice and develop capacity in Cambodia for rice quality assessment and MAS

The sensory qualities of Cambodian rice varieties will be determined and QTLs for these will be identified using new technology for genotyping and phenotyping. A quality evaluation program is essential to ensure adoption of the germplasm developed in this project and after. CARDI has partially equipped laboratories for assessing quality and MAS.

- Activity 1: Determining the quality of preferred traditional rice varieties using populations segregating for quality by associating their chemical, rheological, and structural properties, and their volatile signatures, with sensory properties, and associating all sets of phenotype data with a map developed by SNP genotyping.

- Activity 2: Upgrading current facilities and capacity at CARDI for high-throughput screening of grain quality for both early- and late-generation materials.

- Activity 3: Upgrading current facilities and capacity at CARDI for MAS to accelerate breeding.

- Activity 4: Training CARDI staff to operate sustainably the future rice grain quality and MAS facilities by training in IRRI's quality evaluation and MAS program and then transferring that information to CARDI, for use in its upgraded quality evaluation program.

- Activity 5: Understand the compounds of taste and flavour that define the quality of the prized variety PRD using a genotyped population (Activity 1) derived from PRD and an unpopular variety and analysing the parents and progeny by advanced profiling of volatile compounds.

Objective 4: Demonstrating commercially viable direct-seeding practises from tropical Australian rice production

Although mechanised, tropical Australian rice production is a dry-season and early wet-season enterprise like in Cambodia geared for commercial sale as seed or paddy. Unlike Cambodia, tropical Australia is driven solely by export market demands with research and commercial endeavours largely contracted by private concerns (e.g., RRAPL and Sunrice, respectively). This pro-active approach for building the adaptive capacity of the Australian rice industry has been made possible by the ease of substitution of direct-seeded aerobic rice production into established irrigation areas without the need to establish paddies. A tailored agronomic package together with adapted germplasm with market acceptance will no doubt be the key output from this objective for the emerging tropical Australian industry. The way in which remote pockets of tropical rice production can react to international rice markets through private industry incentives may provide a model in which Cambodia can follow. The existing skill base provided by I&I NSW and RRAPL for germplasm evaluation and pure seed production and dissemination will be used to realise milestones for the following activities:

- Activity 1: RRAPL to manage and contract germplasm evaluation and pure seed production in tropical Australia.

- Activity 2: Identify and recommend germplasm that is both adapted to aerobic culture and market ready for both export and domestic markets.

- Activity 3: Develop phenotypic screens that will provide repeatable quantitative data on seedling vigour and tolerance of transient drought for promising photoperiod-insensitive germplasm identified from Australian and Cambodian trials.

A related objective is to increase the capacity of private entrepreneurs to develop rice seed production and sales of newly selected/released CARDI rice varieties. This objective is outside this project, but it is planned that it will be conducted by CAVAC Program's Agribusiness and Business Enabling Components in close collaboration with the ACIAR-led Research and Extension Component.

5 Methodology

Objective 1

An ex ante assessment of germplasm needs of Cambodian farmers and traders will be conducted in the first project year by a private company contracted by this project. Questions for the survey will be developed in consultation with IRRI social scientists. The survey will be conducted at the district level in the target areas in 15 provinces of Cambodia (www.cambodiaatlas.com). The data gathered from the PDA, farming families, millers, and traders will be analysed by the project social scientist in collaboration with IRRI. The recommendations of the survey will be used immediately to determine priority areas for the breeding and quality evaluation activities of this project and breeding strategies, and they will be used at the end of the project to quantify and qualify the impact of the activities undertaken in this project.

Objective 2

Two breeding strategies are likely to be used in this project, but the balance of each will become clear once the survey data are analysed.

Strategy 1: Evaluation of available germplasm

A large set of elite breeding lines/varieties obtained from IRRI, Cambodia, Australia, and other centres, including lowland indica lines (including lines with aroma, or BPH resistance, or tungro tolerance), rainfed lines with drought tolerance, aerobic rice lines with high early vigour and strong weed competitiveness, and lines with tolerance of submergence, will be screened on-station in appropriate conditions: transplanted lowland, transplanted and drought-stressed lowland, direct-seeded aerobic, and submergence. Agronomic traits and adaptability will be determined in the field. Quality traits will be evaluated at CARDI and/or at IRRI. Selected lines will then be further evaluated in hotspots in multiple locations. Locally adapted germplasm for lowland, rainfed (including submergence), and aerobic ecosystems will be identified. Farmers, traders, and local researchers/technicians will be invited to participate in PVS organised at each experimental site. Seed of preferred cultivars will be provided to farmers starting from the third year. Agronomically superior lines with other desired traits will be released as varieties and disseminated for cultivation in Cambodia under various ecosystems.

Strategy 2: Initiation of new breeding programs

It is possible that the survey will indicate that an introgression program is required for submergence or drought tolerance, or aroma. Such a program requires a donor parent, markers specific to the gene, and markers for evaluating the genetic background. Primer sequences will be provided and Cambodian scientists will be trained in the use of the markers to select progeny from a backcrossing program that carry the gene of interest. For the dry-season lowland system, the main breeding goal will be high yield potential and desired grain quality. For the wet-season rainfed lowland rice, besides yield potential and grain quality, tolerance of drought and submergence will be considered in breeding. Conventional breeding methods will be used to select for drought tolerance, while MAS will be used to select for submergence tolerance and a number of quality traits. For direct-seeded aerobic rice, conventional breeding will be applied to develop upland-adapted, high-yielding, and preferred varieties. In these breeding programs, early-generation lines will be screened in a disease nursery inoculated with common diseases of Cambodia for resistance screening at CARDI, and evaluated in other centres of Cambodia. Selection for resistance to BPH will be conducted in some selected hotspots in Cambodia. Advanced progeny for each ecosystem will be available for testing in the fourth-fifth year of the project in OYT.

Strategy 1 will lead to the release of improved germplasm/varieties during the tenure of the project. Strategy 2 will lead to stress-tolerant derivatives of Cambodian varieties and the transfer of desired grain quality to high-yielding and stress-tolerant material, thus making available a new set of elite breeding lines and segregating populations for future release.

CAVAC is a large AusAID-funded project that is expected to commence activities in Cambodia in early 2010. The project will address issues of rice-based agriculture and the development of irrigation in target districts in three provinces: Takeo and Kampot in the south and Kampong Thom in the north-west. This project has close linkages to CAVAC components. CAVAC will collaborate with this project in three key areas: training CAVAC trainers and extension workers in the management of farmer field trials, testing varieties, and participatory methods; sharing of extension publications and research findings; and joint farmers' workshops and field days at shared sites.

Once the CAVAC agribusiness component is active, the project will use the business skills to be included on the CAVAC team to conduct a feasibility study and further develop rice seed production in Cambodia. This will cover other supply chains for inputs such as appropriate herbicides, for improving cultivation and varieties in Cambodia. There will also be links with the irrigation specialists to help rice farmers better use water resources. The project will also benefit by linking with the business development component of CAVAC, which will analyse the value chain and look at new market opportunities for growers and wholesalers.

Objective 3

Selected F_6 populations derived from parents differing in quality will be grown in Cambodia, and grain and DNA shipped to IRRI for genotyping and analysis. Volatiles and compounds affecting aroma will be extracted and analysed by gas chromatography (GC) methods at IRRI, forming phenotype sets 1 and 2. Rheological properties will be determined using a rheometer and texture tester forming phenotype set 3; for phenotype set 4, starch structure will be analysed by size exclusion chromatography and capillary electrophoresis. Populations will be genotyped at 384 loci on the Illumina BeadXpress platform at IRRI. One population consisting of 365 progeny will be created and multiplied at CARDI to 100-g samples each, and shipped to UQ for phenotyping. The set will be cryoground and volatile compounds emitted during cooking will be detected by two-dimensional GC with Time of Flight Mass Spectrometry (TOF MS). A subset of the population will undergo sensory profiling. Associations between sensory data, phenotype datasets, and genotype will be determined using standard biometric QTL analysis tools.

Capacity will be developed at CARDI to measure the quality of the material sent from IRRI, current popular Cambodian varieties, and progeny derived from crosses. CARDI cannot measure quality currently because its quality evaluation program is not fully equipped. Several low-cost wet chemistry methods have been developed over the years (Juliano 1985), which allow rapid low-cost screening of many samples. The program needs only three pieces of equipment for it to become operational. The first is a mechanism for polishing and grinding small samples of rice. The smallest conventional mill will polish a minimum of 120 g, and breeders are often able to provide samples of only about 5 g. IRRI polishes small samples using a commercial paint shaker and custom-built sample holders for sample sizes ranging from 3 to 15 g. The same technology will be acquired and used at CARDI. Second, a spectrophotometer is required to measure amylose content, which is one of the key indices of sensory quality. A new method is being developed and tested by the INQR (Fitzgerald et al 2009a) (CARDI is not participating because it does not own a spectrophotometer). Acquisition of the spectrophotometer would allow CARDI to participate in INQR projects. The last piece of equipment CARDI requires for the quality evaluation program is an instrument to measure the physical quality of the grain. Grain shape is important to consumers, traders, and millers in other rice-growing countries, so it is also likely to be important in Cambodia. There are three options for measuring the shape of rice grains: callipers (extremely low throughput and statistically unsound), an image analysis system (SeedCount) that is high throughput but does not output precise data, and another image analysis system being developed in Thailand. Early in this project, the Thai system and SeedCount will be evaluated for capacity, throughput, and accuracy. CARDI staff will be trained to carry out quality evaluation by spending 6 months in the IRRI program learning the methods, the problems, and their solutions, and learning how to analyse and curate data. Following this, IRRI staff will commission the CARDI quality evaluation program and ensure that the IRRI-trained staff can operate and troubleshoot its program.

Capacity will be built at CARDI to use marker-assisted selection (MAS) to “fast-track” aspects of its breeding program in which a gene is known and markers are available. The first marker that will be implemented will be for tracking submergence-tolerant progenies in backcross populations. A gene (*SUB1*)-specific marker can be used conveniently for high-throughput screening for tolerance. Aroma is the other trait for which markers can be adopted in the breeding program. The genetic and biochemical basis of aroma is well characterised (Bradbury et al 2008, Kovach et al 2009), and choosing to screen progeny for aroma using a molecular marker makes economic sense, and is fully justified in Section 2.2.

Objective 4

A robust program of germplasm evaluation and seed increase will be undertaken at key nodes in tropical Australia (e.g., Mackay QLD; Katherine NT) using statistically sound design and analysis tools. RRAPL will coordinate agronomic management of the trials and day-to-day activities will be undertaken by local state agencies or farm managers at trial sites. Germplasm (including 23 Cambodian varieties) sourced from the Mekong region is already in Australian quarantine with seed increase to be fast-tracked so that relevant varieties are evaluated in this project. IRRI accessions with drought and aerobic adaptation are ready for evaluation in Australia in the 2009/10 season. Wet-season trials will generally be evaluated under aerobic conditions, with dry-season production being either aerobic or conventional lowland depending on the availability of irrigation water. Breeders’ seed of promising entries will be increased at selected sites. Depending on varietal rights, seed will be available to growers under contract, to ensure that the pure seed program remains pure.

Drought screening will be undertaken in appropriate conditions (late-sown temperate or dry-season tropical) using Metafin (drip tape 25 cm deep in soil profile) irrigation on beds. This system has been used by the I&I NSW rice breeding program for the last two years for its aerobic nurseries and it provides an accurate selection environment. Seedling vigour will be assessed using existing protocols, including deep-seed direct-drill trials in heavy clay soil.

6 Achievements against activities and outputs/milestones

Objective 1: Identify the current and future germplasm needs of Cambodian farmers and traders to determine the priorities and strategies for new germplasm development and dissemination

No	Activity	Outputs/ milestones	Completion date	Comments
1.1	Conduct an ex ante assessment of farmers' and traders' needs.	Private company recruited to carry out survey.	Y1M9	**Completed**. Indochina Research (Cambodia) Ltd. contracted to do the survey in October 2010.
		Survey questions developed in consultation with IRRI's Social Sciences Division.	Y1M10	**Completed.** Survey questionnaire finalized in December 2010. The survey was conducted during 12/2010-1/2011.
		Historical data collected by PDA obtained.	Y1M11	**Completed**.
1.2	Analyse the survey data to prioritize strategies for germplasm development, submit report to stakeholders and a paper to a journal.	Analysis completed and recommendations made for current needs and future trends.	Y1M12	**Completed**. Analysis completed in February 2011. Results were provided to project breeders for setting up breeding goals.
		Knowledge of different needs of farmers, consumers, and traders.	Y1M12	**Completed**. Needs of farmers, consumers, and traders were included in the survey. Briefly, short duration, high yield, and good grain quality for dry-season crop, and medium to long duration, high yield, good quality, and tolerance of drought and floods for wet-season crop. Results published in *Field Crops Research* in 2015.

1.3	Conduct workshops with government, industry, and researchers, identify priorities for germplasm dissemination and design a detailed strategy.	Workshops held to promote newly identified material.	Y4, 5	**Completed**. Newly identified lines were reported and discussed at the Cambodia Rice Research Forum on 1 May 2012, in which 140 government officials, including 24 PDA officials, NGO and industry representatives, scientists, and researchers participated. Promising lines identified were also reported and discussed at the ACIAR Policy Meeting: A Policy Dialogue on Rice Futures held on 7-9 May 2014 in Phnom Penh attended by about 60 government officials, researchers, and NGO representatives. On 16 May 2014, 110 researchers from PDAs of five provinces (Kampot, Takeo, Prey Veng, Svay Rieng, and Kandal) and three research stations were invited to see the promising lines in fields at CARDI. Two field days, one in Prey Veng on 20 May and another in Kampot on 21 May 2014, were held to introduce new lines to 62 local researchers and government officials, and progressive farmers. Varieties that were newly released such as Damnoeb Sbai Mongkul and CAR14 under the project were reported at MAFF's annual meetings in 2014 and 2015, and foundation seeds were provided to all PDAs for multiplication and dissemination.
1.4	Empower PDA staff to conduct appropriate varietal extension activities.	Staff trained and resourced to grow demonstration trials in dry and wet seasons.	Y1, 2, 3 M11 Y2, 3, 4 M5	**Completed**. PDAs of Takeo, Kampot, Prey Veng, and Kampong Thom provinces were resourced to conduct multilocation and demonstration trials in every dry and wet season in Y1-Y5.
1.5	Train CARDI, GDA, and PDA in conducting on-farm participatory varietal selection.	Staff trained to carry out PVS. PVS data gathered, analysed, and used for selection.	Y2, 3, 4 M6	**Completed**. CARDI, GDA, and PDA project staff trained to carry out PVS, and PVS was conducted every season with multilocation trials. PVS data were used for selection by breeders, and for varietal release.

PC = partner country, A = Australia

Objective 2: Strategic development and dissemination of improved rice germplasm for different agro-ecological rice systems in Cambodia

No	Activity	Outputs/ milestones	Completion date	Comments
2.1	Development and dissemination of suitable improved germplasm with desired quality for direct-seeded aerobic rice, including that with early vigour and weed competitiveness, and	Breeding lines and elite germplasm with useful genetic variability for target traits such as early vigour and drought tolerance obtained from IRRI, Australia, and other centres, with suitable grain quality. At least 400 breeding lines evaluated at CARDI and other stations in Cambodia.	Y1M12 Y2M12	**Completed**. 284 lines (175 aerobic rice + 109 rainfed rice with drought tolerance) were collected from IRRI, Australia, and CARDI in July 2010. **Completed**. 284 lines were first evaluated under aerobic conditions at CARDI in WS 2010. Later, evaluation expanded to other stations.

	drought tolerance (related agronomy work will be conducted under CSE 2009/037 on rice establishment, component 2 of MSA-FSRP).	Breeding lines evaluated in multi-location tests in collaboration with PDA and through PVS.	Y3M12	**Completed**. Selections from the 284 lines underwent continuous evaluation and selection at Bati, Prey Pdau, and CARDI from DS 2011 to WS 2013. Also in Prey Veng and Kampot in DS 2014. PVS was conducted every season.
		At least five promising high-quality lines identified for release and seed multiplied.	Y4M12	**Completed**. Six lines with good grain quality identified. More lines identified as particularly suitable for aerobic systems. Seeds are available, but, since upland area is far from the project provinces, these lines haven't been tested in OFAT for possible varietal release.
		New crosses made between Cambodian cultivars and donors possessing drought tolerance and early vigour. Segregating population generated and phenotyped for quality.	Y4M12	**Completed**. Ten crosses were made in WS 2011. The progenies were then continuously advanced and selected. In DS 2014, 246 F_5 lines were phenotyped under both lowland and drought conditions, and for grain quality.
		Promising progenies evaluated in observational yield trial.	Y5M12	**Completed**. 67 F_6 lines evaluated in observational yield trials with two replicates under both lowland and drought conditions at CARDI in WS 2014.
2.2	Development and dissemination of suitable improved germplasm with desired quality for rainfed lowland systems exhibiting submergence tolerance carrying the *SUB1* gene and/or drought tolerance.	Breeding lines received from IRRI, Australia, and other centres evaluated at CARDI and other hotspots in Cambodia for quality and stress (biotic and abiotic) resistance.	Y2M6	**Completed**. 121 advanced lines with *SUB1* from IRRI evaluated under lowland, stagnant water, and submergence conditions in WS 2010 at CARDI, and under lowland conditions in WS 2011-12. Seventy-six backcross lines ($BC_{3-4}F_{5-8}$) screened for drought tolerance (vegetative) in DS 2011. Selections then underwent evaluation and selection for yield and quality under both lowland and drought conditions in WS 2011-13.
		Promising high-quality lines evaluated in multilocation trials in target rainfed environments involving PVS.	Y5M12	**Completed**. A new variety (Damnoeb Sbai Mongkul) was released in Dec. 2013. Thirteen promising BC lines with drought tolerance and good grain quality were selected and evaluated in four multilocation trials under rainfed and drought conditions in WS 2014. Five most promising lines identified.
		New population generated from crosses of well-adapted Cambodian varieties with donors for submergence tolerance/lodging resistance.	Y2M6	**Completed**. Five crosses of local varieties with IR64-Sub1 were made in DS 2011, and BC_1 populations created in WS 2011 for submergence tolerance using MAS. Four crosses made in WS 2011 for lodging resistance and/or grain quality using conventional method. These lines have been advanced to F_4.
		Introgression of *SUB1* and *AG1* gene into a popular Cambodian variety using MAS; BC_2 population gained.	Y6M3	**Completed**. Introgressing of *SUB1* and *AG1* genes into Phka Rumduol using MAS started in 2013 at IRRI. BC_2F_1 population was gained in June 2015. However, to complete the introgression, one more round of backcrossing and genotyping is needed to create and identify the desired BC_3F_1 plants.
2.3	Development and dissemination of suitable improved germplasm having early maturity and	Breeding lines obtained from IRRI, Australia, and other centres.	Y2M6	**Completed**. Obtained 969 lowland lines and 123 rainfed lines from IRRI by 2011 for the breeding target.
		A set of 300 breeding lines evaluated	Y2M12	**Completed**. In total, 1,092 lines primarily evaluated at CARDI in WS

	photoperiod insensitivity with desired quality for irrigated dry-season and supplementary irrigated rice.	for high yield and quality and resistance to BPH and yellowing syndrome of viral diseases in irrigated production system.		2010-11 for selection on maturity, yield, quality, and pest and disease resistance. However, since the population of naturally occurring BPH was insufficient, screening for BPH tolerance was not effective.
		Promising lines evaluated in multi-location trials in collaboration with PDA and through PVS.	Y3M6	**Completed**. Selections from the primary evaluation further evaluated in groups in trials at CARDI, Bati, and Prey Pdau stations, and then in Takeo, Kampot, Kampong Thom, and Prey Veng provinces in collaboration with PDAs and through PVS, from DS 2011 to WS 2014 (by batch).
		Ten promising lines suitable for dry-season cultivation identified.	Y3M12	**Completed**. Fourteen promising early lines identified for dry-season cultivation.
		Two high-yielding, high-quality varieties released in Cambodia.	Y5M12	**Completed**. IR06L164 was released as a new variety (namely, CAR14) in March 2015, and another, IR04N155, as CAR15 in June 2015.
		New genetic donors for aroma, other quality traits, and short maturity identified.	Y2M6	**Completed**. Sen Pidao and Phka Rumduol identified as donors for quality traits; some IR lines as donors for short maturity and drought tolerance.
		Crosses made between Cambodian cultivars with donors for grain quality and short maturity; segregating population developed.	Y2M12	**Completed**. Ten crosses made in WS 2011, and since then progenies advanced continuously season after season. 246 lines at F_5 in DS 2014.
		Advanced progenies evaluated in OYT and promising lines identified for future testing and release.	Y5M12	**Completed**. Sixty-seven F_6 lines were evaluated in OYT with two replicates under lowland conditions at CARDI in 2014 WS. Twenty-three promising lines were identified for future testing and release.

PC = partner country, A = Australia

Objective 3: Understand scientific basis of sensory quality of Cambodian rice and develop capacity in Cambodia for rice quality assessment and MAS

No	Activity	Outputs/ milestones	Completion date	Comments
3.1	Identify and define the quality of the preferred traditional varieties of rice by understanding their structural, metabolomics, and rheological properties, and associating these with a SNP map and sensory profiling.	Populations grown at CARDI.	Y2 M12	**Completed**. A number of improved traditional varieties grown, and a cross made at CARDI in WS 2010 for developing the population for study on sensory quality of Cambodian rice.
		Knowledge of quality traits in popular Cambodian varieties.	Y3, 4, Y5M6	**Completed.** Seven most popular Cambodian varieties, including Phka Rumduol, Phka Romeat, Riang Chey, CAR4, and CAR6, were measured in grain quality at IRRI in 2011, and Cambodia officially released 40 varieties in 2013. Knowledge of the quality traits of Cambodian varieties acquired.
		Knowledge of the structure of grain components and their interactions during cooking to give specific sensory qualities.	Y3, 4, Y5M6	**Completed**. Evaluation of rheological and textual characteristics of cooked rice of Cambodian varieties was done in 2013, and that of the population of 384 RILs was done in 2014.
		Knowledge of volatile and water-soluble compounds that define taste and aroma.	Y3M12	**Completed**. Metabolomics work with Cambodian rice varieties and the population of 384 RILs done at UQ in 2013-14.
		Sensory data of the population.	Y5M6	**Completed**. Sensory-related traits, texture, and rheological characteristics evaluated by instruments at IRRI in 2013-14, but not sensory per se due to the limit of sample size.
		SNP map of a selected F_6 population segregating for quality.	Y5M6	**Completed**. Genotyping done at IRRI in 2014, and SNP map acquired.
		Associations made between sensory data and other phenotype data, and between all phenotype data and SNP map.	Y5M12	**Ongoing**. Preliminary analysis done by a PhD student at UQ.
		Identification of QTLs for Cambodian quality.	Y5M12	**Ongoing**. Preliminary analysis done by a PhD student at UQ.
3.2	Upgrading current facilities and capacity at CARDI for high-throughput screening of grain quality for both early- and late-generation material.	Small sample polisher bought and installed at CARDI.	Y3M6	**Completed**. Installed at CARDI in November 2011.
		Spectrophotometer bought and installed at CARDI for analysis of amylose.	Y3M6	**Completed**. Installed at CARDI in November 2011.
		Instrument for physical quality selected,	Y3M6	**Completed**. S21 installed at CARDI in November 2011.

		bought, and installed at CARDI.		
		All equipment set up, installed, and calibrated.	Y3M12	**Completed**. Four IRRI staff came to CARDI in November 2011 to install and calibrate the instruments.
		Staff trained in the use of the equipment and analysis and recording of the data.	Y2M12	**Completed**. CARDI staff member Ouk Sothea was trained at IRRI in grain quality measurement in Sep-Nov 2011. Four IRRI staff came to CARDI to train the whole CARDI team in November 2011. Two IRRI staff came to CARDI again in August 2012 to settle issues on the use of S21.
		Breeders use quality data to make selection decisions.	Y2M6	**Completed**. Breeders used quality data for selection from season to season.
3.3	Upgrading current facilities and capacity at CARDI for MAS to accelerate breeding.	Equipment and chemicals purchased and MAS laboratory facilities upgraded.	Y2M12	**Completed**. A PCR machine, Gel Documentation System, and Udy Cyclone Mill purchased and installed in September 2013. Chemicals and other supplies purchased.
		MAS protocols adopted for submergence tolerance and aroma.	Y3M6	**Completed**.
		In-house capacity for MAS adopted for routine screening of populations for target traits.	Y4M6	**Completed**. CARDI now has the capacity to run MAS in terms of facility. CARDI staff together with a PhD student from UQ screened 67 F_6 lines for aroma using MAS at CARDI in 2014.
3.4	Train CARDI staff to operate rice grain quality laboratory and analysis and MAS laboratory and adoption of marker application in breeding.	On-the-job training for two CARDI scientists at IRRI for marker application and grain quality analysis for 6 months.	Y2M6	**Completed**. However, only one CARDI staff (Ouk Sothea) was trained at IRRI in 2011 because CARDI could not spare another.
		Three IRRI staff travel to Cambodia, install equipment, and ensure that CARDI staff can operate the programs.	Y2M6	**Completed**. Four IRRI staff travelled to CARDI in November 2011 to commission the CARDI lab and to train CARDI staff. One IRRI staff came to CARDI in September 2012 to train again, and make standard operating procedure in Khmer on MAS.
		One CARDI scientist trained in Australia to adopt MAS using gene-based markers.	Y2M6	**Completed but revised**. CARDI could not spare a scientist to be trained in Australia. Instead, CARDI team was trained in Cambodia by IRRI staff.
3.5	Understand the compounds of taste and flavour that define the quality of the prized variety PRD using three new metabolomic profiling platforms for volatile, primary, and secondary compounds and a population derived from PRD and an unpopular variety.	Population developed at CARDI.	Y1M6	**Completed**. Cross of PRD × TK made in WS 2010.
		F_5 progeny multiplied at CARDI and parents sent to UQ for profiling.	Y4M1	**Completed**. F_5 progeny multiplied at CARDI in WS 2013 and F_6 in WS 2014.
		Population sent to UQ.	Y4M10	**Completed**. 384 (365 lines) milled samples of F_6 RILs, including parents, sent to UQ in January 2014.
		Progeny analysed by GCGCTOFMC, UPLCMSMS, and GCMS.	Y5M12	**Going on**. A subset of the progeny has been analysed by GCGCTOFMS and GCMS. The full set is yet to be analysed in the JAF to JCC. The 2013 F_6 could not be analysed fully because we were waiting until the F_7 material arrived so the samples from both years could be analysed in a single analytical run for scientific rigour. Our data so far indicate that the

				parents differ significantly in grain traits, and the compounds that identify PRD are a set of fragrant heterocycles, aldehydes, and other hydrocarbons.

PC = partner country, A = Australia

Objective 4: Demonstrating commercially viable direct-seeded practises from tropical Australian rice production

No	Activity	Outputs/ milestones	Completion date	Comments
4.1	RRAPL to manage and contract germplasm evaluation and pure seed production in tropical Australia.	Five germplasm evaluation trials per year in tropical areas accompanied by pure seed production of entries (I&I NSW, RRAPL).	Y2M6 & M11 Y3M6 & M11 Y4M6 & M11 Y5M6	**Completed:** WA Govt., NT Govt., and Andrew Barfield (QLD) were engaged to provide replicated trials conducted in both the dry and wet season of tropical Northern Australia. A total of six sites were tested across the three states. 203 varieties have been evaluated across the five years.
4.2	Identify and recommend germplasm that is both adapted to aerobic culture and market-ready for both export and domestic markets.	Germplasm entries with analyses of agronomic and grain quality attributes (I&I NSW, RRAPL).	Y2M8 & M12 Y3M8 & M12 Y4M8 & M12	**Completed:** 203 varieties assessed with both positive agronomic traits and quality market traits. Ten varieties have been selected to continue evaluation with both agronomic and quality traits.
4.3	Develop phenotypic screens that will provide repeatable quantitative data on seedling vigour and tolerance of transient drought for promising photoperiod-insensitive germplasm identified from Australian and Cambodian trials.	Number of entries screened from photoperiod-insensitive germplasm (I&I NSW, IRRI, CARDI).	Y2M12 Y3M12 Y4M12	**Completed**: Establishment counts and seedling vigour measurements were recorded for each trial. Drought screens completed under drip tape at 2-5-cm deep. All varieties selected for photoperiod insensitivity. Blast screen for Coastal Plains, NT, variety assessments.

PC = partner country, A = Australia

7 Key results and discussion

7.1 Rice germplasm needs in Cambodia from the survey

The survey on rice germplasm needs of Cambodian people shows what and how farmers grow and what rice varieties farmers, millers, and traders prefer. Farmers mostly use direct seeding (broadcast) to establish the rice crop for both recession and dry-season (DS) rice, while using transplanting mostly in the wet season (WS). Farmers use a number of varieties, but these vary from season to season and from place to place. In general, farmers grow relatively short-duration varieties in the DS, mostly IR504 and IR66, while in the wet season farmers mostly grow various photoperiod-sensitive local varieties such as Phka Rumduol and Phka Knghei.

Farmers, millers, and traders prefer rice varieties with the following characteristics:

- Short growth duration for recession and dry-season rice, and medium to long duration for wet-season rice (fit to the rainfed weather pattern and crop rotation needs)
- High yield
- Resistance to abiotic (drought and floods) and biotic (pest and disease) factors
- Resistance to lodging
- Slender grain
- Aroma
- Low chalkiness
- Translucent grain
- High head rice
- Medium texture after cooking

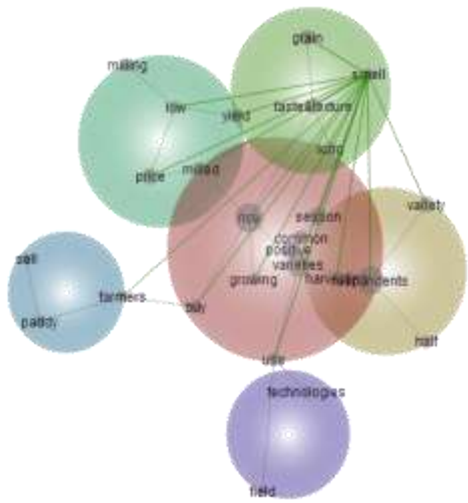


Fig. 1. Leximancer analysis of the survey data showing important themes and concepts.

The survey data were analysed using Leximancer, which enables analysis of qualitative data to extract important themes and concepts. Figure 1 shows the Leximancer analysis. The most important themes in the red bubble show that agronomic traits and quality are important. Analysis of the patterns and text indicate that, in terms of quality, aroma and texture were the most important traits. The survey clearly indicates that improvements to rice varieties must ensure that quality is included. Therefore, both agronomic traits and grain quality traits were considered in selection in the breeding programs under this project. Since broadcast is widely used to establish the rice crop in Cambodia, especially in the DS, in multilocation trials testing the most promising lines targeted at the lowland system, both broadcasting and transplanting were employed.

7.2 Variety released and elite lines identified

For the aerobic rice system, about 10 promising lines have been identified at stations. They typically yield 4–4.5 t/ha under aerobic soil conditions (Table 3). However, since upland areas, mostly in the northeast and southwest of Cambodia, are far from the project provinces, and this type of rice is not suitable for the project provinces, it is difficult to test the identified material in On-farm Adaptive Trials (OFAT) by farmers. Adoption of the promising aerobic lines will rely on a separate project or national extension system to disseminate them to the upland areas in Cambodia. The material can also be used in plains for water-saving regimes, since there is not much irrigation in the dry season and too much rainfall water in the wet season. The adoption of identified aerobic rice lines in plains is limited.

Table 3. Means of promising aerobic rice lines across sites CARDI, Bati (Takeo Province), and Prey Pdau (Kampong Speu Province) in the wet season (WS) 2011-12 and the dry season (DS) 2012.

Line	Days to Flowering (d) 2012 WS	Plant height (cm) 2012 WS	Yield (t/ha) 2012 WS	Yield (t/ha) 2012 DS	Yield (t/ha) 2011 WS	Yield mean over 3 seasons (t/ha)
IR78936-B-9-B-B-B	74	94	4.4	4.7	4.5	4.5
IR80013-B-141-4-1	76	101	4.5	3.9	4.6	4.3
IR66	71	90	4.1	4.3	4.6	4.3
IR07L122	71	106	4.6	3.8	4.3	4.2
IR06G113	76	93	3.8	4.5	4.2	4.1
IR05A235	75	99	4.3	3.9	4.1	4.1
IR78875-207-B-1-B	76	105	4.9	3.0	4.3	4.1
CT 6510-24-1-2	74	98	4.3	3.4	4.5	4.1
IR06L136	72	93	3.9	4.0	4.2	4.0
IR06L167	71	105	4.1	3.8	4.1	4.0
IR06L141	78	91	4.1	3.9	4.1	4.0
Rumpe (check)	71	86	4.2	3.5	4.4	4.0
IR69502-6-SRN-3-UBN-1-B	77	98	4.4	3.3	4.2	3.9
IR06L164	72	100	3.9	3.4	4.4	3.9
IR81040-B-78-U 2-1	72	104	4.0	3.2	4.4	3.9
$LSD_{0.05}$	1.1	3.9	0.4	0.33	0.47	

Aerobic rice varieties can adapt to irrigated environments well. This is a finding from two consecutive seasons' multilocation trials testing a subset of six aerobic rice lines under both aerobic and irrigated conditions. In this testing, IR06L164 consistently performed well. This result supported the decision to release IR06L164 as a lowland variety, but with drought tolerance.

For the irrigated lowland system, from the first batch of 577 introductions, six promising lines with short duration, high yield, and acceptable grain quality were identified (Tables 4 and 5), and were tested in 99 OFATs in the 2014 DS and 75 OFTAs in the 2014 WS. Consequently, two of the six lines were officially released in early 2015.

- **CAR14 (IR06L164):** 95 days of growth duration, 90 cm in plant height, 6.8 mm in length, 1.8 mm in width of milled grain, medium amylose content, 4.2 t/ha of typical yield with potential up to 7.5 t/ha. Adapted to both irrigated and aerobic soil conditions.
- **CAR15 (IR04N155):** 100 days of growth duration, 100 cm in plant height, 7.0 mm in length, 2.1 mm in width of milled grain, medium amylose content, 4.0 t/ha of typical yield with potential up to 7.4 t/ha.

Table 4. Overall means of six promising early lines evaluated under irrigated conditions in three dry (DS) and wet (WS) seasons in 2012-13 across a number of sites in five provinces (Phnom Penh, Takeo, Kampot, Kampong Thom, and Prey Veng) of Cambodia.

	2013 DS, across 12 sites					2012 WS, across 8 sites					2012 DS, across 9 sites		
Line	DTF† (d)	HT (cm)	Yield (t/ha)	> IR504	> Chul'sa	DTF (d)	HT (cm)	Yield (t/ha)	> IR504	> Chul'sa	DTF (d)	HT (cm)	Yield (t/ha)
IR03L148	69	99	4.3	31%	22%	72	102	4.7	20%	5%	NA‡	NA	NA
IR04N155	69	95	4.0	24%	15%	71	97	4.8	23%	8%	69	94	4.3
IR06L164	70	94	3.8	17%	9%	69	94	4.5	17%	2%	NA	NA	NA
IR07L167	71	99	4.3	32%	23%	71	102	4.5	16%	2%	71	95	4.2
IR77674-3B-8-2-2-8-2-4	69	92	4.2	28%	19%	69	95	4.2	7%	–6%	72	88	3.6
IR83415-B-SDO3-3-AJY1	69	89	3.8	17%	9%	69	91	4.4	14%	0%	71	83	4.1
Chul'sa (check)	67	85	3.5	8%	0%	69	86	4.4	14%	0%	69	81	4.5
IR504 (check)	61	76	3.3	0%	–7%	64	87	3.9	0%	–12%	64	73	4.5
$LSD_{0.05}$	0.4	1.4	0.16			2.2	6.6	0.41			2.3	3.1	0.35

† DTF = days to flowering; HT = plant height; >IR504 = percentage of yield over IR504; >Chul'sa = percentage of yield over Chul'sa. ‡ NA, not available.

Table 5. Grain quality characteristics of six promising early lines.

Line	Chalkiness (%)	Grain shape (L/W)†	Amylose content (%)	Head rice (%)	Gelatinization temperature‡	Gel consistency (mm)
IR03L148	3	3.5	27.1	65.0	I/L	100
IR04N155	28	3.3	25.7	67.6	HI/I	98
IR06L164	6	3.4	25.6	65.8	HI/I	90
IR07L167	2	3.5	24.7	69.2	I	100
IR77674-3B-8-2-2-8-2-4	5	3.9	26.3	62.6	I/L	75
IR83415-B-SDO3-3-AJY1	8	3.4	30.5	68.3	I	100
Chul'sa (check)	8	3.5	22.2	69.4	HI/I	90

† L/W = grain length/width; ‡ H = high; I = intermediate; L = low.

From the second batch of 515 introductions, eight most promising lines have been identified after testing in multilocation trials across four consecutive seasons in 2013-14. These lines significantly outyield local popular variety Chul'sa in most cases (Table 6) and have good grain quality (Table 7). These promising lines are being tested in 40 OFATs in four provinces (Kampong Thom, Siem Reap, Battambang, and Pursat) in the 2015 WS for possible varietal release.

Table 6. Overall means of a new set of eight promising lines evaluated at multilocations in the dry and wet seasons of 2013-14 in Cambodia.

	2013 wet season									**2013 dry season**					
	On-farm, 16 sites			Early set, 6 sites			Medium set, 6 sites			Early set, 4 sites			Medium set, 4 sites		
Line	DTF† (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IR10L149	71	94	5.1	75	95	4.7	NA	NA	NA	72	92	3.7	NA	NA	NA
IR87759-10-1-2-2	72	94	5.1	NA	NA	NA	79	96	3.9	NA	NA	NA	80	95	3.6
IR04L186	73	98	5.0	77	97	4.6	NA	NA	NA	75	94	3.5	NA	NA	NA
IR87753-5-1-6-4	72	97	4.6	77	99	4.8	NA	NA	NA	76	95	3.4	NA	NA	NA
IR09L337	71	97	4.5	75	98	4.7	NA	NA	NA	72	93	3.5	NA	NA	NA
IR87747-16-1-1-1	NA	NA	NA	77	96	4.6	NA	NA	NA	75	94	3.1	NA	NA	NA
IR87761-53-1-1-4	NA	NA	NA	NA	NA	NA	80	94	4.4	NA	NA	NA	80	90	4.2
IR87761-66-2-3-2	NA	NA	NA	NA	NA	NA	80	95	4.7	NA	NA	NA	80	95	3.6
Chul'sa (check)	69	89	4.4	73	89	3.9	NA	NA	NA	70	88	3.4	NA	NA	NA
$LSD_{0.05}$	0.4	1.1	0.19	1.8	3.8	0.5	1.9	3.6	0.42	1.9	3.9	0.51	2	4.7	0.53

	2014 wet season									**2014 dry season**					
	OFAT, 25 sites			Direct seeding, 1 site			Transplanting, 1 site			On-farm, 16 sites			On-station, 6 sites		
Line	DTF† (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IR10L149	62	94	4.3	65	97	3.4	77	102	3.4	77	98	3.7	80	97	3.8
IR87759-10-1-2-2	NA	NA	NA	67	95	3.6	83	105	3.3	79	99	4	84	95	4.1
IR04L186	62	92	4.0	NA	NA	NA	NA	NA	NA	79	100	4	84	97	3.8
IR87753-5-1-6-4	64	95	4.3	66	97	3.7	81	105	3.3	79	100	4	83	97	3.9
IR09L337	62	94	4.3	66	96	3.8	75	103	3.3	77	99	3.7	79	98	4.2
IR87747-16-1-1-1	NA	NA	NA	67	94	3.6	78	106	3.2	NA	NA	NA	82	98	4.1
IR87761-53-1-1-4	NA	NA	NA	69	93	3.8	84	99	3.4	79	98	3.9	82	91	3.9
IR87761-66-2-3-2	66	96	4.7	66	96	3.7	78	102	3.4	80	99	4	83	94	3.7
Chul'sa (check)	NA	NA	NA	64	90	3.7	75	93	3.7	72	86	3.6	74	84	4
$LSD_{0.05}$	0.4	1.1	0.21	2.4	6.4	0.88	1	7	0.55	1.1	2.2	0.28	2.8	4	0.35

† DTF = days to flowering; HT = plant height; NA = not available.

Table 7. Grain quality characteristics of a new set of eight promising lines for the irrigated system in Cambodia.

Line	Chalkiness (%)	Grain shape (L/W)†	Amylose content (%)	Head rice (%)	Gelatinization temperature‡	Gel consistency (mm)
IR04L186	14	3.5	26.7	46.7	L	95
IR09L337	6	3.5	20.1	59.5	HI/I	100
IR10L149	7	3.7	25.4	36.1	L	100
IR87747-16-1-1-1	22	3.6	19.1	51.2	HI	79
IR87753-5-1-6-4	17	3.5	19.0	47.8	HI/I	97
IR87759-10-1-2-2	21	3.5	20.1	50.2	I	94

IR87761-53-1-1-4	29	3.5	29.2	42.2	I	90
IR87761-66-2-3-2	8	3.6	20.6	51.8	HI	70

† L/W = grain length/width; ‡ H = high; I = intermediate; L = low.

Screening for resistance to brown planthopper was performed every dry season in the whole life of the ACIAR breeding project. However, because of insufficient naturally occurring population of BPH, field screening has never been successful since 2010. In the 2014 WS, a screening for BPH resistance was conducted in a greenhouse at CARDI. The result shows that 4 of the 16 most promising lines had moderate resistance to BPH (Table 8). Partly because of the BPH resistance of line IR04N155, it was officially released as a variety.

Table 8. Reaction of 16 promising lines to brown planthopper (2014 WS, CARDI).

Line	Replicate-I	Replicate-II	Replicate-III	Mean	Reaction to BPH
IR07L167	7	9	9	9	HS
IR77674-3B-8-2-2-8-2-4	9	9	9	9	HS
IR03L148	5	5	3	5	MS
IR04N155	**3**	**3**	**5**	**3**	**MR**
IR06L164	9	9	9	9	HS
IR83415-B-SD03-3-AJY1	**3**	**3**	**3**	**3**	**MR**
IR04L186	**3**	**3**	**5**	**3**	**MR**
IR09L337	7	7	9	7	S
IR10L149	5	5	3	5	MS
IR67014-45-3-1	7	7	9	7	S
IR87747-16-1-1-1	9	9	9	9	HS
IR87753-5-1-6-4	**3**	**3**	**3**	**3**	**MR**
IR87759-10-1-2-2	7	7	7	7	S
IR87761-53-1-1-4	9	9	9	9	HS
IR87761-66-2-3-2	7	7	5	7	S
IR87808-21-2-2-3	5	5	5	5	MS
Check 1, highly susceptible (TN1)					
Check 2, moderately resistant (IR-Kesar)					

For the rainfed lowland system, a new variety, Damnoeb Sbai Mongkul, was officially released in December 2013 after being tested in OFATs in three consecutive wet seasons in 2011-13. Breeder seed was distributed to 24 PDAs in April 2014 for multiplication and dissemination.

- **Damnoeb Sbai Mongkul**: glutinous, photoperiod sensitive, moderately tolerant of drought and floods, tall, and typically yields 3.1 t/ha under rainfed conditions.

Additionally, 13 backcross lines with improved drought tolerance of Phka Rumduol and improved grain quality of CAR3 were identified at CARDI (Tables 9 and 10) in the 2013 WS. These lines were further tested in multilocation trials under both rainfed and drought conditions at four sites in the 2014 WS. Five of them were found most promising as they outyielded their recurrent parent Phka Rumduol under either rainfed or drought conditions (Table 11). These five lines are being tested in 40 OFATs in four provinces in the 2015 WS for possible varietal release.

Table 9. Agronomic traits of 13 promising backcross lines evaluated under aerobic, lowland, and lowland drought conditions at CARDI in the 2013 wet season.

Line	Aerobic conditions				Lowland conditions				Lowland drought conditions			
	DTF† (d)	HT (cm)	YLD (t/ha)	>PRD	DTF (d)	HT (cm)	YLD (t/ha)	>PRD	DTF (d)	HT (cm)	YLD (t/ha)	>PRD
CAR3 (check)	108	154	3.3	–7%	121	132	3.3	14%	122	115	2.1	43%
CIR 792-19-3-3-105-1-B	101	148	4.0	13%	109	127	3.2	9%	109	110	2.1	45%
CIR 827-13-15-B-3-3-1-29-1-5	105	153	3.8	10%	117	133	3.0	2%	116	94	1.9	26%
CIR 827-13-15-B-3-3-1-29-3-4	106	148	3.4	–4%	118	128	2.7	–9%	116	111	1.8	20%
CIR 827-15-17-B-4-4-1-32-2-3	104	157	3.5	–1%	113	129	2.8	–6%	117	112	1.4	–3%
CIR 827-16-18-B-3-5-30-2-10-1-2	112	161	3.0	–15%	120	133	2.7	–9%	119	113	1.9	29%
CIR 827-21-23-B-5-7-47-1-13-1-4	95	150	3.3	–5%	117	119	2.5	–15%	111	107	1.6	9%
CIR 827-21-23-B-5-7-47-1-13-3-1	103	159	3.6	2%	113	134	3.3	14%	114	114	1.8	20%
CIR 827-21-23-B-5-7-47-1-13-4-3	103	155	3.8	9%	113	125	2.8	–5%	115	100	1.5	0%
CIR 827-2-4-B-5-1-1-27-1-2	103	159	4.4	25%	104	126	3.4	17%	104	114	2.3	55%
CIR 827-25-27-B-2-9-56-1-18-1-4	105	155	3.2	–9%	104	123	2.9	–1%	107	111	1.7	15%
CIR 827-4-6-B-4-2-1-28-1-3	105	142	3.4	–4%	110	117	3.0	4%	110	102	1.8	20%
CIR 827-4-6-B-4-2-1-28-3-1	107	153	3.7	6%	116	128	2.6	–12%	116	111	1.8	23%
CIR 827-4-6-B-4-2-8-1-1-1-1	100	148	3.7	7%	106	118	2.6	–13%	108	109	1.7	13%
Phka Rumduol (check)	99	157	3.5	0%	105	123	2.9	0%	108	105	1.5	0%
$LSD_{0.05}$	2	13	0.7		5	9	0.9		2	9	0.5	

† DTF = days to flowering; HT = plant height; YLD = grain yield; >PRD = percentage in yield more than Phka Rumduol.

Table 10. Grain quality traits of 13 promising backcross lines.

Line	Length (mm)	L/W†	GT	GC (mm)	AC (%)	Chalk	Aroma	Softness	Stickiness	Taste	Acceptability
CAR3 (check)	6.4	2.7	I	55	22.5	High	No?	3	3	3	3
CIR 792-19-3-3-105-1-B	6.5	2.7	HI	93	13.8	high	No?	3	2	3	3
CIR 827-13-15-B-3-3-1-29-1-5	7.2	3.5	I/L	86	18.5	low	No?				
CIR 827-13-15-B-3-3-1-29-3-4	7.1	3.4	I/L	89	15.6	low	No?				
CIR 827-15-17-B-4-4-1-32-2-3	7.1	3.4	I/L	74	19.9	low	No?				
CIR 827-16-18-B-3-5-30-2-10-1-2	7.0	3.4	I	70	14.5	low	No?	3	3	3	3
CIR 827-21-23-B-5-7-47-1-13-1-4	7.1	3.4	L	80	14.8	low	No?				
CIR 827-21-23-B-5-7-47-1-13-3-1	7.1	3.5	I	86	14.0	low	Yes	3	3	2	2
CIR 827-21-23-B-5-7-47-1-13-4-3	7.1	3.4	I	71	15.8	low	No?				
CIR 827-2-4-B-5-1-1-27-1-2	7.0	3.3	I	76	15.7	low	No?	3	3	3	3
CIR 827-25-27-B-2-9-56-1-18-1-4	7.2	3.5	I/L	65	13.7	low	Yes				
CIR 827-4-6-B-4-2-1-28-1-3	7.0	3.2	I	77	15.3	low	No?	2	2	3	3
CIR 827-4-6-B-4-2-1-28-3-1	7.0	3.1	I	82	15.7	low	No?	2	2	2	2
CIR 827-4-6-B-4-2-8-1-1-1-1	7.1	3.4	I	63	13.6	low	Yes	2	2	2	2
Phka Rumduol (check)	7.0	3.4	I	65	13.7	low	Yes	2	2	2	2

† L/W = ratio of grain length over width; GT = gelatinization temperature; GC = gel consistency; AC = amylose content.

Table 11. Means of five elite backcross lines tested in multilocation trials under rainfed lowland and drought conditions in the 2014 wet season in Cambodia.

Line	Rainfed lowland (4 sites)				Drought (4 sites)	
	DTF (d)	Height (cm)	Yield (t/ha)	>PRD	Yield (t/ha)	>PRD
CIR 827-4-6-B-4-2-1-28-3-1	116	133	4.5	20%	3.9	22%

CIR 827-13-15-B-3-3-1-29-1-5	116	133	4.0	8%	3.7	16%
CIR 827-2-4-B-5-1-1-27-1-2	111	127	4.1	9%	3.7	15%
CIR 827-21-23-B-5-7-47-1-13-1-4	114	129	4.3	16%	3.6	13%
CIR 827-21-23-B-5-7-47-1-13-4-3	114	128	4.2	12%	3.5	8%
Phka Rumduol (recurrent parent)	111	129	3.8		3.2	
$LSD_{0.05}$	3	5	0.5		0.4	

DTF = days to flowering; >PRD = percentage of yield higher than Phka Rumduol, the recurrent parent.

7.3 Advance in new breeding programs

A total of 246 photoperiod-insensitive and early F_5 lines were evaluated under both lowland and lowland drought conditions for agronomic traits and in the lab for grain quality traits in the 2014 DS. Sixty-seven selected lines (F_6) were evaluated in replicated trials under both lowland and drought conditions in the 2014 WS, and 128 F_6 selected plants were advanced to F_7 at CARDI. The 67 lines were screened for aroma using Badh 2.1 marker at CARDI and for grain quality at IRRI. Twenty-three most promising lines were finally selected (Table 12) and are being further evaluated in five multilocation trials in five provinces in the 2015 WS.

Some 169 photoperiod-sensitive backcross F_4 lines were obtained in WS 2013 and 99 F_4 lines from single crosses were obtained in WS 2014. A BC_2F_1 population for introgressing *SUB1* and *AG1* genes into Phka Rumduol was obtained in June 2015 at IRRI. Continuous breeding efforts are needed to advance these breeding lines.

Table 12. Means of F_6 (agronomic traits)/F_7 (quality traits) early lines evaluated in 2014 WS at CARDI.

Line	**Parentage**	**DTF** (d)	**HT** (cm)	**Yield** (t/ha)	**Yield in drought** (t/ha)	**Aroma**	**Chalk** (%)	**AC** (%)	**GT**	**GC**	**Head rice** (%)
CIR845-19-8-1-B	IR66/Sen Pidao	84	82	5.4	4.8	Segregating	18	21.8	L	100	44.4
CIR846-19-1-1-B	Rumpé/Sen Pidao	86	86	4.9	4.7	Fragrant	20	22.2	L	97	44.9
CIR846-19-1-2-B	Rumpé/Sen Pidao	86	91	4.8	4.8	Fragrant	9	15.4	L	80	45.8
CIR846-6-2-2-B	Rumpé/Sen Pidao	89	95	4.8	4.6	Fragrant	14	15.0	L	78	41.8
CIR847-17-2-3-B	Chul'sa/Sen Pidao	82	98	5.9	4.3	Segregating	6	16.5	L	85	40.2
CIR847-2-2-1-B	Chul'sa/Sen Pidao	86	91	5.3	5.7	Segregating	8	13.8	L	75	37.2
CIR847-25-2-1-B	Chul'sa/Sen Pidao	89	92	5.1	4.4	Fragrant	10	14.4	L	71	46.1
CIR847-8-2-2-B	Chul'sa/Sen Pidao	87	96	5.8	4.9	Segregating	8	14.5	I/L	98	49.1
CIR848-9-4-3-B	IR66/Phka Rumduol	85	91	4.8	4.8	Segregating	21	27.0	I/L	100	32.2
CIR848-9-4-6-B	IR66/Phka Rumduol	84	90	6.3	5.0	Segregating	14	22.3	L	100	40.8
CIR850-1-2-1-B	Sen Pidao/IR04L186	87	90	5.3	5.4	Fragrant	14	15.3	I	97	48.0
CIR850-1-2-2-B	Sen Pidao/IR04L186	86	95	5.5	5.8	Fragrant	20	15.3	I	89	45.1
CIR850-1-3-3-B	Sen Pidao/IR04L186	84	93	5.3	4.7	Fragrant	8	16.1	I/L	76	40.1
CIR850-7-2-1-B	Sen Pidao/IR04L186	82	95	5.8	4.8	Fragrant	22	26.9	L	75	42.8
CIR851-27-4-1-B	Sen Pidao/IR06L164	83	100	5.0	5.3	Fragrant	13	21.6	I/L	65	47.1
CIR851-3-2-4-B	Sen Pidao/IR06L164	85	99	5.4	4.9	Fragrant	16	22.3	Seg	75	40.4
CIR851-6-5-1-B	Sen Pidao/IR06L164	84	96	5.0	5.0	Segregating	13	16.3	I/L	68	47.8
CIR851-8-5-1-B	Sen Pidao/IR06L164	86	99	5.3	2.8	Fragrant	10	21.0	L	68	45.3
CIR852-5-1-2-B	Sen Pidao/IRRI 154	88	92	5.0	4.7	Fragrant	3	14.9	I/L	66	49.3
CIR853-7-1-2-B	Sen Pidao/IR03L146	76	93	4.5	3.8	Fragrant	1	14.2	L	68	24.4
CIR853-7-2-1-B	Sen Pidao/IR03L146	78	101	4.5	4.8	Fragrant	0	14.6	I/L	72	39.5
CIR855-14-2-1-B	Sen Pidao/IR05A233	84	92	4.8	5.4	Segregating	6	16.5	I/L	83	34.1

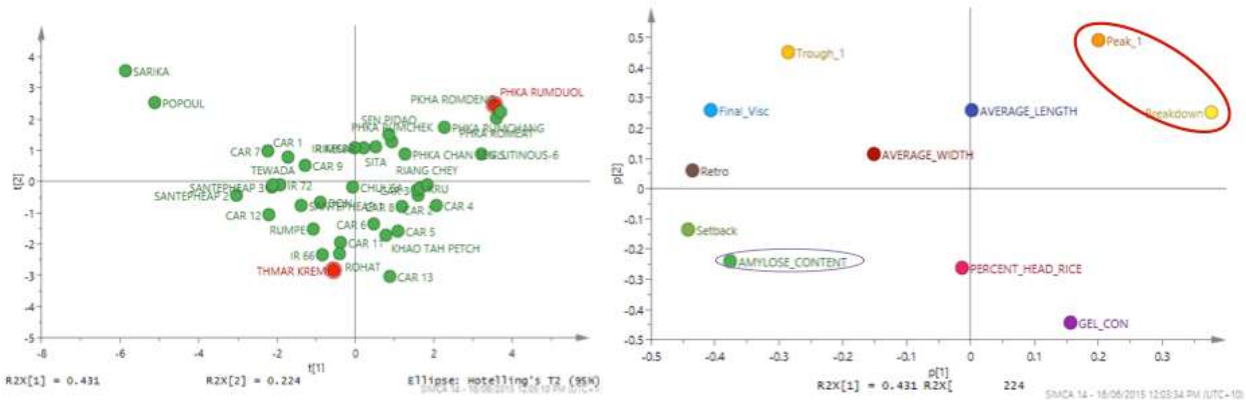
CIR855-4-2-2-B	Sen Pidao/IR05A233	84	94	5.1	4.4	Segregating	10	14.8	I/L	69	43.5

DTF = days to flowering; HT = plant height; yield (DT) = yield under drought conditions; AC = amylose content; GT = gelatinization temperature; GC = gel consistency.

7.4 Advance in study on sensory quality of Cambodian rice

Based on the survey data, the major traits of importance to the actors in the value chain were aroma and texture. It is well known in rice science that aroma is due to the presence of one compound, 2-acetyl 1-pyrroline (2AP), but it is equally well known in consumer science that different classes of aromatic rice smell and taste different, and that there must be more than one compound that defines aroma. Texture is also a combination of phenotypes ranging from the sensory experience of the first bite, then further bites, and eventual formation of the bolus. In order to develop tools for quality evaluation, the definition of each trait must be known, and, to keep pace with new selection techniques, the knowledge must be delivered as a panel of genetic markers.

In order to determine the physical and genetic basis of texture and aroma, we developed a mapping population. Quality evaluation was conducted on a large panel of Cambodian rice varieties that constitute the germplasm pool to find the textural indicators in Pkha Rumduol (PRD) and then to identify a variety that was a suitable parent for the population. Figure 2a shows a principal components analysis (PCA) of the germplasm, with PRD highlighted, and another variety, Thmar Krem (TK), that has quality traits that are the most statistically different from PRD. Figure 2b shows the factors leading to the arrangement on PC1 and PC2 in Figure 2, showing peak viscosity and breakdown, and amylose content as the most discriminating textural parameters.



a b

Fig. 2. (a) PCA of quality evaluation of Cambodian rice varieties (left) and (b) the loadings plot showing the discriminating traits (right).

Although the textural factors suggested that TK would be the suitable parent to cross with PRD, we also carried out metabolomic profiling of the volatile compounds in the grain to ensure that the two varieties differ also for aromatic quality. Figure 3 shows the PCA of the same varieties, showing three clear clusters. The first cluster contains PRD and other Phka varieties; the second cluster, discriminated along PC1, includes TK and other traditional and nonaromatic varieties. The third cluster, separated on PC2, contains nonaromatic improved varieties. The results indicated that TK was a suitable parent for creating a mapping population with PRD. The population was created in the first year of the project, and was advanced rapidly through generations to reach F_6 by the final year of the project. The population of 384 RILs (basically from 365 F_5 lines) derived from PRD × TK was genotyped at IRRI using 6K SNP Infinium. A total of 692 polymorphic loci were found between the parents, distributed quite evenly across all of the 12 chromosomes (Fig. 4), and should be sufficient for QTL mapping.

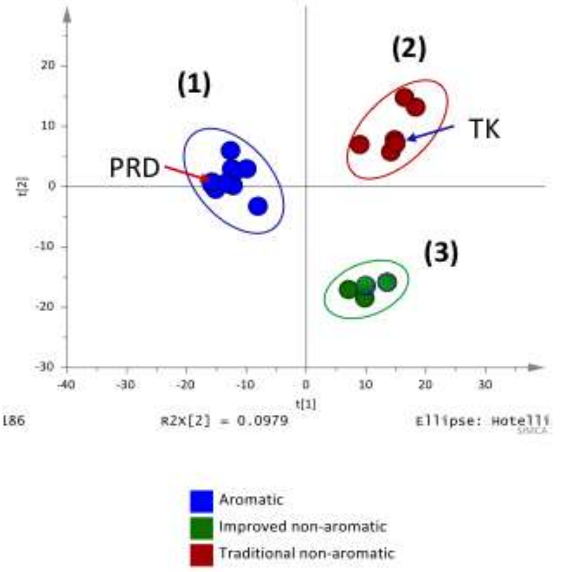


Fig. 3. PCA of volatile metabolites in Cambodian rice.

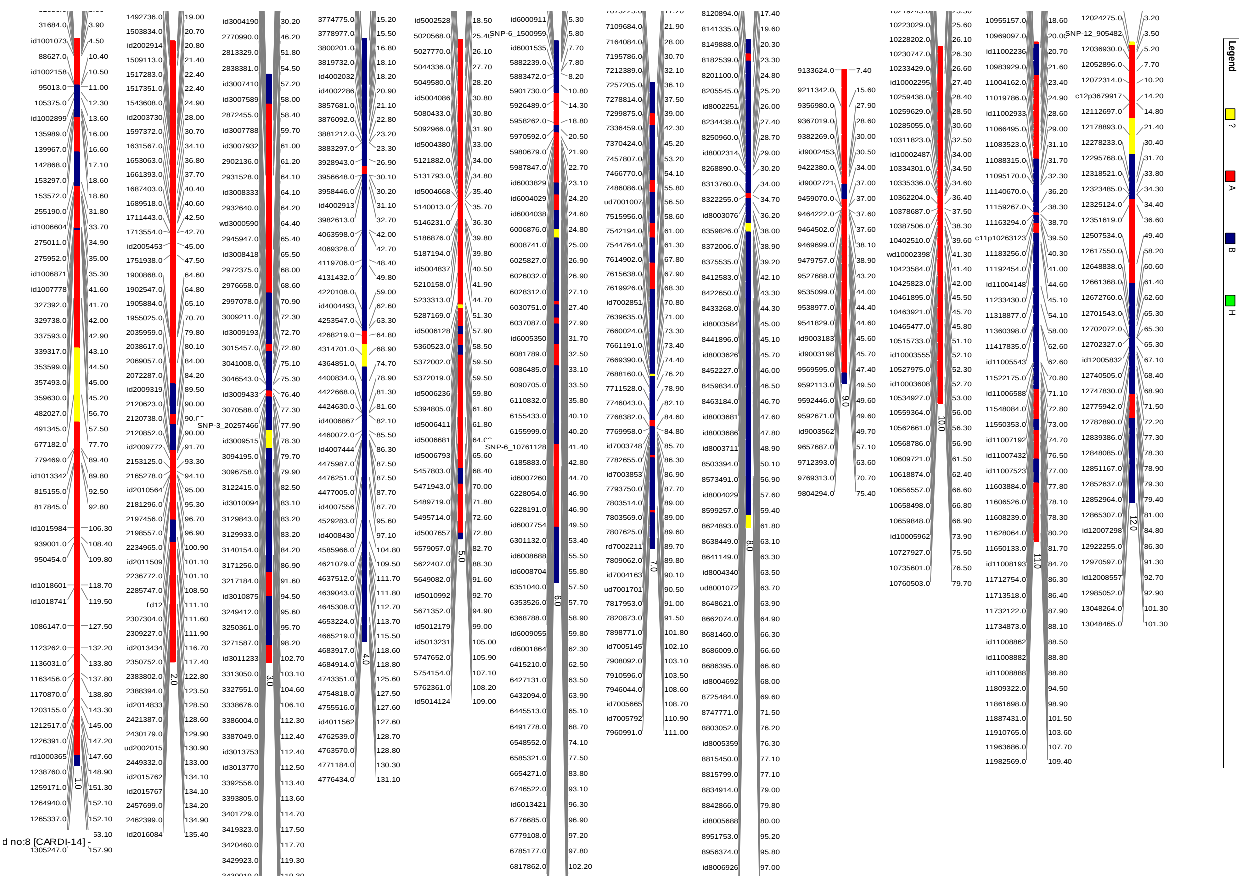


Fig. 4. Location of 692 polymorphic SNPs between PRD and TK.

Table 13. Discriminating compounds of taste and flavour between PRD and TK.

Compound	Aroma	PRD	TK
2AP	Popcorn	63228	328
Pentanal	Almond	109,558	285,155
Hexanal	Grassy	1,159,487	6,890,128
Heptanal	Floral	58553	37800
Octanal	Fruit/Floral	31709	32893
Nonanal	Floral	58249	31634
Decanal	Citrus	16463	37045
2-heptenal	Dairy	52241	6809
2-octenal	Fatty/Green	nd	964096
2-nonenal	Fatty/Rancid	nd	4004321
2-decenal	Fried citrus	nd	908818
Vanillin	Vanilla	67756	64036
Indole	Faecal	nd	153115
2(3H)-Furanone, dihydro-5-methyl-	Rotten grape	1123363	7742357

Analysis of volatile compounds showed that the basic fragrance compound 2AP in PRD was about 200 times as much as that in TK. In addition, pleasant-smelling aldehydes were more abundant in PRD than in TK, whereas unpleasant aromas (2-octenal, 2-nonenal, 2-decenal, indole) were found only in TK. Seven unpleasant-smelling furanones were found present in both PRD and TK, but the peak abundance of these in TK was 6–7 times higher than in PRD (Table 13).

Phenotyping of the population on physical traits (chalkiness and grain shape), cooking traits (amylose content, gelatinisation temperature, gel consistency), and viscosity profile was completed at IRRI. The analysis showed that there were two main clusters of progeny, one clustering with PRD and the other with TK. The major discriminating factors between the clusters were again peak viscosity, breakdown, and amylose content. Metabolomics phenotyping is ongoing at UQ, but analysis of a subset showed that there are two main clusters for volatile compounds and a small cluster between the two groups.

QTL mapping of the quality traits and the volatile compounds showed a strong QTL for peak viscosity and breakdown, which was upstream of the waxy locus. This indicates that the short arm of chromosome 6 houses a hot spot of genes that participate in starch synthesis in ways that influence important textural traits.

Preliminary QTL analysis was carried out for the saturated and unsaturated aldehydes shown in Table 13 and again in the analysis of the progeny (data not shown). QTLs were not found, which could mean that the aldehydes are produced chemically and not genetically. Aldehydes can be products of the oxidation of fatty acids. In order to determine whether fatty acid profiles differed between PRD and TK, the set of Cambodian varieties underwent fatty acid analysis. Interestingly, PRD and TK differ significantly in their fatty acid profile and, even more interestingly, the PCA analysis of the fatty acids showed two distinct clusters: one for aromatic rice and one for nonaromatic rice. The most discriminating for PRD is the monounsaturated oleic acid and for TK linoleic and linolenic acid. Scientifically, this raises extremely interesting questions regarding the link between fatty acid profiles and aroma. This will form the basis of the John Allwright scholarship.

The final goal of this study is to identify QTLs that are responsible for good sensory quality traits by associating the genotyping and phenotyping datasets. The QTLs can then be fine-mapped and used in MAS. However, deep metabolomics profiling is to be done by a PhD student at UQ in three years and thus can't be completed in the life of this project.

7.5 CARDI's breeding capacity enhanced

CARDI's grain quality lab is equipped with a polisher to mill small samples, a spectrophotometer to determine amylose content, and a grain analyzer (S21) to measure physical traits (grain shape, chalkiness, translucency, head rice) in the project. CARDI's molecular lab is also equipped with supplemental instruments such as a PCR, Gel Documentation System, fume hood, analytical balance, and an Udy Cyclone Mill. Both labs are functional. CARDI staff were also trained in the use of these instruments in grain quality evaluation and MAS, and in plant/line selection, experimental design, and data analysis. With this capacity building, CARDI is capable to run a breeding program more efficiently and at a high level.

7.6 Achievements in Australia

As the overall analysis on grain yield for all sites is still ongoing as part of a future publication (Snell et al 2015), for this report, a subset of trials is discussed below with respect to adaptation to upland (Table 14), aerobic (Table 15), and lowland (Table 16) systems, and inherent characteristics needed in addition to grain yield.

Table 14. Grain yield (at 14% water content) of several upland trials conducted as part of the Australian component of this project.

VARIETY	LIS09	EM09	KRS10	LIS10	KRS11	CPS12	KRS13
Amaroo	2.08	1.99	0.88	*	*	*	*
Azucena	*	*	1.55	*	3.09	1.34	1.94
B6144F-MR-6	*	*	*	*	3.96	3.36	2.11
Bengal	*	2.20	*	*	*	1.99	*
Doongara	2.33	2.51	0.00	*	*	*	*
IR 64	*	*	*	*	3.17	3.33	1.99
IR 78877-048-B-B-2	*	*	*	*	5.88	3.14	2.18
IR 79913-B-176-B-4	*	*	*	*	3.68	2.69	2.18
Jefferson	1.30	1.64	*	*	*	1.80	*
Kyeema	3.61	3.97	*	*	*	1.67	*
Langi	1.31	2.96	*	*	*	*	*
Lemont	1.53	3.36	1.17	*	3.19	*	*
NTR426	*	*	1.26	*	2.88	2.48	2.22
NTR587	*	*	*	*	*	3.67	2.45
Pandan Wangi (10)	*	*	*	*	*	1.84	1.85
Pandan Wangi (7)	*	*	*	*	*	2.15	1.84
PSBRC 9	*	*	2.16	*	3.23	3.35	2.41
Quest	1.94	1.77	*	*	*	0.00	*
Reiziq	1.37	1.26	*	*	*	*	*
Tachiminori	2.76	4.00	2.64	3.89	3.47	*	3.01
Takanari	*	*	*	*	3.30	3.12	1.93
Vandana	*	*	*	2.07	1.74	*	*
Viet1	*	*	*	*	*	1.98	1.71
Viet4	*	*	*	*	*	4.36	2.78
YRL126	2.33	2.67	*	*	*	*	*
YRM69	1.66	2.38	*	5.47	*	*	*
Yunlu29	3.56	3.90	5.80	*	3.89	1.88	2.35
LSD 5%	1.11	0.58	*	0.76	0.94	*	0.34

For the upland trials conducted in this study, crop maturity, tolerance of blast, and biomass yield had as much bearing on local adaptation as yield per se. As all these trials were conducted in the wet season, a bit of a gamble was taken in the appropriate varietal mix to maximise the return based on the duration of a historic wet season. In Lismore, this resulted in a shorter maturity (hence, most of the varieties "fell out" of this table) than at other sites because of a run of late-commencing summer rains. A very wet start at the coastal plains site (CPS12) resulted in severe incursion of blast at establishment, which obliterated Quest, and impinged on the grain yield of other sensitive varieties (e.g., Kyeema). Grain yield (Table 14) was far from the primary economic value of these varieties as the ability to cut and bale the crop for livestock feed has as much value for the locations considered here (O'Gara 1998, Eastwick et al 2012).

Table 15. Grain yield (at 14% moisture content) of several aerobic trials conducted as part of the Australian component of this project.

VARIETY	MKY08	MKY09	FWI10	FWI11	FWI12	DPW12	YDP12
Amaroo	7.68	6.44	2.28	1.18	*	*	*
B6144F-MR-6	*	4.16	*	7.16	2.00	0.00	0.00
Bengal	4.28	9.22	*	*	*	*	*
Doongara	7.13	7.85	*	2.94	2.82	*	*
IR72	*	8.43	*	3.69	3.42	*	*
Jefferson	7.34	8.21	*	*	*	*	*
Langi	*	7.57	*	4.14	5.46	*	*
Lemont	8.02	8.05	6.55	1.56	1.54	3.81	8.16
Milyang	4.29	8.58	6.36	3.47	*	*	*
Newbonnet	6.54	9.43	*	*	*	*	*
NTR426	*	6.75	*	2.29	0.97	*	*
Pandan Wangi (10)	*	5.87	0.59	1.28	*	*	*
Pandan Wangi (7)	*	*	4.61	1.92	0.82	*	*
PSBRC 9	*	5.39	*	3.32	*	0.01	2.66
Quest	*	5.95	2.61	4.77	2.34	4.58	11.96
Reiziq	*	5.39	*	*	*	4.18	13.40
Tachiminori	*	5.40	6.58	5.05	3.74	4.45	7.34
Takanari	*	8.03	4.37	4.19	2.48	0.56	5.82
Vandana	*	4.09	4.36	3.65	*	2.26	1.44
YRM69	*	9.42	*	*	*	7.13	13.03
Yunlu29	6.79	2.33	*	11.75	9.91	0.32	1.99
LSD 5%	0.79	2.29	0.73	1.79	*	0.53	1.10

Trials at Mackay (MKY) and Kununarra (FWI) were irrigated intermittently on raised beds for RRAPL and LFS (DPW12 and YDP12, respectively) conventional paddy bays where flooded based on evapotranspiration demand.

In aerobic trials, grain yield (Table 15) was governed by maturity, but due more to avoidance or tolerance of cold rather than water stress. In Mackay and at southern sites (LFS and RRAPL), late-occurring cold (from young microspore to flowering stage) reduced grain yield drastically for full-season varieties (B6144F-MR-6 and Yunlu 29), while cold was encountered during the vegetative stage in Kununurra (FW11 and FW12) for these varieties, resulting in the reverse being true (Siva et al 2012).

Continued work on sowing times for the tropical north is a new feature of the RIRDC project "Agronomic options for profitable rice-based farming systems in northern Australia" (PRJ-007497). The limitation of cold in Kununurra is more an artefact of the largely tropical varietal base employed in this area and could be quickly remedied through the deployment of cold-tolerant material being bred at Yanco NSW for this purpose (Ye et al 2009). Difficulty in getting seed across to Western Australia has been the major obstacle due to quarantine restrictions, with the required methyl-bromide fumigation being a cost-prohibitive measure that has restricted varietal exchange during the life of this project.

Table 16. Grain yield (at 14% moisture content) of several lowland trials conducted as part of the Australian component of this project.

VARIETY	TF11	TF11w	MKY11	MKY11w	MKY12	Mky12w
Amaroo	*	*	4.72	7.53	*	8.67
B6144F-MR-6	*	*	5.18	*	3.70	*
Bengal	*	*	8.83	*	6.70	*
Cypress	*	*	7.32	*	5.42	*
Doongara	*	7.17	6.67	14.80	5.34	10.65
Fin	*	7.78	6.20	11.37	*	*
IR 64	3.92	6.89	8.45	11.91	6.11	8.42
IR72	3.60	8.89	7.70	12.82	6.59	*
Jefferson	*	*	7.84	*	5.43	7.27
Kyeema	*	8.92	6.34	11.42	3.01	11.28
Langi	*	6.67	6.52	10.47	5.24	11.75
Lemont	*	7.61	7.67	11.95	5.25	10.15
NTR426	4.11	8.00	6.14	7.44	*	*
Pandan Wangi (7)	3.49	7.17	*	9.22	*	8.66
PSBRC 9	*	*	6.27	*	5.53	*
Quest	*	9.61	4.35	8.27	4.95	6.39
Sen Pidao	*	*	*	11.90	5.80	8.49
Tachiminori	3.15	*	5.75	10.76	4.14	8.85
Takanari	4.75	*	9.52	11.34	6.12	8.76
ULP RI7	*	*	5.99	13.60	*	*
Vandana	4.10	*	5.77	8.93	*	6.46
Viet 1	*	8.28	*	9.23	6.10	*
Viet 4	*	11.17	*	13.46	6.06	*
Viet 5	*	8.83	*	10.41	4.44	*
Viet 8	*	*	*	10.05	4.35	*
YRL39	*	*	6.92	8.88	4.38	9.33
YRM69	*	*	6.09	9.57	*	*
Yunlu 29	2.17	*	2.77	7.32	3.02	*
LSD 5%	0.60	0.83	1.11	0.77	0.93	1.40

Where "w" suffix represents winter or dry-season trials for the respective sites of Tortilla Flats and Mackay.

When temperature isn't limiting, dry-season production seems the most economical productive period, with grain yields doubling for most varieties evaluated here.

The argument can be made that, on a gross margin basis, wet-season production is cheaper, rarely requiring irrigation. The rainfed nature of supply and hence the limitation of solar radiation generally results in poor conversion to grain yield and, under extreme cases, excessive lodging that compromises the quality of the grain produced. The warmer temperature during grain maturation of dry-season production can have varied effects on amylose and protein content of the grain as well as the gelatinisation temperature, and hence the cooking quality of the rice (Ward et al 2011). This can, depending on quality type of the variety, be beneficial or detrimental and warrants as much consideration as the grain yield itself. In fact, inferior grain quality, despite the impressive agronomic performance of new variety Fin (Norman et al 1989), was a partial contributor to the cessation of rice production in tropical northern Queensland.

In addition to cooking quality, the diverse range of environments encountered through this study from a consistent germplasm base has allowed scope to investigate other grain attributes that influence grain marketability. In particular, the aroma derived from Southeast Asian varieties seems more pronounced in tropical Australia than the same variety grown in temperate locales (Fig. 5).

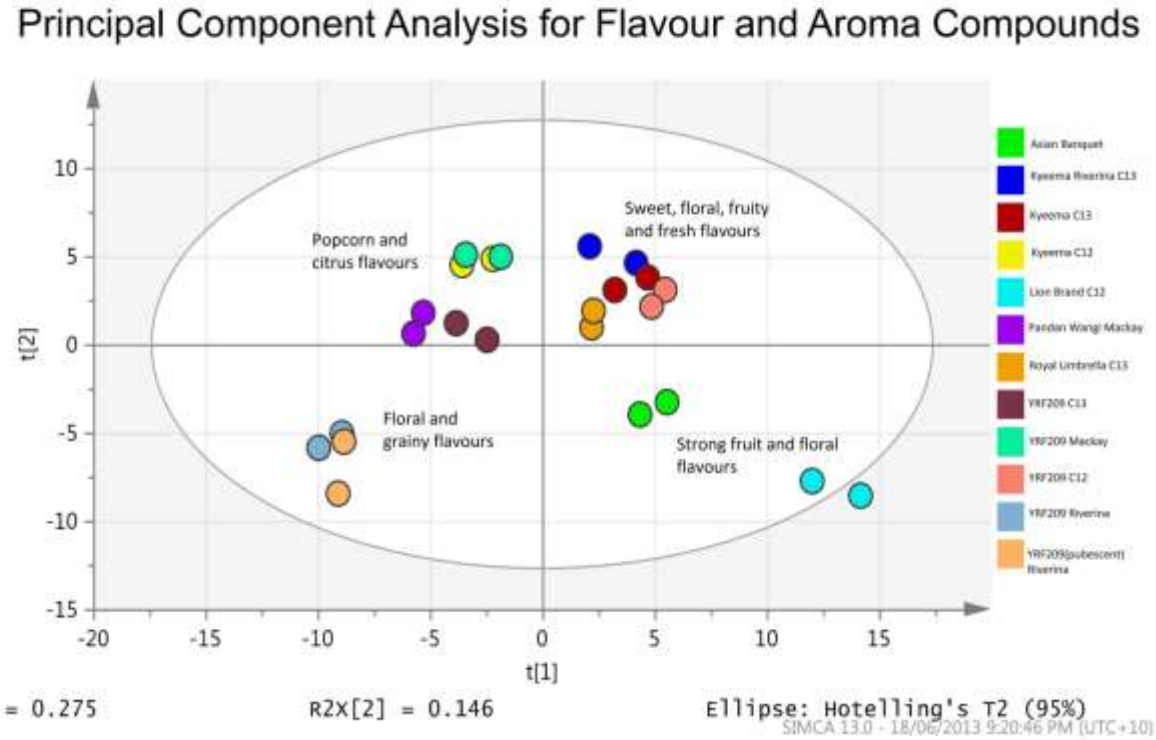


Fig. 5. Principal components analysis of flavour compounds showing the relationships between samples based on a suite of aroma compounds. Laboratory duplicates for each sample are shown, indicating consistency within sample measurement. A greater distance between samples indicates a difference in flavour profile, with dominating aromas being shown for each quadrant.

Such differences have been noted on sensory panels of interested parties, and in part have buoyed the likelihood of commercial investment into rice production in the tropical north. In addition, such geographical nuances are being investigated further in the RIRDC project “Developing superior aromatic germplasm for Australia” (PRJ-008568), in which the influence of stress (water/temperature/salt) on levels of aroma in the grain will be studied.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Knowledge on rice germplasm needs in Cambodia obtained by this project gives insights into rice germplasm to other relevant projects, national and international rice breeders, and project designers.

CARDI's ability to assess grain quality allows CARDI to be a qualified member of the international network on rice quality, and to participate in new projects related to grain quality assessment. CARDI's capacity in MAS enhanced by this project allows CARDI to quickly improve a variety using MAS in future breeding programs.

The S21 instrument for physical traits discovered and adopted by the project has great impact in quality evaluation programs. This instrument was showcased at the 3rd International Network for Quality Rice Symposium in August 2011, and recommended for all quality evaluation programs to replace subjective measurements of chalk, manual sorting of broken grains, and manual measurement of grain dimensions.

QTLs for sensory quality to be identified by associating SNP mapping and phenotyping datasets will result in a useful breeding tool for quickly improving rice sensory quality through MAS. This will benefit quality breeding efforts nationally and internationally in the future.

Australia

This project has allowed for the evaluation of a broad range of rice germplasm across a wide geographic spread of Northern Australia, as well as the opportunity to test this germplasm across different seasons and different cultural (growing) practices.

We can conclude that rice can be successfully grown at all sites, but an understanding of the constraints and limitations must accompany any growing recommendations.

Further evaluation of blast-resistant, drought-tolerant, and specialty-type rice should continue to focus on successful rice varieties that will provide an economic and scientific solution to rice production across Northern Australia.

WA – Ord River Irrigation Area

Focus should be on the growing season from May to September (dry season), as the wet season has proven difficult for access to fields and availability of labour. Both permanent flood culture and aerobic alternate wetting and drying (AWD) culture of growing appear to be successful for some varieties.

N.T. – Tortilla Flats (Adelaide River), Katherine, and Coastal Plains

The Adelaide River area offers some larger areas of suitable topography and soil types for rice growing. Like the Ord River, the area is best suited to a dry-season planting because of the limitations of access during the wet season. Rice yields reaching 11.5 t/ha have been recorded in trials at Adelaide River. There has also been some commercial-scale rice production in the area, which is proving to look promising.

Katherine has provided the opportunity to test some summer (wet-season) trial options. A good source of underground water exists in the area, and much of the water is applied via sprinkler (centre pivots) in the region. The rice trials have also tested using sprinkler irrigation. Results have been disappointing because of both environmental pressure and residual problems with herbicide.

The Coastal Plains site provided another wet-season opportunity to test varieties. It also acted as a site for blast screening of many of the varieties, as blast was prevalent at this location. One of the Australian medium-grain varieties was totally wiped out by rice blast (*Magnaporthe grisea*) fungus. Most Australian rice varieties have not been tested or bred for resistance to the fungus. Generally, rice yields were disappointing for this trial site.

Queensland – Mackay

The trial site, located only 7 km to the west of Mackay in traditional sugar cane cropping country, has given us the opportunity to test rice varieties in both the wet (December to May) and dry (July to December) seasons in every year of the project. This site has also provided us with seed multiplication and a repository for maintaining germplasm for trialling.

Rice trials were always conducted using AWD irrigation techniques on a reasonably flat bed. The soil can be described as a deep grey/brown loam with excellent structure and fertility. Yields of up to 12.5 t/ha have been gained for more than one variety, which equates into some excellent economics and opportunities for commercial farmers.

8.2 Capacity impacts – now and in 5 years

Cambodia

Commissioning of CARDI's grain quality and molecular labs by installing a number of instruments enables CARDI to quickly and objectively evaluate important quality traits such as grain shape, head rice, translucence, and amylose content using small samples, and to run MAS to quickly introgress a target gene into a specific background. This significantly enhances CARDI's capacity in breeding, and will allow CARDI to better run future breeding programs in the long term, beyond 5 years.

The knowledge in trial design and management, plant/line selection, and data analysis the researchers of CARDI, GDA, and PDAs learned from this project will be definitely applied in the future, thus favouring future projects technically.

Australia

Many papers have been written about the potential of Australia's North for rice growing. The constraints have been identified as suitable varieties, diseases, insects, birds, isolation, and infrastructure. The availability of land and water gives natural attraction and suitability to these areas.

Some people say that, if infrastructure in the form of storage and milling were available, then farmers would be more interested in growing rice. On the other hand, likely operators of storage and milling would like to know that there is likelihood that a successful and reliable agronomic package can be provided for a rice farming system. They would also like to know that the varieties grown are suitable for a specific market.

It is the blend of these two views that will lead to the start of a localised Northern Rice Industry along with the economics to support both growers and marketers.

There is currently only one commercial rice marketing business outside NSW. It has been shown in NSW that this is likely to change with the development of a number of boutique-type mills in recent years as some of the nine authorised rice buyers. SunRice is still the major buyer and seller of rice in Australia and it is in a unique situation in which it is a company wholly owned by its own growers. This tight relationship between growers and marketers allows for this business to be successful at both a domestic and international level.

If rice is to be a successful option in Northern Australia in the near future, further support from the federal government for projects similar to this linked with additional R, D, and E support from state and territory governments will be required.

8.3 Community impacts – now and in 5 years

Cambodia

Farmers in the upland areas in Cambodia grow traditional varieties that yield low (1–2 t/ha). Although promising aerobic lines identified by this project have not reached these areas by the end of the project, they are most likely to be disseminated to upland communities by the national extension systems or future projects in 5 years to benefit these communities.

Currently, limited varieties are available to farmers for cultivation in the dry season. The dissemination of newly released early-maturing varieties CAR14 and CAR15 and eight promising early lines that are higher yielding and have higher quality give farmers more and better options. By carrying out PVS with multilocation trials and OFATs by this project, the elite lines/varieties have already been adopted by some farmers at the project sites in Takeo, Kampot, Prey Veng, and Kampong Thom. These lines have also been introduced to Kampong Speu, Kampong Cham, and Say Rieng provinces by an ADB project (Emergency Food Assistance Project, 2012-14); to Battambang, Takeo, and Svay Rieng provinces by a CAVAC project (Support to Rice Value Chain Improvement, 2013-14); to Prey Veng, Kampong Chhnang, Pursat, Kampong Thom, Siem Reap, and Battambang provinces by a SEARICE project (Southeast Asia Regional Initiatives for Community Empowerment: Participatory Conservation, Development, and Sustainable Use of Seeds in Cambodia, 2011-13); and to Sihanouk province by Majestic World Farms. The eight early lines are now being tested in OFATs. We expect that two to three of the eight lines will be released in 2 years to come.

The released photoperiod-sensitive variety Damnoeb Sbai Mongkul is available to all 24 provinces. This provides farmers with opportunities to produce glutinous rice from now on, and ensures more stable production under rainfed conditions because it is moderately tolerant of both drought and flooding. Five identified rainfed lines with drought tolerance and high quality are being tested in OFATs. We expect that one to two of them could be released in 3 years. The new version of PRD with *SUB1* and *AG1* genes that will be available in 2 years will provide Cambodian farmers with a good approach to coping with flooding/submergence stresses, and poor rice establishment due to poor land levelling.

The newly launched USAID-funded project titled *Accelerating the Adoption of Stress-tolerant Rice Varieties by Smallholder Farmers in Nepal and Cambodia* (2015-18) led by IRRI relays the varietal evaluation in Cambodia after the ACIAR project, and accelerates the adoption of new varieties by farmers in the Tonle Sap region. The target is to cover 80% of the rice area with promoted rice varieties in four provinces (Kampong Thom, Siem Reap, Battambang, and Pursat) in 3 years. We believe that, with the USAID project, the impact of the ACIAR project at the community level will be huge in the near future, first in the Tonle Sap region and gradually throughout Cambodia.

Australia

Local communities and even broader regions are striving for successful agricultural options across Northern Australia. The Ord River Irrigation Area is a classic example where many crops have been tested on both an R&D level and a commercial level. There are still only a few main options being successfully grown there. These are sandalwood (60%), chia, melons, pumpkins, and chickpeas. Rice, cotton, and sugar cane have been grown at a commercial level before, but the constraints mentioned above have always halted their potential.

If a rice industry could be set up in any of these local areas of Northern Australia, it would offer a diversity of opportunity to not only local farmers but also to the businesses that support the rice farming and processing industry.

8.3.1 Economic impacts

At this moment, it is still hard to estimate and predict the magnitude of economic impacts of this project because a few new varieties were just recently released and have not been adopted on a large scale. However, we are certain that higher rice production, and thus higher benefits, will be brought to Cambodian farmers by adopting the higher-yielding and higher-quality varieties/lines. Within 5 years, along with more official releases of identified lines and larger scale adoption of them, rice production in Cambodia will be significantly increased. Based on a recent report, about 70% of the rice land in the dry season is planted to IR504, which is low-yielding and has poor quality. If IR504 is replaced with the new early cultivars released or identified by the project, dry-season rice production in Cambodia will increase by 20–30%. Drought and flooding are the two biggest abiotic constraints to Cambodian rice production and they have become more and more severe because of climate change. According to the annual MAFF report 2013, 9% of the wet-season rice was destroyed in 2012 and 15% in 2013 by drought and flooding. Adoption of the newly developed varieties/lines with drought tolerance and/or submergence tolerance will mitigate the damage from these stresses and thus secure rice production in the wet season. Once a new version of PRD with *SUB1* and *AG1* genes is available, farmers can plant the seeds into 15–20 cm of water or onto a poorly levelled field at no cost in crop establishment, thus increasing water-use efficiency and reducing the cost for irrigation and land preparation, while mitigating damage from flooding and ensuring rice production.

Australia

Although yields of 10 t/ha have been reached in all Northern States and Territories during this project, the suitability to specific markets is what will be required if the varieties are to be commercially successful. Each state and territory has taken a different direction at the end of this project, with the plantings of more “niche” or specialty lines to try to find a suitable high-return market place.

Western Australia has taken the direction of commercially testing one coloured variety (Yunlu 29) and one high-yielding line (NTR 587). Northern Territory is testing more fragrant rice lines also in the hope of finding a high-yielding market-suitable variety. Queensland is continuing to grow NSW-derived varieties that have known grain qualities for marketing, but may not be best suited agronomically to the regions.

8.3.2 Social impacts

Cambodia

Rice is the staple food and cash crop in Cambodia, and it contributes much to the country’s GDP. The adoption of higher-yielding and better-quality early rice varieties will increase the total dry-season rice production for export and strengthen Cambodia’s competitiveness in the international market because of the better product quality. The adoption of stress-tolerant varieties will reduce the damage by drought and flooding, thus stabilizing/increasing the traditional quality rice production. In other words, the Cambodian rice industry will be more resilient to climate change. This could make Cambodia a much larger and more stable rice exporter in 5 years, and consequently bring more benefits to rice farmers and contribute to poverty alleviation in rural areas.

Australia
The Australian rice farming system is developed around the use of large-scale machinery with large-scale irrigation infrastructure to support it. The high production across a large scale drives the required efficiencies to allow for the successful cultivation and marketing of rice. In the Riverina District of NSW where most Australian rice is grown, the crop is grown across the summer months with high temperatures, lots of clear blue skies, low humidity, and a reasonable diurnal variation in temperatures. This crop is almost completely reliant on irrigation water for success. In the drought years of 2007 to 2010, Riverina rice production almost ceased because of the lack of irrigation water supplies. Local communities were devastated. The largest mill in the Southern Hemisphere at Deniliquin was closed, and naturally there were severe social impacts.

Being able to maintain a consistent industry is in the best interest of growers, processors, and the local communities. This must be the same case for Northern Australia.

8.3.3 Environmental impacts

Cambodia
Replacing current varieties with better ones has no impact on the environment in Cambodia. The higher productivity of early varieties could motivate farmers to grow more rice in the dry season in areas where there is irrigation, but this should not damage the environment.

Australia
The growing of rice has very little impact on the local environment. Ideally, any water drainage is maintained on-farm during the growing period and recycled back through the irrigation system. Herbicides are used only at early growth stages and have little or nil impact on the surrounding environment. Nutrient loads applied to rice crops are usually used by the crop or filtered through the cropping system.

8.4 Communication and dissemination activities

Cambodia
Field days
A field day combined with PVS at the project sites is an approach for varietal evaluation and dissemination. Local farmers, researchers, and commune leaders (30–40 people) were asked to vote for and encouraged to grow the lines they preferred. Below are the field days the project organized.
2011 May 20, Bati in Takeo
2011 May 26, Chamkiri in Kampot
2011 Nov 29, Dunkeo in Takeo
2011 Nov 30, Chamkiri in Kampot
2011 Dec 30, Prey Pdau in Kampong Speu
2012 Apr 2, in Prey Veng
2012 Apr 3, in Svay Rieng
2013 May 3, Bati in Takeo
2013 May 4, Prey Padu in Kampong Speu
2013 May 12, Mong Russei in Battambang (65 farmers were each given 5 kg of seed of newly released variety Damnoeb Sbai Mongkul)
2013 May 19, Kamchay Mear in Prey Veng
2014 May 16, at CARDI (110 local researchers from Kampot, Takeo, Prey Veng, Say Rieng, and Kandal provinces, and three GDA research stations)
2014 May 20, Kamchay Mear in Prey Veng
2014 May 21, Chamkiri in Kampot
2015 April 27, Siem Reap District in Siem Reap

Meetings and workshops

Project findings were presented or communicated at the following meetings and workshops:
Project meeting in Nov 2010 at CARDI
Project meeting in July 2011 at GDA
Project meeting in Aug 2012 at CARDI
Project meeting in May 2013 in Australia
Meeting with MAFF in Nov 2011
Cambodia Rice Research Forum in April 2012 in Phnom Penh, organized by IRRI and MAFF
IRRI Breeders' Week in Sep 2012 at IRRI
A Policy Dialogue on Rice Futures in May 2014 in Phnom Penh, organized by ACIAR
Project meeting in July 2014 at CARDI
International Rice Conference in Oct 2014 in Thailand
Introductory Workshop on the USAID seed project in February 2015 in Phnom Penh
IRRI Breeders' Week in March 2015 at IRRI
CCAFS Media Workshop in May 2015 in Phnom Penh
Inception and Planning Workshop on the USAID seed project in June 2015 in Phnom Penh

Others

This project communicated the findings with and provided the most promising lines to the following projects, NGOs, and PDAs in Cambodia for testing and dissemination:
(1) SEARICE project "Participatory Conservation, Development, and Sustainable Use of Seeds in Cambodia" (2011-13), 10 lines were provided and tested in 2012 in six provinces (Prey Veng, Svay Rieng, Kampong Thom, Siem Reap, Battambang, and Kampong Chhnang); eight lines were provided and tested in 2013 in the same provinces; five lines in the 2014 DS in three provinces (Siem Reap, Battambang, and Kampong Chhang); and five lines in the 2014 WS in seven provinces (same as above).
(2) ADB project "Emergency Food Assistance" (2012-14), five lines were provided and tested in the 2014 DS in 20 farmers' field in three provinces (Kampong Speu, Kampong Cham, and Svay Rieng).
(3) CAVAC project "Support to Rice Value Chain Improvement," 10 lines in 2013 and 15 lines in 2014 were provided and tested in Battambang, Takeo, and Svay Rieng.
(4) Majestic World Farm, five lines were provided and tested in a number of farmers' fields in 2013-14 in Sihanouk Province.
(5) IFAD project "Project for Agricultural Development and Economic Empowerment (PADEE)" (2012-18), six most promising lines were provided and tested in OFATs in more than seven provinces.
(6) PDAs, breeder seed of the newly released variety Damnoeb Sbai Mongkul was distributed to 24 PDAs in April 2014 for seed multiplication and subsequent cultivation.
(7) USAID project "Accelerating the Adoption of Stress-tolerant Rice Varieties by Smallholder Farmers in Nepal and Cambodia" (2015-18). Three newly released varieties and most promising lines have been provided to the project for evaluation, demonstration, and dissemination in Kampong Thom, Siem Reap, Battambang, and Pursat provinces.

Australia

Field days and discussion groups

Aug 2010 – ORIA Rice Field Day
Aug 2011 – Tortilla Flats
Sept 2012 – ORIA Rice Field Day
June 2013 – Mid-Term Review
Sept 2013 – ORIA Rice Field Day

Media

Year	Month	Media outlet	Type	Title/Topic
2008	February	Richmond River Sun	PRINT	Dry-land rice shows potential
	April	QLD Country Life	PRINT	Future crop – is rice back?
	May	Media release	PRINT	Rice riding a wave of interest on the North Coast
	September	West Australian	PRINT	Ord River farmers pin hopes on trial rice crop
2009	February	QLD Country Life	PRINT	Emerald's first rice trials
	November	Rural Weekly	PRINT	Rice shows promise as CQ irrigated grain crop
2010	June	ABC Rural	AUDIO	Field day shows there's strong interest in rice
	August	Media release	PRINT	CHRRUP Supports Innovation on the Central Highlands
2011	March	ABC Rural	AUDIO	Rice trialled again at Tortilla Flats
	April	Scoop	PRINT	A crop out of the ordinary
	May	Countryman	PRINT	Bumper rice return on cards in the Kimberley
	May	ABC Rural	AUDIO	Keeping rice on top a challenge for Ord growers
	June	Rural Weekly	PRINT	Research proof is in the rice pudding
	June	Katherine Times	PRINT	Top End rice trials continue
	July	Agriculture Today	PRINT	Direct seeding here needs no paddies
	August	Media release	PRINT	Fungal disease detected in northern rice crop
	October	ABC Radio	AUDIO	Dry season rice harvested at Tortilla trials
2012	April	ABC TV	FILM	Coastal Plains and rice
	August	ABC Radio	AUDIO	Northern rice funding to help find a variety tolerant to fungal disease
2013	March	ABC Rural	AUDIO	Professor urges more rice growing in the Top End
	March	QLD Country Hour	AUDIO	Which rice variety grows best under NQ weather?
	May	ABC Rural	AUDIO	Dryland rice trial reaches harvest phase
	August	Media release	PRINT	Harvest tests crops for further Ord expansion
	September	WA Country Hour	AUDIO	Rice field day
	November	ABC Rural	AUDIO	Commercial rice trials go missing up north
	December	Farm Weekly (WA)	PRINT	Nice rice
2014	April	The Kimberley Echo	PRINT	Ord rice trials to focus on quality, not quantity
	April	ABC Rural	AUDIO	Slow response from APVMA cost Ord rice industry

9 Conclusions and recommendations

9.1 Conclusions

The project identified the rice germplasm needs of Cambodia through a survey. The key point is that grain quality is as important as grain yield, and that tolerances of drought and flooding are win traits for the rainfed lowland system. These traits have been addressed in the breeding programs under this project.

Three varieties (CAR14, CAR15, and Damnoeb Sbai Mongkul) were released under the project. A number of promising lines have been identified for each of the aerobic, irrigated, and rainfed lowland systems. However, aerobic rice lines have not been tested in OFATs for release because this system doesn't fit well in the project provinces. Eight early lines for the irrigated system and five sensitive lines with drought tolerance for the rainfed system have already been in OFATs, the last testing before possible varietal release, supported by the newly launched USAID project. Adoption of these new varieties/lines will make an immediate and significant contribution to the nation's strategic plan of increasing agricultural production and decreasing poverty.

New breeding programs at CARDI are successful. For developing photoperiod-insensitive varieties targeted at dry-season cultivation, 23 promising F_7 lines selected for short duration, high yield, and good grain quality have been developed and are being evaluated in multilocation trials in five provinces. For developing photoperiod-sensitive varieties targeted at wet-season cultivation, populations are now at the F_4 stage. Introgression of *SUB1* and *AG1* genes into PRD to improve its submergence tolerance and its ability to germinate in water is ongoing at IRRI. BC_2F_1 has been gained and genotyped. The entire introgression work will be completed in 2016.

The study on sensory quality of Cambodian rice has almost been completed. Genotyping a population of 384 RILs using 6K SNP Infinium was completed at IRRI, and 692 loci were found polymorphic between the parents. Phenotyping the population on grain quality traits was also completed at IRRI. Phenotyping on metabolomics was done at UQ. Analysis of volatile compounds for aroma of the parents was completed at UQ. Preliminary analysis to link the datasets to identify QTLs for sensory quality has been done. However, deep and complete analysis is needed to conclude this study.

CARDI's quality and molecular labs were equipped and commissioned, and CARDI's project staff were trained in running quality analysis and MAS using the equipped machines, and in managing breeding nurseries. CARDI now has the capacity to run breeding programs at a high level independently. GDA project staff were also trained in experiment management, PVS, and data analysis. These enhanced capacities will have a long and significant impact in Cambodia.

Australia

The diversity of geographic locations, seasons, growing cultures, and rice varieties has allowed this project to deliver some very useful data about options for rice growing across Northern Australia.

The use of alternate wetting and drying (AWD) growing culture was shown to have reasonable resilience to bird pressure. Some of the 203 varieties tested across Northern Australia have shown very good potential to be grown in this system.

Each location tested has shown that there is a unique growing season that is ideal for the local environment that is experienced. Likewise, some varieties perform much better in some environments than in others. Northern Australia has many climatic variations according to the region.

Support for commercial-scale rice growing can be driven by farmers with these types of results, but it will always be limited unless further research, development, and extension are provided to support the system. The development of infrastructure will have to accompany any planned increase in localised rice farming areas. This will most likely be in the form of private investment.

Grain quality has also shown promise from the assessment of material produced as part of these trials. There is promise for high-value fragrant rice varieties, and the opportunity exists to grow some specialty and coloured types of rice.

Blast disease has a major impact on many current Australian rice varieties as they have not been bred for resistance. It is a high risk to grow these varieties on a commercial basis in some areas.

9.2 Recommendations

Some new lines developed at CARDI are at F_4 stage. It will take at least 4 years to advance and evaluate these lines before any fixed promising line comes out. Gene introgression using MAS at IRRI and a study on sensory quality at UQ are ongoing. Financial support to continue these research activities is needed.

Varietal development is a long process, and it needs continuous financial support. Investment in varietal development from the Cambodian government is very limited. International aid to support varietal development for the long run is always helpful to Cambodia.

Rainfed lowland will continue to be the major rice system in Cambodia, where drought and floods are two major constraints to its rice production. Traditional cultivars that are widely grown in the wet season in Cambodia are relatively low-yielding but have good grain quality. Future breeding efforts should continue to focus on improving yield potential and tolerance of abiotic stresses, while maintaining good grain quality.

Bacterial blight is severe in the wet season, especially to the prized variety PRD and other traditional varieties. Identification of the predominant BB races in Cambodia and the donors with resistance genes is the first step in breeding for BB resistance in future breeding projects. CARDI has no facilities for screening for disease resistance in a breeding program. Investment in this is urgently needed.

Anaerobic germination is critical to rice establishment in direct-seeded systems. This project was improving anaerobic germination (with *AG1*) together with submergence tolerance (with *SUB1*) of PRD using MAS at IRRI. It is necessary to introgress *AG1* into more varieties in the future in consideration of the broad adoption of direct seeding in Cambodia.

Australia

Northern Australia rice production can be successful if careful attention is paid to the growing system and varieties selected.

Many of the varieties sourced for this project have come from Southeast Asian origin, and have provided a diversified data set to map possibilities for the future source of genetics when focusing on Northern Australia for rice yield and grain quality.

To fully quantify the potential of these promising rice lines, it is recommended that the best producing and best quality germplasm be used as a base for further introductions and a base for future breeding. If the opportunity arises, a new project focused on the development of these variety types in the breeding, growing, and quality assessment areas should be considered.

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11 Appendixes

11.1 Appendix 1: Combined analysis for varietal trials in Cambodia

Dule Zhao

1. Screening for aerobic rice cultivars in Cambodia

One hundred and seventy-five aerobic rice lines/cultivars and 109 rainfed lines with drought tolerance from IRRI and Australia, were evaluated in single plot under aerobic soil conditions at CARDI in the 2010 wet season (WS). Sixty two lines were selected based on both agronomic and grain quality traits, and further evaluated in trials with 3 replications under aerobic soil conditions at CARDI, Bati, and Polors stations in the 2011 dry season (DS). From the 62 lines, 44 lines were selected and evaluated in similar trials at CARDI, Bati, and Prey Phau stations both in the 2011 WS and 2012 DS. In the 2012 WS, 31 lines were selected from the 44 and evaluated at the same stations. The trials were manually direct seeded with a seeding rate of 80 kg/ha. The plot was six 4-m rows 25 cm apart. The trials were fertilized at a rate of 60N:30P_2O_5:30K_2O with N in three equal splits and PK in one as basal. Soil was kept moist throughout the whole growing season by surface irrigation. Data collected each season from the 3 sites were analyzed combinedly (yield in the 2012 DS included Bati and Prey Pdau sites only).

Table 1. Means of aerobic rice lines across three sites CARDI, Bati, and Prey Pdau in the dry (DS) and wet (WS) seasons of 2012 and the WS of 2011

Line	Days to flowering 2012WS (d)	Plant height 2012WS (cm)	Yield 2012WS (t/ha)	Yield 2012DS (t/ha)	Yield 2011WS (t/ha)	Yield overall mean (t/ha)
IR 78936-B-9-B-B-B	74	94	4.4	4.7	4.5	4.5
IR 80013-B-141-4-1	76	101	4.5	3.9	4.6	4.3
IR 66	71	90	4.1	4.3	4.6	4.3
IR 07L122	71	106	4.6	3.8	4.3	4.2
IR 06G113	76	93	3.8	4.5	4.2	4.1
IR 05A235	75	99	4.3	3.9	4.1	4.1
IR 78875-207-B-1-B	76	105	4.9	3.0	4.3	4.1
CT 6510-24-1-2	74	98	4.3	3.4	4.5	4.1
IR 06L136	72	93	3.9	4.0	4.2	4.0
IR 06L167	71	105	4.1	3.8	4.1	4.0
IR 06L141	78	91	4.1	3.9	4.1	4.0
Rumpe (CK)	71	86	4.2	3.5	4.4	4.0
IR 07L290	75	103	4.3	3.5	4.1	4.0
IR 05N412	81	97	4.3	3.5	4.2	4.0
IR 06L168	72	97	3.8	4.1	4.0	4.0
IR 69502-6-SRN-3-UBN-1-B	77	98	4.4	3.3	4.2	3.9
IRRI 154	78	96	4.3	3.2	4.2	3.9
IR 06L164	72	100	3.9	3.4	4.4	3.9
IR 81040-B-78-U 2-1	72	104	4.0	3.2	4.4	3.9
IR 06L129	71	99	3.7	3.5	4.4	3.9
IR 08L343	79	107	4.0	3.4	4.0	3.8
IR 78937-B-3-B-B-1	73	91	4.3	2.9	4.1	3.8
IR 04A393	73	101	3.9	3.1	4.2	3.7
IR 08L403	71	106	3.8	3.4	4.0	3.7
BP 223 E-MR-5	70	111	4.0	2.5	4.7	3.7
IR 03L120	72	101	4.0	3.0	4.2	3.7
IR 05A233	77	94	4.1	3.4	3.6	3.7
IR 04A305	74	99	3.9	2.6	4.4	3.7
IR 03L148	73	103	3.6	3.1	4.1	3.6
IR 05A139	83	102	4.1	2.3	4.2	3.6
IR 06L142	72	91	3.7	2.8	4.0	3.5
IR 07L166	72	99	3.7	2.5	4.2	3.5
$LSD_{0.05}$	1.1	3.9	0.4	0.33	0.47	

The analysis shows that IR78936-B-9-B-B-B performed well consistently across seasons and outyielded the reference Rumpe by 0.5 t/ha (12% higher) on average across seasons (Table 1). A few other lines like IR 80013-B-141-4-1, IR 66, and IR 07L122 showed promising. These lines mature in about 100-105 days under direct seeded conditions, and have a plant height of around 100 cm, thus have potential usage in uplands in the WS, and in lowlands with limited irrigation in the DS in Cambodia. The analysis also shows that there was a significant Genotype x Environment (data now shown), though the 3 testing sites are not geologically far, and that a few lines such as IR 78875-207-B-1-B and BP 223 E-MR-5 performed very differently across seasons, especially so between WS and DS (Figure 1). The reasons remain unclear, but perhaps it is because of a significant Genotype x Season for such genotypes, indicating that farmers may need to choose different cultivars to cultivate in different seasons.

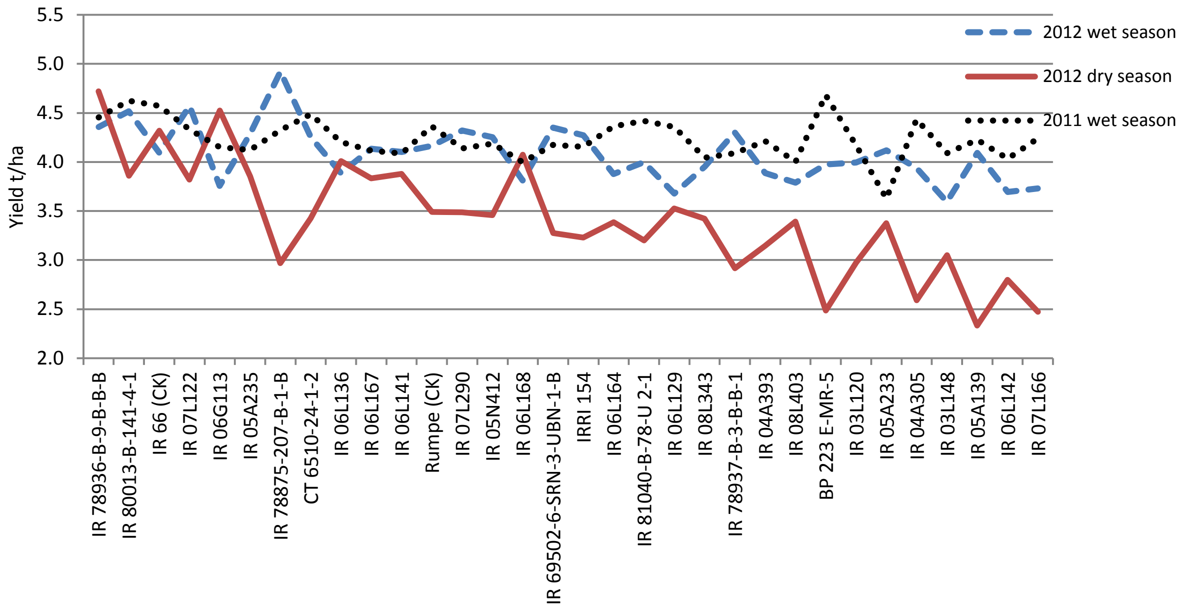

Figure 1. Yield means of aerobic lines across three sites CARDI, Bati, and Prey Pdau in the 2011 wet season, and 2012 dry and wet seasons.

In the 2013 WS, a subset of aerobic rice lines was evaluated in replicated trials at the same three stations to test their performance under aerobic and lowland conditions, respectively. The management of the aerobic trial was similar to the aforementioned, but the plot was increased to 10 m^2 and fertilizer rate to 100 kg/ha N, 40 kg/ha P_2O_5, and 40 kg/ha K^2O. The lowland trial was transplanted but seeded on the same date as for the aerobic trial, and with a row spacing of 20 cm. In the 2014 DS, the trial was repeated at four stations.

Analysis shows that these aerobic rice lines are all adapted to lowland conditions, and yielded higher under lowland conditions than under aerobic conditions in most cases (Table 2 and 3). A common phenomenon is that all these lines have a 4-10-day shorter growth duration under directed seeded aerobic conditions than under transplanted lowland conditions (Tables 2 and 3). The longer growth duration under transplanting regime may result from transplanting shock. IR 06L164 consistently performed well under both aerobic and lowland conditions across dry and wet seasons.

Table 2. Overall means of aerobic rice lines tested under both aerobic and lowland soil conditions across three sites Bati, CARDI, and Prey Pdau stations in the wet season of 2013

Line	Aerobic conditions (3 sites)			Lowland conditions (3 sites)			Difference (aerobic-lowland)		
	Days to flowering (d)	Height (cm)	Yield (t/ha)	Days to flowering (d)	Height (cm)	Yield (t/ha)	Days to flowering (d)	Height (cm)	Yield (t/ha)
IR 06L136	73	94	4.5	80	100	4.0	-8	-6	0.4
IR 06L164	73	101	4.3	81	101	4.2	-9	1	0.1
IR 81040-B-78-U 2-1	71	109	4.3	81	108	3.6	-10	1	0.7
IR 06L141	77	99	4.1	85	97	4.1	-8	2	0.0
IR 06L167	71	106	4.0	79	107	4.8	-8	-1	-0.8
IR 69502-6-SRN-3-UBN-1-B	78	98	3.8	85	100	4.5	-7	-2	-0.7
Chul'sa (check)	68	89	3.8	78	87	3.7	-9	2	0.0
Rumpe (check)	72	85	3.6	80	90	3.3	-8	-6	0.3
$LSD_{0.05}$	2.3	4.0	0.8	1.3	3.5	0.8			

Table 3. Overall means of aerobic rice lines tested under both aerobic and lowland soil conditions across four sites Bati, Prey Pdau, Kampot and Prey Veng stations in the dry season of 2014.

Line	Aerobic conditions (4 sites)			Lowland conditions (4 sites)			Difference (Aerobic-Lowland)		
	Days to flowering (d)	Height (cm)	Yield (t/ha)	Days to flowering (d)	Height (cm)	Yield (t/ha)	Days to flowering (d)	Height (cm)	Yield (t/ha)
IR 06L136	73	91	3.6	79	97	4.6	-7	-6	-1.0
IR 06L141	81	85	3.6	86	90	4.3	-5	-5	-0.6
IR 06L164	75	96	4.1	81	95	4.9	-6	1	-0.8
IR 06L167	72	94	4.0	80	101	4.3	-8	-7	-0.2
IR 69502-6-SRN-3-UBN-1-B	80	92	3.6	85	95	4.3	-5	-3	-0.7
IR 81040-B-78-U 2-1	74	97	3.7	81	103	4.2	-7	-6	-0.5
Rumpe (check)	73	87	3.7	79	90	4.4	-7	-4	-0.7
Chul'sa (check)	69	79	3.7	73	82	4.1	-4	-2	-0.3
$LSD_{0.05}$	4	5	0.7	4	5	0.4			

2. Screening for early maturing cultivars for dry season cultivation in Cambodia

Eight hundred and two lowland, rainfed and aerobic lines imported from IRRI in 2010 were firstly evaluated under lowland conditions at CARDI in the 2010 WS. 114 lines were then selected based on agronomic traits and evaluated in two groups (early and medium, based on growth duration) in 3-replicate trials at three stations (CARDI, Bati, Polors) in the 2011 DS. 66 lines were further selected on both agronomic and grain quality traits and evaluated in the similar trials at three stations (CARDI, Bati, and Prey Pdau) in the 2011 WS. 13 most promising lines were then identified and advanced to mulilocation testing on a large scale for three consecutive seasons. The testing sites were 9 in three provinces (Phnom Penh, Takeo, and Prey Veng) in the 2012 DS, 13 in five provinces (Phnom Penh, Takeo, Prey Veng, Kampot, and Kampong Thom) in the 2012 WS, and 16 in the same five provinces in the 2013 DS. These varietal trials were either transplanted or direct-seeded (broadcast), had 3 replications with 10 m^2 plots, and were fertilized at a NPK rate of 60, 30, 30 kg/ha, respectively. Data analysis includes successful trials only.

Six lines, IR 03L148, IR 04N155, IR 06L164, IR 07L167, IR 77674-3B-8-2-2-8-2-4, and IR 83415-B-SDO3-3-AJY1, were selected based on the agronomic and quality traits, multiplied in the 2013 WS, and were promoted to On-farm Adaptive Trials (OFAT) in the 2014 DS for varietal release. Briefly, these lines are early maturing (about 100 days) and short (about 100 cm), significantly outyield local references (Table 4), and possess acceptable grain quality characteristics (Table 5).

After being tested in more than 160 OFATs across dry and wet seasons of 2014, two lines were officially released for the irrigated system by CARDI in 2015. They were IR 06L164 (named as CAR14) and IR 04N155 (named as CAR15).

Table 4. Overall means of early lines evaluated in 3-replicated trials under irrigated conditions at a number of sites in three dry (DS) and wet (WS) seasons in 2012-2013 in five provinces Phnom Penh, Takeo, Kampot, Kampong Thom, and Prey Veng

	2013 DS, across 12 sites					2012 WS, across 8 sites					2012 DS, across 9 sites		
Line	DTF† (d)	HT (cm)	Yield (t/ha)	>IR504	>Chul'sa	DTF (d)	HT (cm)	Yield (t/ha)	>IR504	>Chul'sa	DTF (d)	HT (cm)	Yield (t/ha)
IRRI 148	66	95	4.3	33%	24%	68	98	4.1	5%	-8%	67	93	3.9
IR 07L167	71	99	4.3	32%	23%	71	102	4.5	16%	2%	71	95	4.2
IR 03L148	69	99	4.3	31%	22%	72	102	4.7	20%	5%	NA‡	NA	NA
IR 77674-3B-8-2-2-8-2-4	69	92	4.2	28%	19%	69	95	4.2	7%	-6%	72	88	3.6
IR 06L158	69	98	4.1	27%	18%	69	102	4.3	11%	-3%	NA	NA	NA
IR 04N155	69	95	4.0	24%	15%	71	97	4.8	23%	8%	69	94	4.3
OM 5796	69	88	4.0	23%	14%	69	93	3.9	1%	-11%	NA	NA	NA
OM 2718	66	87	3.9	20%	11%	69	91	4.4	12%	-2%	67	84	4.3
IR 06L164	70	94	3.8	17%	9%	69	94	4.5	17%	2%	NA	NA	NA
IR 83415-B-SDO3-3-AJY1	69	89	3.8	17%	9%	69	91	4.4	14%	0%	71	83	4.1
IR 73678-6-9-B	65	91	3.7	14%	6%	68	93	4.4	14%	0%	67	88	4
OM 3535	69	87	3.7	14%	6%	70	92	4.5	15%	1%	69	80	3.9
IR 06L132	67	92	3.5	8%	0%	68	93	4.4	14%	0%	67	92	4.4
Chul'sa (check)	67	85	3.5	8%	0%	69	86	4.4	14%	0%	69	81	4.5
IR 504 (check)	61	76	3.3	0%	-7%	64	87	3.9	0%	-12%	64	73	4.5
$LSD_{0.05}$	0.4	1.4	0.16			2.2	6.6	0.41			2.3	3.1	0.35

† DTF, days to flowering; HT, plant height; >IR504, percentage of yield over IR504; >Chul'sa, percentage of yield over Chul'sa.

‡ NA, not available.

Table 5. Grain quality characteristics of six promising lines for cultivation in Cambodia

Line	Chalkiness (%)	Grain shape (L/W)†	Amylose content (%)	Head rice (%)	Gelatinization Temperature‡	Gel consistency (mm)
IR 03L148	3	3.5	27.1	65.0	I/L	100
IR 04N155	28	3.3	25.7	67.6	HI/I	98
IR 06L164	6	3.4	25.6	65.8	HI/I	90
IR 07L167	2	3.5	24.7	69.2	I	100
IR 77674-3B-8-2-2-8-2-4	5	3.9	26.3	62.6	I/L	75
IR 83415-B-SDO3-3-AJY1	8	3.4	30.5	68.3	I	100
Chul'sa (check)	8	3.5	22.2	69.4	HI/I	90

† L/W, grain length/width

‡ H, high; I, intermediate; L, low.

Another set of 17 lines, selected from the second imported batch of 515 IRRI lowland and rainfed lines, were intensively tested in 2013-2014 (Table 6). 8 of them have been identified as the most promising lines based on their agronomic and grain quality traits (highlighted in Table 6 and 7). These lines are divided into 2 groups and each is being tested in 40 OFATs in Kampong Thom, Siem Reap, Battambang, and Pursat provinces in the 2015 WS for possible varietal release.

Table 6. Overall means of a second set of promising lines evaluated in on-station and on-farm trials in the dry and wet seasons of 2013-2014 in Cambodia. Highlighted lines are promoted to on-farm adapted trials for further testing in the 2015 wet season for varietal release.

	2013 wet season									2013 dry season					
	On-farm, 16 sites			Early set, 6 sites			Medium set, 6 sites			Early set, 4 sites			Medium set, 4 sites		
Line	DTF[†] (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IR 10L149	**71**	**94**	**5.1**	**75**	**95**	**4.7**	**NA**	**NA**	**NA**	**72**	**92**	**3.7**	**NA**	**NA**	**NA**
IR 87759-10-1-2-2	**72**	**94**	**5.1**	**NA**	**NA**	**NA**	**79**	**96**	**3.9**	**NA**	**NA**	**NA**	**80**	**95**	**3.6**
IR 87761-53-1-1-1	73	98	5.0	NA	NA	NA	79	92	4.3	NA	NA	NA	79	91	4.3
IR 04L186	**73**	**98**	**5.0**	**77**	**97**	**4.6**	**NA**	**NA**	**NA**	**75**	**94**	**3.5**	**NA**	**NA**	**NA**
IR 09A102	72	95	5.0	NA	NA	NA	79	92	4.1	NA	NA	NA	80	92	4.1
IR 87759-12-2-1-2	73	94	4.9	NA	NA	NA	79	93	4.2	NA	NA	NA	79	94	3.8
IR 87753-5-2-1-3	73	98	4.9	NA	NA	NA	79	97	4.5	NA	NA	NA	79	86	4.1
IR 87808-21-2-2-2	72	97	4.9	NA	NA	NA	80	95	4.3	NA	NA	NA	79	95	3.8
IR 87759-7-1-2-2	73	97	4.8	NA	NA	NA	79	97	4.3	NA	NA	NA	80	93	4.0
IR 87741-29-1-1-4	73	95	4.8	NA	NA	NA	79	95	4.3	NA	NA	NA	79	96	3.5
IR 87760-17-2-1-1	72	98	4.7	NA	NA	NA	79	95	4.2	NA	NA	NA	80	97	3.7
IR 87761-51-1-3-1	72	95	4.6	77	97	4.8	NA	NA	NA	76	95	3.2	NA	NA	NA
IR 87753-5-1-6-4	**72**	**97**	**4.6**	**77**	**99**	**4.8**	**NA**	**NA**	**NA**	**76**	**95**	**3.4**	**NA**	**NA**	**NA**
IR 09L337	**71**	**97**	**4.5**	**75**	**98**	**4.7**	**NA**	**NA**	**NA**	**72**	**93**	**3.5**	**NA**	**NA**	**NA**
IR 87747-16-1-1-1	**NA**	**NA**	**NA**	**77**	**96**	**4.6**	**NA**	**NA**	**NA**	**75**	**94**	**3.1**	**NA**	**NA**	**NA**
IR 87761-53-1-1-4	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**80**	**94**	**4.4**	**NA**	**NA**	**NA**	**80**	**90**	**4.2**
IR 87761-66-2-3-2	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**80**	**95**	**4.7**	**NA**	**NA**	**NA**	**80**	**95**	**3.6**
Chul'sa (check)	69	89	4.4	73	89	3.9	NA	NA	NA	70	88	3.4	NA	NA	NA
$LSD_{0.05}$	0.4	1.1	0.19	1.8	3.8	0.50	1.9	3.6	0.42	1.9	3.9	0.51	2.0	4.7	0.53

	2014 wet season									2014 dry season					
	OFAT, 25 sites			Direct seeding, 1 site			Transplanting, 1 site			On-farm, 16 sites			On-station, 6 sites		
Line	DTF[†] (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IR 10L149	**62**	**94**	**4.3**	**65**	**97**	**3.4**	**77**	**102**	**3.4**	**77**	**98**	**3.7**	**80**	**97**	**3.8**
IR 87759-10-1-2-2	**NA**	**NA**	**NA**	**67**	**95**	**3.6**	**83**	**105**	**3.3**	**79**	**99**	**4.0**	**84**	**95**	**4.1**
IR 87761-53-1-1-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IR 04L186	**62**	**92**	**4.0**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**79**	**100**	**4.0**	**84**	**97**	**3.8**
IR 09A102	NA	NA	NA	65	93	3.5	78	105	3.8	78	98	3.7	82	95	4.0
IR 87759-12-2-1-2	NA	NA	NA	67	94	3.3	83	107	3.6	80	99	3.9	82	98	3.8
IR 87753-5-2-1-3	NA	NA	NA	67	93	3.2	79	104	3.6	79	99	3.8	85	96	3.9
IR 87808-21-2-2-2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IR 87759-7-1-2-2	66	95	4.6	NA	NA	NA	NA	NA	NA	80	99	3.7	83	95	3.8
IR 87741-29-1-1-4	NA	NA	NA	66	91	3.1	77	97	3.0	80	101	3.8	83	98	3.9
IR 87760-17-2-1-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IR 87761-51-1-3-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	84	94	3.9
IR 87753-5-1-6-4	**64**	**95**	**4.3**	**66**	**97**	**3.7**	**81**	**105**	**3.3**	**79**	**100**	**4.0**	**83**	**97**	**3.9**
IR 09L337	**62**	**94**	**4.3**	**66**	**96**	**3.8**	**75**	**103**	**3.3**	**77**	**99**	**3.7**	**79**	**98**	**4.2**
IR 87747-16-1-1-1	**NA**	**NA**	**NA**	**67**	**94**	**3.6**	**78**	**106**	**3.2**	**NA**	**NA**	**NA**	**82**	**98**	**4.1**
IR 87761-53-1-1-4	**NA**	**NA**	**NA**	**69**	**93**	**3.8**	**84**	**99**	**3.4**	**79**	**98**	**3.9**	**82**	**91**	**3.9**
IR 87761-66-2-3-2	**66**	**96**	**4.7**	**66**	**96**	**3.7**	**78**	**102**	**3.4**	**80**	**99**	**4.0**	**83**	**94**	**3.7**

Chul'sa (check)	NA	NA	NA	64	90	3.7	75	93	3.7	72	86	3.6	74	84	4.0
$LSD_{0.05}$	0.4	1.1	0.21	2.4	6.4	0.88	1	7	0.55	1.1	2.2	0.28	2.8	4.0	0.35

† DTF, days to flowering; HT, plant height

Table 7. Grain quality characteristics of the second set of promising early lines. Highlighted are promoted to on-farm adaptive trials in the 2015 wet season for varietal release.

Line	Chalkiness (%)	Grain shape (L/W)†	Amylose content (%)	Head rice (%)	Gelatinization Temperature‡	Gel consistency (mm)
IR 04L186	**14**	**3.5**	**26.7**	**46.7**	**L**	**95**
IR 09A102	40	3.2	20.0	53.6	HI	94
IR 09L337	**6**	**3.5**	**20.1**	**59.5**	**HI/I**	**100**
IR 10L149	**7**	**3.7**	**25.4**	**36.1**	**L**	**100**
IR 87741-29-1-1-4	NA	NA	NA	NA	NA	NA
IR 87747-16-1-1-1	**22**	**3.6**	**19.1**	**51.2**	**HI**	**79**
IR 87753-5-1-6-4	**17**	**3.5**	**19.0**	**47.8**	**HI/I**	**97**
IR 87753-5-2-1-3	7	3.6	19.1	43.9	I	75
IR 87759-10-1-2-2	**21**	**3.5**	**20.1**	**50.2**	**I**	**94**
IR 87759-12-2-1-2	28	3.5	19.7	60.3	I	100
IR 87759-7-1-2-2	4	3.6	20.2	46.0	I	90
IR 87760-17-2-1-1	6	3.7	20.3	49.7	I	95
IR 87761-51-1-3-1	25	3.5	19.9	49.9	HI	94
IR 87761-53-1-1-1	33	3.5	28.8	43.3	I	94
IR 87761-53-1-1-4	**29**	**3.5**	**29.2**	**42.2**	**I**	**90**
IR 87761-66-2-3-2	**8**	**3.6**	**20.6**	**51.8**	**HI**	**70**
IR 87808-21-2-2-2	4	3.7	20.4	36.9	HI	100

† L/W, grain length/width
‡ H, high; I, intermediate; L, low.

Broadcasting pre-germinated seeds onto puddled soil is an establishment method that is widely used by Cambodian farmers. In one multilocation trial, we used both transplanting and broadcasting methods to establish the crops. Out of 12 successful trials in the DS 2013, 5 were transplanted and 7 broadcasted, while in the WS 2013, 8 trials were transplanted and 8 broadcasted. Analysis shows that compared with transplanting, broadcasting shortened the growth duration by 4 days in the DS and 12 days in the WS on average, but at a cost of yield deduction by 0.7 t/ha in the DS and 0.3 t/ha in the WS on average (Table 8 and 9). However, correlation analysis shows that correlation coefficient between the two establishment methods was 0.88 in days to flowering, 0.88 in plant height, and 0.66 in yield in the DS 2013, and correspondingly, 0.52, 0.66, and 0.81 in the WS 2013. These results indicate that the performance of a cultivar is quite consistent cross the two establishment methods, and that establishment methods may not affect the efficiency of varietal evaluation. It should be noted that this is just an approximate comparison of the two rice establishment methods, because the two types of trials were not arranged in the same or adjacent fields.

Table 8. Overall means across sites of early lines evaluated with different establishment methods (transplanting vs broadcast) under lowland conditions in 2013 dry season in Cambodia.

Line	Transplanting, across 5 sites			Broadcast, across 7 sites			Difference (Transplanting-Broadcast)		
	DTF† (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IRRI 148	69	96	5.2	64	94	3.7	5	1	1.5
IR 77674-3B-8-2-2-8-2-4	71	95	5.1	67	89	3.5	3	6	1.5
IR 07L167	72	98	4.9	70	99	3.9	2	-1	1.0
IR 06L158	72	99	4.8	68	97	3.6	4	3	1.2
IR 03L148	71	98	4.8	67	100	3.9	4	-2	0.9
IR 04N155	71	98	4.7	67	93	3.6	4	5	1.1
OM 5796	71	92	4.4	67	85	3.7	5	7	0.7
OM 2718	68	87	4.3	65	87	3.6	3	0	0.7
IR 73678-6-9-B	68	94	4.1	63	89	3.4	5	5	0.7
IR 06L164	73	96	4.0	68	93	3.7	5	3	0.4
OM 3536	73	88	4.0	67	87	3.5	6	0	0.5
IR 83415-B-SDO3-3-AJY1	70	94	3.9	67	85	3.7	3	9	0.2
Chul'sa (check)	71	86	3.7	65	84	3.4	6	2	0.3
IR 06L132	69	93	3.7	66	90	3.4	4	3	0.3
IR 504 (check)	65	75	3.3	59	76	3.2	6	-1	0.1
Mean	70	93	4.3	66	90	3.6	4	3	0.7
$LSD_{0.05}$	0.6	1.9	0.15	0.5	1.9	0.25			

† DTF, days to flowering; HT, plant height

Table 9. Overall means across sites of early lines evaluated with different establishment methods (transplanting vs broadcasting) under lowland conditions in the 2013 wet season in Cambodia.

Line	Transplanting Across 8 sites			Broadcasting Across 8 sites			Difference (Transplanting-Broadcasting)		
	DTF† (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)	DTF (d)	HT (cm)	Yield (t/ha)
IR 87761-53-1-1-1	79	100	5.2	66	96	4.9	13	3	0.4
IR 87759-10-1-2-2	78	99	5.2	66	89	5.0	12	10	0.2
IR 87808-21-2-2-2	78	101	5.1	66	93	4.6	12	9	0.6
IR 87753-5-2-1-3	78	102	5.1	68	94	4.7	11	8	0.4
IR 10L149	76	97	5.1	65	91	5.0	11	7	0.1
IR 87759-12-2-1-2	79	99	5.1	67	89	4.7	12	10	0.4
IR 09A102	78	99	5.1	66	91	4.9	12	7	0.2
IR 04L186	78	104	5.0	68	93	5.0	10	11	0.1
IR 87741-29-1-1-4	78	100	4.9	68	91	4.6	11	10	0.3
IR 87759-7-1-2-2	79	102	4.9	67	91	4.7	12	11	0.2
IR 87760-17-2-1-1	79	104	4.8	65	92	4.5	13	12	0.3
IR 87753-5-1-6-4	78	102	4.8	66	92	4.4	12	10	0.4
IR 09L337	76	103	4.8	67	91	4.2	10	11	0.6

IR 87761-51-1-3-1	79	100	4.8	65	90	4.5	13	10	0.3
Chul'sa (check)	75	94	4.6	64	85	4.3	11	9	0.3
Mean	78	100	5.0	66	91	4.7	12	9	0.3
$LSD_{0.05}$	0.5	1.9	0.3	0.5	1.3	0.2			

† DTF, days to flowering; HT, plant height

3. Improving drought tolerance and grain quality of local varieties

Backcross (BC) populations were developed at CARDI to improve the drought tolerance of Phka Rumduol, a famous Cambodian jasmine rice variety, and to improve the grain quality of CAR3, a local variety with drought tolerance. 180 $BC_{3\text{-}4}F_4$ (Phka Rumduol/CAR3, CIR827) and BC_3F_6 (CAR3/Phka Rumduol, CIR792) populations were screened for drought tolerance in the 2011 DS. 131 selected plants from the drought screening were developed into lines under rainfed conditions for selection on agronomic traits in the 2011 WS. 58 lines selected from the 131 were then evaluated in replicated trials under both lowland and drought conditions in the 2012 WS. From the 58 lines, 28 were selected based on their field performance under both conditions and their quality traits, and further evaluated under lowland, drought, and aerobic conditions in the 2013 WS.

Analysis shows that some lines with Phka Rumduol as recurrent parent (e.g. CIR 827-2-4-B-5-1-1-27-1-2, CIR 827-21-23-B-5-7-47-1-13-3-1, CIR 827-13-15-B-3-3-1-29-1-5) outyielded Phka Rumduol under either lowland or drought or aerobic conditions (Table 10), but were similar to Phka Rumduol in grain quality (Table 11). Some lines with CAR3 as recurrent parent (e.g. CIR 792-19-3-3-105-1-B, CIR 792-6-2-5-57-16-B-2) were similar to CAR3 in agronomic performance (Table 10), but possessed improved grain quality (Table 11). Out of the 28 lines, 13 promising lines were selected and further evaluated in multilocation trials under both rainfed and drought conditions at 4 sites in the WS 2014. Finally, 5 most promising lines with high yield potential, drought tolerance, and good grain quality have been identified (Table 12) and are being tested in 40 OFATs in 4 provinces Kampong Thom, Siem Reap, Battambang, and Pursat in the 2015 WS for possible varietal release.

Table 10. Agronomic traits of 28 backcross lines evaluated under aerobic, lowland, and lowland drought conditions at CARDI in the 2013 wet season

Line	Aerobic conditions				Lowland conditions				Lowland drought conditions			
	DTF† (d)	HT (cm)	YLD (t/ha)	>PRD	DTF (d)	HT (cm)	YLD (t/ha)	>PRD	DTF (d)	HT (cm)	YLD (t/ha)	>PRD
CAR3 (ck)	108	154	3.3	-7%	121	132	3.3	14%	122	115	2.1	43%
CIR 792-19-3-3-105-1-B	101	148	4.0	13%	109	127	3.2	9%	109	110	2.1	45%
CIR 792-19-3-3-105-21-B-2	103	157	3.3	-4%	109	127	3.7	26%	110	112	2.0	34%
CIR 792-6-2-5-57-119-B	103	155	2.5	-30%	111	131	3.1	8%	115	104	2.0	35%
CIR 792-6-2-5-57-16-B-2	106	144	3.6	2%	111	129	3.0	2%	115	106	2.0	38%
CIR 827-13-15-B-3-3-1-29-1-1	106	150	3.4	-2%	110	122	1.9	-34%	122	105	1.3	-10%
CIR 827-13-15-B-3-3-1-29-1-5	105	153	3.8	10%	117	133	3.0	2%	116	94	1.9	26%
CIR 827-13-15-B-3-3-1-29-3-4	106	148	3.4	-4%	118	128	2.7	-9%	116	111	1.8	20%
CIR 827-15-17-B-4-4-1-32-2-3	104	157	3.5	-1%	113	129	2.8	-6%	117	112	1.4	-3%
CIR 827-16-18-B-3-5-30-2-10-1-1	105	167	3.8	8%	113	130	2.2	-25%	109	119	1.5	-1%
CIR 827-16-18-B-3-5-30-2-10-1-2	112	161	3.0	-15%	120	133	2.7	-9%	119	113	1.9	29%
CIR 827-16-18-B-3-5-30-2-10-1-3	88	140	2.8	-20%	98	125	1.9	-36%	100	113	1.2	-18%
CIR 827-16-18-B-3-5-30-2-10-2-4	107	162	3.1	-10%	117	127	3.0	2%	114	110	1.6	9%
CIR 827-21-23-B-2-6-1-36-1-2	106	157	2.9	-18%	120	124	2.4	-17%	116	115	1.5	2%
CIR 827-21-23-B-5-7-47-1-13-1-4	95	150	3.3	-5%	117	119	2.5	-15%	111	107	1.6	9%
CIR 827-21-23-B-5-7-47-1-13-2-2	90	135	3.4	-4%	99	112	2.7	-6%	101	90	1.5	-2%
CIR 827-21-23-B-5-7-47-1-13-2-4	103	152	3.2	-10%	108	120	2.3	-22%	114	105	1.8	20%
CIR 827-21-23-B-5-7-47-1-13-3-1	103	159	3.6	2%	113	134	3.3	14%	114	114	1.8	20%
CIR 827-21-23-B-5-7-47-1-13-4-1	86	143	2.2	-37%	99	102	2.0	-32%	99	97	0.7	-51%
CIR 827-21-23-B-5-7-47-1-13-4-3	103	155	3.8	9%	113	125	2.8	-5%	115	100	1.5	0%
CIR 827-23-25-B-4-8-53-1-15-1-3	94	144	3.3	-5%	100	120	2.8	-5%	100	113	1.6	9%
CIR 827-2-4-B-5-1-1-27-1-2	103	159	4.4	25%	104	126	3.4	17%	104	114	2.3	55%
CIR 827-25-27-B-2-9-56-1-18-1-4	105	155	3.2	-9%	104	123	2.9	-1%	107	111	1.7	15%
CIR 827-25-27-B-2-9-56-6-23-1-3	92	142	2.9	-18%	98	116	1.8	-40%	99	103	1.4	-7%
CIR 827-25-27-B-2-9-56-6-23-1-4	107	163	3.1	-11%	118	129	2.4	-17%	117	115	1.4	-6%
CIR 827-4-6-B-4-2-1-28-1-3	105	142	3.4	-4%	110	117	3.0	4%	110	102	1.8	20%
CIR 827-4-6-B-4-2-1-28-3-1	107	153	3.7	6%	116	128	2.6	-12%	116	111	1.8	23%
CIR 827-4-6-B-4-2-8-1-1-1-1	100	148	3.7	7%	106	118	2.6	-13%	108	109	1.7	13%
CIR 827-4-6-B-4-2-8-1-1-1-2	100	150	2.9	-17%	109	113	2.1	-27%	109	104	2.0	32%
Phka Rumduol (check)	99	157	3.5	0%	105	123	2.9	0%	108	105	1.5	0%
LSD0.05	2	13	0.7		5	9	0.9		2	9	0.5	

† DTF, days to flowering; HT, plant height; YLD, grain yield; >PRD, percentage in yield more than Phka Rumduol.

Table 11. Grain quality traits of 28 backcross lines evaluated at CARDI

Line	Length (mm)	L/W†	GT	GC (mm)	AC (%)	Chalk	Aroma	Softness	Stickiness	Taste	Acceptability
CAR3 (check)	6.4	2.7	I	55	22.5	high	No?	3	3	3	3
CIR 792-19-3-3-105-1-B	6.5	2.7	HI	93	13.8	high	No?	3	2	3	3
CIR 792-19-3-3-105-21-B-2	6.3	2.6	HI	79	17.1	high	No?				
CIR 792-6-2-5-57-119-B	6.5	2.7	HI	75	16.9	high	No?				
CIR 792-6-2-5-57-16-B-2	6.5	2.7	HI	95	13.1	high	Yes?	2	2	2	2
CIR 827-13-15-B-3-3-1-29-1-1	7.0	3.2	I/L	88	12.5	Low	No?	2	2	2	2
CIR 827-13-15-B-3-3-1-29-1-5	7.2	3.5	I/L	86	18.5	Low	No?				
CIR 827-13-15-B-3-3-1-29-3-4	7.1	3.4	I/L	89	15.6	Low	No?				
CIR 827-15-17-B-4-4-1-32-2-3	7.1	3.4	I/L	74	19.9	Low	No?				
CIR 827-16-18-B-3-5-30-2-10-1-1	7.1	3.4	I/L	85	17.1	Low	No?				
CIR 827-16-18-B-3-5-30-2-10-1-2	7.0	3.4	I	70	14.5	Low	No?	3	3	3	3
CIR 827-16-18-B-3-5-30-2-10-1-3	7.1	3.4	L	90	17.4	Low	No?				
CIR 827-16-18-B-3-5-30-2-10-2-4	6.9	3.3	HI	85	14.4	Low	No?				
CIR 827-21-23-B-2-6-1-36-1-2	6.9	3.3	HI/L	89	13.5	Low	No?				
CIR 827-21-23-B-5-7-47-1-13-1-4	7.1	3.4	L	80	14.8	Low	No?				
CIR 827-21-23-B-5-7-47-1-13-2-2	6.4	3.2	I/L	84	13.6	Low	No?				
CIR 827-21-23-B-5-7-47-1-13-2-4	7.1	3.5	HI	83	15.5	Low	No?				
CIR 827-21-23-B-5-7-47-1-13-3-1	7.1	3.5	I	86	14.0	Low	Yes	3	3	2	2
CIR 827-21-23-B-5-7-47-1-13-4-1	6.7	3.2	I/L	64	14.3	Low	No?				
CIR 827-21-23-B-5-7-47-1-13-4-3	7.1	3.4	I	71	15.8	Low	No?				
CIR 827-23-25-B-4-8-53-1-15-1-3	7.1	3.3	I	69	24.6	Low	No?				
CIR 827-2-4-B-5-1-1-27-1-2	7.0	3.3	I	76	15.7	Low	No?	3	3	3	3
CIR 827-25-27-B-2-9-56-1-18-1-4	7.2	3.5	I/L	65	13.7	Low	Yes				
CIR 827-25-27-B-2-9-56-6-23-1-3	7.0	3.3	I/L	69	14.8	Low	No?				
CIR 827-25-27-B-2-9-56-6-23-1-4	7.1	3.3	HI/L	83	13.1	Low	Yes				
CIR 827-4-6-B-4-2-1-28-1-3	7.0	3.2	I	77	15.3	Low	No?	2	2	3	3
CIR 827-4-6-B-4-2-1-28-3-1	7.0	3.1	I	82	15.7	Low	No?	2	2	2	2
CIR 827-4-6-B-4-2-8-1-1-1-1	7.1	3.4	I	63	13.6	Low	Yes	2	2	2	2
CIR 827-4-6-B-4-2-8-1-1-1-2	6.7	3.2	I	72	14.3	Low	Yes				
Phka Rumduol (check)	7.0	3.4	I	65	13.7	Low	Yes	2	2	2	2

† L/W, ration of grain length over width; GT, gelatinization temperature; GC, gel consistence; AC, amylose content.

Table 12. Means of 5 elite backcross lines tested in multilocation trials under rainfed lowland and drought conditions in the 2014 wet season in Cambodia

	Rainfed lowland (4 sites)				Drought (4 sites)	
Lines	DTF (d)	Height (cm)	Yield (t/ha)	>PRD	Yield (t/ha)	>PRD
CIR 827-4-6-B-4-2-1-28-3-1	116	133	4.5	20%	3.9	22%
CIR 827-13-15-B-3-3-1-29-1-5	116	133	4	8%	3.7	16%

CIR 827-2-4-B-5-1-1-27-1-2	111	127	4.1	9%	3.7	15%
CIR 827-21-23-B-5-7-47-1-13-1-4	114	129	4.3	16%	3.6	13%
CIR 827-21-23-B-5-7-47-1-13-4-3	114	128	4.2	12%	3.5	8%
Phka Rumduol (recurrent parent)	111	129	3.8		3.2	
$LSD_{0.05}$	3	5	0.5		0.4	

DTF: Days to flowering; >PRD: percentage of yield higher than Phka Rumduol

4. A glutinous variety released for the rainfed ecosystems in Cambodia

After testing in On-farm Adaptive Trials at a number of sites in 2011-2013 in three to four provinces, A glutinous lines previously selected by CARDI was released in December 2013 in Cambodia. The new cultivar, namely Damnoeb Sbai Mongkul, typically yields 3.1 t/ha (Table 13), is tall (150 cm) and photoperiod sensitive - flowering in the middle of November (Figure 2), and is moderately tolerant to both drought and flooding, thus can be widely grown in the wet season in Cambodia. It has big slender grain (thousand grain weight: 34g, milled grain length/width: 3.3), low gelatinization temperature, low amylose content (1.6%), and soft texture after cooking.

Breeder seed of this new variety has been produced and disseminated to 24 Provincial Department of Agriculture for seed production in the WS 2014.

Table 13. Yield of Damnoeb Sbai Mongkul evaluated in On-farm Adaptive Trials under rainfed conditions in the wet seasons of 2011-2013 in Cambodia

	2011 WS		**2012 WS**		**2013 WS**	
Trial No.	12		24		44	
Province	Kampong Thom Kampot Takeo		Battambang Prey Veng Takeo		Battambang Prey Veng Takeo Siem Reap	
Line	Damnoeb Sbai Mongkul	Local cultivars	Damnoeb Sbai Mongkul	Local Cultivars	Damnoeb Sbai Mongkul	Local cultivars
Yield (t/ha)	2.9±1.0	2.6±0.9	3.1±0.6	3.0±0.4	3.1±0.8	2.8±0.9
Range (t/ha)	1.3-3.9	1.2-3.9	2.0-4.2	2.0-3.9	1.7-4.4	0.8-4.0

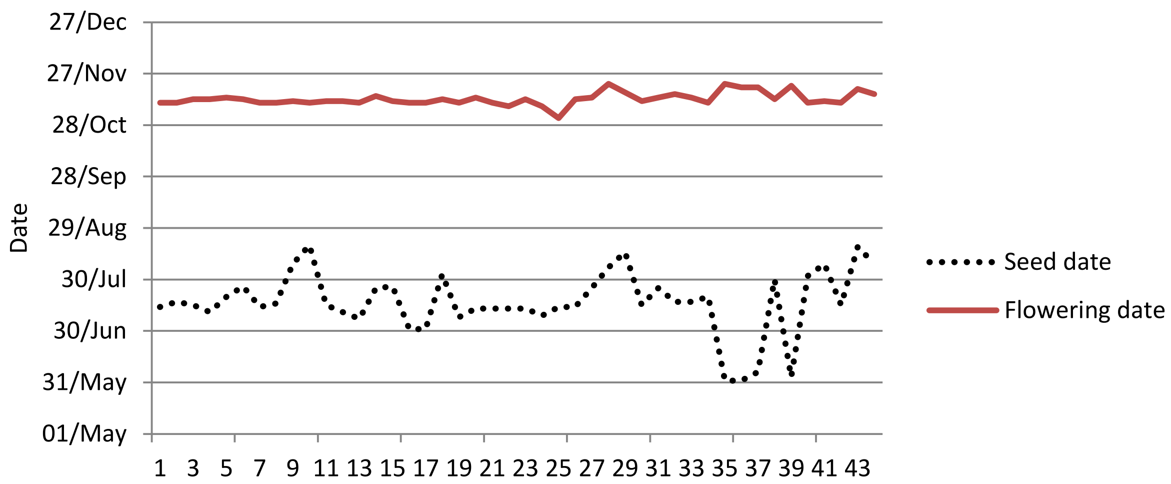

Figure 2. Relationship between seeding and flowering date from 80 On-farm Adaptive Trials in 2011-2013, showing consistent flowering time regardless seeding date.

5. New advanced breeding lines with short duration, drought tolerance, and aroma

The new breeding program targeting at short duration, drought tolerance, and aroma was initiated in 2011 at CARDI by the project. After continuous advancing and selection in 5 seasons, 67 F_6 lines were selected and evaluated in replicated trials under both lowland and drought conditions at CARDI in the WS 2014. Presence of aroma gene was verified by running Badh 2.1 marker for each F_6 line in CARDI's molecular lab. Harvested F_7 seeds of all lines underwent measurement of grain quality traits at IRRI. Finally, 23 promising lines were selected for further testing. These lines are mostly high-yielding under both lowland and drought conditions, carry aroma gene, have low chalkiness, and low to medium amylose content (Table 14). These lines are being evaluated in the multilocation trials in 4 provinces in the WS 2015.

Table 14. Means of F_6 (agronomic traits)/F_7 (quality traits) early lines evaluated in 2014-2015

Line	Parentage	DTF	HT	Yield	Yield (DT)	Aroma	Chalk	AC	GT	GC	Head rice
		d	cm	t/ha	t/ha		%	%			
CIR845-19-8-1-B	IR66/Sen Pidao	84	82	5.4	4.8	Segregating	18	21.8	L	100	44.4
CIR846-19-1-1-B	Rumpé/Sen Pidao	86	86	4.9	4.7	Fragrant	20	22.2	L	97	44.9
CIR846-19-1-2-B	Rumpé/Sen Pidao	86	91	4.8	4.8	Fragrant	9	15.4	L	80	45.8
CIR846-6-2-2-B	Rumpé/Sen Pidao	89	95	4.8	4.6	Fragrant	14	15.0	L	78	41.8
CIR847-17-2-3-B	Chul'sa/Sen Pidao	82	98	5.9	4.3	Segregating	6	16.5	L	85	40.2
CIR847-2-2-1-B	Chul'sa/Sen Pidao	86	91	5.3	5.7	Segregating	8	13.8	L	75	37.2
CIR847-25-2-1-B	Chul'sa/Sen Pidao	89	92	5.1	4.4	Fragrant	10	14.4	L	71	46.1
CIR847-8-2-2-B	Chul'sa/Sen Pidao	87	96	5.8	4.9	Segregating	8	14.5	I/L	98	49.1
CIR848-9-4-3-B	IR66/Phka Rumduol	85	91	4.8	4.8	Segregating	21	27.0	I/L	100	32.2
CIR848-9-4-6-B	IR66/Phka Rumduol	84	90	6.3	5.0	Segregating	14	22.3	L	100	40.8
CIR850-1-2-1-B	Sen Pidao/IR04L186	87	90	5.3	5.4	Fragrant	14	15.3	I	97	48.0
CIR850-1-2-2-B	Sen Pidao/IR04L186	86	95	5.5	5.8	Fragrant	20	15.3	I	89	45.1
CIR850-1-3-3-B	Sen Pidao/IR04L186	84	93	5.3	4.7	Fragrant	8	16.1	I/L	76	40.1
CIR850-7-2-1-B	Sen Pidao/IR04L186	82	95	5.8	4.8	Fragrant	22	26.9	L	75	42.8
CIR851-27-4-1-B	Sen Pidao/IR06L164	83	100	5.0	5.3	Fragrant	13	21.6	I/L	65	47.1
CIR851-3-2-4-B	Sen Pidao/IR06L164	85	99	5.4	4.9	Fragrant	16	22.3	seg	75	40.4

CIR851-6-5-1-B	Sen Pidao/IR06L164	84	96	5.0	5.0	Segregating	13	16.3	I/L	68	47.8
CIR851-8-5-1-B	Sen Pidao/IR06L164	86	99	5.3	2.8	Fragrant	10	21.0	L	68	45.3
CIR852-5-1-2-B	Sen Pidao/IRRI 154	88	92	5.0	4.7	Fragrant	3	14.9	I/L	66	49.3
CIR853-7-1-2-B	Sen Pidao/IR03L146	76	93	4.5	3.8	Fragrant	1	14.2	L	68	24.4
CIR853-7-2-1-B	Sen Pidao/IR03L146	78	101	4.5	4.8	Fragrant	0	14.6	I/L	72	39.5
CIR855-14-2-1-B	Sen Pidao/IR05A233	84	92	4.8	5.4	Segregating	6	16.5	I/L	83	34.1
CIR855-4-2-2-B	Sen Pidao/IR05A233	84	94	5.1	4.4	Segregating	10	14.8	I/L	69	43.5
Sen Pidao (check)		88	92	4.8	4.8						
$LSD_{0.05}$		1	7	1.1	2.1						

DTF: days to flowering; HT: plant height; Yield (DT): yield under drought conditions; AC: amylose content; GT: gelatinization temperature; GC: gel consistency

6. Screening for BPH tolerance/resistance

Screening for tolerance/resistance of brown plant hopper (BPH) at hot spots was performed every dry season in the whole life of the ACIAR breeding project. However, due to insufficient naturally-occurred population of BPH, field screening has never been successful since 2010. In 2014-2015, 16 most promising lines were screened for BPH resistance in a greenhouse at CARDI. The result shows that 4 out of 16 lines had moderate resistance to BPH (Table 15). Partly because of the BPH resistance of line IR04N155, it was officially released as a variety namely CAR15.

Table 15. Reaction of promising lines to brown plant hopper (2014-2015, CARDI)

Lines	R-I	R-II	R-III	Mean	Reaction to BPH
IR 07L167	7	9	9	9	HS
IR 77674-3B-8-2-2-8-2-4	9	9	9	9	HS
IR 03L148	5	5	3	5	MS
IR 04N155	**3**	**3**	**5**	**3**	**MR**
IR 06L164	9	9	9	9	HS
IR 83415-B-SD03-3-AJY1	**3**	**3**	**3**	**3**	**MR**
IR 04L186	**3**	**3**	**5**	**3**	**MR**
IR 09L337	7	7	9	7	S
IR 10L149	5	5	3	5	MS
IR 67014-45-3-1	7	7	9	7	S
IR 87747-16-1-1-1	9	9	9	9	HS
IR 87753-5-1-6-4	**3**	**3**	**3**	**3**	**MR**
IR 87759-10-1-2-2	7	7	7	7	S
IR 87761-53-1-1-4	9	9	9	9	HS
IR 87761-66-2-3-2	7	7	5	7	S
IR 87808-21-2-2-3	5	5	5	5	MS
Check1, Highly Susceptible (TN1)					
Check2, Moderately Resistant (IR-Kesar)					

11.2 Appendix 2: CARDI final report

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Summary

This final report described the main activities implemented and the achievement from wet season (WS) of 2010 until dry season (DS) of 2015. An enormous number of experiments have been conducted at many locations in both wet and dry seasons in CARDI, Takeo, Kampot and Prey Veng provinces as summarized in table below.

Type of trial	WS10	DS11	WS11	DS12	WS12	DS13	WS13	DS14
High quality	3 (3)		3 (3)	3 (3)	3 (3)	1 (2)	3 (3)	
Very early		1 (4)	1 (4)	2 (14)	2 (14)	1 (11)	2 (14)	
Early	3 (3)	1 (1)		1 (3)	1 (1)	1 (4)	1 (1)	2 (14)
Medium		1 (1)	1 (2)	1 (1)	1 (3)	1 (4)	1 (4)	
Aerobic	2 (3)	1 (1)	1 (1)	1 (1)	1 (1)		1 (2)	1 (2)
Drought		1 (1)	1 (1)					
Submergence	1 (2)		1 (1)		1 (1)			
BPH				1 (1)		1 (1)		1 (1)
POFAT			2 (70)		1 (32)		1 (44)	
Tested genotypes	14	283	252	442	296	154	105	86
Seed increase	231	177	615	85	100	102	57	73

A total of 1392 introduced breeding lines (2010: 866 lines from IRRI and 14 lines from Australia; 2011: 398 lines selected by Dule and Ratmuny, 56 BPH resistant lines, 51 lines from Dr Johnson and 21 lines from Dr Brar) were tested under different conditions at CARDI and targeted provinces during last two years. All introduced lines are mostly photoperiod insensitive maturing in a wide range from about 100 days to 150 days with dwarf to semidwarf plant type. In addition, 50 CARDI breeding lines and 88 INGER breeding lines (IRFAON=44, IIRON=44) were tested at CARDI since 2010 wet season.

Type of sources	WS2010	2011	Promising	Released
Aerobic	254		4	1
Lowland	383	398	8	1
Submergence	121			
INGER	88			
Basmati types	20		1	
Drought (D. Johnson)		51	1	
Elite lines (Brar)		21		
BPH		56		
Australia	14			
Existing	52			1
Total	932	526	14	3

A total of 73 populations have been developed and advanced for different objectives.
A total of 14 genotypes have been identified as promising genotypes for early maturity.
Five genotypes developed for quality and drought tolerance were selected as promising genotypes and they are 1. CIR792-19-3-3-105-1-B, 2. CIR827-13-15-B-3-3-1-29-3-4, 3. CIR827-21-23-B-5-7-47-1-13-1-4, 4. CIR827-21-23-B-5-7-47-1-13-4-3 and 5. CIR827-16-18-B-3-5-1-34-62-1.

In connection with the previous and PADEE projects, three rice varieties were released under this project and they are:

1) **Damnoeb Sbai Mongkul:** released in late 2014. It is a photoperiod late maturing variety that flowers within the second week of November with its average yield of 3.20 t/ha. The variety has a plant height in average of 150 cm, its panicle length of 29 cm and its 100 paddy grain weight of 3.40 g. Quality analysis using quality lab equipped by CSE/2009/005 project, Damnoeb Sbai Mongkul has low GT (6.5), soft GC (97.7) and 1.6% of amylose content. Its milled grain is slender with 7.0 mm in length and 2.1 mm in width.
2) **CAR14:** released in early 2015. The line (IR06L164) was developed by IRRI. CAR14 (CAR=Cambodian Rice) matures in 95 days, with 0.9 m in height. Its milled grain is 6.8 mm in length and 1.8 mm in width. Its amylose content is 18.6%. Its average grain yield is 4.2t/ha with potential up to 7.5 t/ha.
3) **CAR15:** released in early 2015. The line was developed by IRRI (IR05N155). CAR15 matures in 100 days, with 1.0 m in height. Its milled grain is 7.0 mm in length and 2.1 mm in width. Its amylose content is 21.6%. Its average grain yield is 4.0 t/ha with potential up to 7.4t/ha.

Objective 2: Strategic development and dissemination of improved rice germplasm for different agro-ecological rice systems in Cambodia

A total of 1458 introduced breeding lines (2010: 920 lines from IRRI and 14 lines from Australia; 2011: 398 lines selected by Dule and Ratmuny, 56 BPH resistant lines, 51 lines from Dr Johnson and 21 lines from Dr Brar) were tested under different conditions at CARDI and targeted provinces during last two years. All introduced lines are mostly photoperiod insensitive maturing in a wide range from about 100 days to 150 days with dwarf to semidwarf plant type. In additional, 44 CARDI breeding lines and 88 INGER breeding lines (IRFAON=44, IIRON=44) were tested at CARDI since 2010 wet season.

A total of 73 populations have been developed and advanced for different objectives. Six promising breeding lines identified by CARDI previous projects have been tested under famer’s management (pre-on farm trial).

Activity 2.1: Development and dissemination of suitable improved germplasm for rainfed lowlands either by introgression programs or evaluation of existing germplasm.

A2.1.1. Varietal improvement for drought tolerance
From drought screening at vegetative phase in dry season 2011, 70 progenies derived from BC_3F_4 and BC_3F_5 of (Phka Rumduol=PRD x CAR3) plants were selected and putting in the pots for dark room treatment. These progenies then were advanced to BC_3F_5 and BC_3F_6 in wet season 2011. Out of 70 progenies, only 39 progenies that are mostly stable and have good grain types were selected for drought trial in wet season 2011 (Table 1). Similarly, 19 BC_3F_6 progenies and one BC_3F_8 progeny (CAR3 x PRD) were selected for testing in wet season 2011 with former set.

Table 1. Varietal development for drought and quality of popular rainfed lowland rice varieties

Population number	Parent	Previous project	Selected 2011	Selected 2012	Selected 2013
1	Phka Romduol x CAR3	BC_3F_4	12	8	6
2	Phka Romduol x CAR3	BC_3F_5	27	16	6
3	CAR3 x Phka Romduol	BC_3F_6	18	4	1
4	CAR3 x Phka Romduol	BC_3F_8	1	0	0
Total selected			58	28	13

Twenty three BC_4F_2 and 53 BC_5F_2 progenies (PRD x CAR3) were generated in wet season 2011 (Table 2). These 76 progenies were advanced under upland drought conditions at CARDI in dry season 2012, from which 58 progenies with 169 breeding lines were selected in wet season 2012. In wet season 2013, these 169 genotypes were advanced in rainfed lowland conditions and 12 genotypes were selected based on plant performance and grain type similar to Phka Rumduol. Some of selected genotypes flowered about 2-3 weeks later than Phka Rumduol.

Table 2. Improvement of Phka Rumduol for drought tolerance.

Population number	Parent	Previous project	Advanced 2011	Advanced 2012	2013 Generation	2013 Selected
5	Phka Romduol x CAR3	BC_4F_1	23	45	6	11
6	Phka Romduol x CAR3	BC_5F_1	53	124	6	1
Total selected			76	169	12	12

Besides, two additional crosses between Phka Rumduol (PRD), Phka Chan Sen Sar (PCSS), and Riang Chey (RC, lodging resistance) were made to improve lodging resistance of PRD and PCSS in wet season 2011. Progenies were advanced to F_4 populations in wet season 2014 at CARDI with 46 progenies selected (PRD/RC=17, PCSS/RC=29).

In wet season 2012, a total of 58 breeding lines (see Table 1) were tested in rainfed lowland and upland (attempting to have drought) conditions at CARDI with two replications. Grain yield and day to maturity were analysed and laboratory testing was done for amylose content and gelatinization temperature. Base on the measured variates, a total of 28 breeding lines was selected.

In wet season 2013, the selected 28 lines were tested in three environments (rainfed lowland drought, rainfed lowland well watered and rainfed upland (aerobic condition) at CARDI. There was an effect of environment, genotype and genotype by environment for day to maturity and grain yield (Table 3, shows 13 selected genotypes). Rainfed lowland drought conditions reduced mean grain yield from 2.71 to 1.61 t/ha, while rainfed upland produced the highest mean grain yield of 3.35 t/ha. This is because of upland soil is high fertile (clay) than the lowland soil (sandy). All tested genotypes were milled and measurement were taken for grain length (MGL, mm), along with chemical properties and chalkiness using quality lab equipped by the project. Cooked rice was evaluated for 12 genotypes. A total of 13 genotypes were selected.

In addition, 13 selected genotypes were further tested in multi-location trials in the wet season 2014 (8 environments outside CARDI and 3 environments in CARDI). Four of those genotypes (G2. CIR792-19-3-3-105-1-B, G8.CIR827-13-15-B-3-3-1-29-3-4, G15. CIR827-

21-23-B-5-7-47-1-13-1-4 and G20. CIR827-21-23-B-5-7-47-1-13-4-3) have been identified for further testing in pre on-farm adaptive trial in wet season 2015 in IRRI-USAID project.

Table 3. Grain yield and grain quality performance of drought population for wet season.

No	Genotype	Day to maturity (day)				Grain yield (t/ha)				MGL	Chemical property				Cooking quality			
		RLD	RLW	RU	Mean	RLD	RLW	RU	Mean	(mm)	GT	GC	AC	CK	Soft	Stick	Taste	Acp
30	PRD (Recipient)	138	135	129	134	1.40	2.81	3.38	2.53	7.0	I	65	13.7	2	2	2	2	2
18	CIR 827-21-23-B-5-7-47-1-13-3-1	144	143	133	140	1.67	3.10	3.44	2.74	7.1	I	86	14.0	6	3	2	2	2
28	CIR 827-4-6-B-4-2-8-1-1-1-1	138	137	130	135	1.67	2.38	3.81	2.62	7.1	I	63	13.6	11	2	2	2	2
27	CIR 827-4-6-B-4-2-1-28-3-1	146	147	136	143	1.78	2.47	3.67	2.64	7.0	I	82	15.7	0	2	2	2	2
22	CIR 827-2-4-B-5-1-1-27-1-2	134	134	133	134	2.22	3.35	4.48	3.35	7.0	I	76	15.7	7	3	2	3	3
7	CIR 827-13-15-B-3-3-1-29-1-5	146	147	135	143	1.78	2.90	3.89	2.85	7.2	L	86	18.5	2				
23	CIR 827-25-27-B-2-9-56-1-18-1-4	137	134	135	135	1.67	2.90	3.13	2.57	7.2	L	65	13.7	4				
15	CIR 827-21-23-B-5-7-47-1-13-1-4	141	147	125	138	1.51	2.38	3.57	2.49	7.1	L	80	14.8	1				
20	CIR 827-21-23-B-5-7-47-1-13-4-3	145	143	133	140	1.44	2.62	3.82	2.63	7.1	I	71	15.8	8				
8	CIR 827-13-15-B-3-3-1-29-3-4	146	148	136	143	1.78	2.50	3.41	2.56	7.1	I	89	15.6	8				
11	CIR 827-16-18-B-3-5-30-2-10-1-2	149	149	142	147	1.81	2.72	2.94	2.49	7.0	I	70	14.5	3	3	2	3	3
26	CIR 827-4-6-B-4-2-1-28-1-3	140	139	135	138	1.73	3.26	3.54	2.84	7.0	I	77	15.3	10	2	2	3	3
9	CIR 827-15-17-B-4-4-1-32-2-3	147	143	134	141	1.27	2.79	3.67	2.57	7.1	L	74	19.9	4				
2	CIR 792-19-3-3-105-1-B	139	139	131	136	2.11	3.17	3.94	3.08	6.5	HI	93	13.8	35	3	2	3	2
1	CAR3 (Donor)	152	151	138	147	2.00	3.44	3.34	2.93	6.4	I	55	22.5	53	3	3	3	3
Environmental mean		141	140	132	138	1.61	2.71	3.35	2.56	RLD=rainfed lowland drought condition								
Environmental LSD 5%		2**	5**	2**	2**	0.46**	0.58**	0.65**	0.32**	RLW=rainfed lowland well watered condition								
Environment (E)		1**				0.19**				RU=rainfed upland								
Genotype (G)		2**				0.32**				GT=gelat. Temperature, GC=gel consistency								
G x E		**				**				AC=amylose content (%), CK=chalkiness (%)								

In addition, the selected 12 genotypes (see Table 2) were tested with 13 genotypes (see Table 1) in three environments at CARDI wet season 2014. One genotype (CIR827-16-18-B-3-5-1-34-62-1) was identified as promising for further testing in pre on farm adaptive trial in wet season 2015 in IRRI-USAID project.

A2.1.2. Varietal testing for glutinous rice

In 2006, CARDI evaluated more than 100 accessions of glutinous conserved at CARDI genebank and selected by pure line of 12 accessions for further testing. Four accessions were selected and then tested in pre-on-farm adaptive trials (POFAT) (Table 4) in 2011. Base on the results, three lines were eliminated. Line 6 (Damnoeb Krapeu, acc. 1166) was continuously tested in 2012 (24 sites) and 2013 (44 sites) using ACIAR-CSE/2009/005 project. Results obtained indicated that Line 6 yielded in average of 3.22 t/ha, and 68 out of 78 farmers preferred the most. This line was then released and named as Damnoeb Sbai Mongkul.

Table 4. Yield performance and farmer's first preference of glutinous lines

Line	`WS2011 (10)		WS2012 (24)		WS2013 (44)		Mean
	GY (t/ha)	1st pref.	GY (t/ha)	1st pref.	GY (t/ha)	1st pref.	
Line 6 (10)	3.0	6	3.21	20	3.27	42	3.22
Line 7 (10)	3.1	2					
Farmer variety (10)	2.8						
Line 1 (20)	2.6	9					
Line 4 (20)	2.3	2					
Farmer variety (20)	2.2						

Number in parenthesis indicates number of tested sites

Damnoeb Sbai Mongkul is a photoperiod late maturing variety that flowers within the second week of November with its average yield of 3.20 t/ha. The variety has a plant height in average of 150 cm, its panicle length of 29 cm and its 100 paddy grain weight of 3.40 g. Quality traits were analyzed using CARDI's quality lab equipped by CSE/2009/005 project, Damnoeb Sbai Mongkul has low GT (6.5), soft GC (97.7) and 1.6% of amylose content. Its milled grain is slender with 7.0 mm in length and 2.1 mm in width.

Activity 2.2: Development and dissemination of suitable improved germplasm with short duration

A2.2.1. Variety Improvement for grain quality and drought tolerance:
Four new populations were created to improve grain quality of popular early maturing varieties in wet season 2011 and advanced to F_5 generation in wet season 2013 with 119 selected progenies (IR66/SPD=41, Rumpe/SPD=32, Chul'sa/SPD=23 and IR66/PRD=23).

Six new crosses were generated using Sen Pidao, recipient, and six IRRI breeding lines (IR04L186, IR06L164, IRRI154, IR03L146, IR07L290 and IR05A233) as drought tolerant donors (base on Dr Zhao) in wet season 2011 and advanced to F_5 populations in wet season at CARDI with 127 progenies selected for further advancing (Table 5).

Table 5. Improvement of Sen Pidao for drought tolerance.

No	Parents		2011	2012		2013	
	Recipient	Donor	WS	DS	WS	DS	WS
1	Sen Pidao	IR 04L186	F_1	F_2	F_3=27	F_4=121	F_5=47
2	Sen Pidao	IR 06L164	F_1	F_2	F_3=27	F_4=101	F_5=36
3	Sen Pidao	IRRI 154	F_1	F_2	F_3=22	F_4=6	F_5=12
4	Sen Pidao	IR 03L146	F_1	F_2	F_3=21	F_4=66	F_5=16
5	Sen Pidao	IR 05A223	F_1	F_2	F_3=21	F_4=71	F_5=16
6	Sen Pidao	IR 07L290	F_1	F_2	0	0	0
	Total selected				118	365	127

A2.2.2. Varietal testing for short maturity
Set I. Two very early maturing lines selected from previous project were continued tested as pre-on farm trial in 30 locations (one failed as rat damaged in seed bed) in wet season 2011. None of line was outyielded that farmer's varieties but OM3536 matured relatively earlier hence half of farmers preferred it (only 19 farmers providing preference) (Table 6). However, both lines have high chalkiness, therefore both were terminated in further tesing.

Table 6. Day to maturity (DTM), yield and first farmer's preference of POFAT-very early

Genotype	DTM (Days)		Yield (t/ha)		First
	Mean	Range	Mean	Range	preference
OM3536	96±6	79-109	3.4±0.7	2.1-4.3	10
CNTLR85033-9-3-1-1	102±6	84-112	3.4±0.7	2.4-4.8	5
Farmer's varieties	101±9	87-117	3.3±0.7	1.6-4.6	4

Set II. This set composes of nine lines tested with 2 checks in 25 environments in dry season 2012 at 9 environments (CARDI=2, Prey Veng=3 and Takeo=5), wet season 2012 at 10 environments (CARDI=2, Prey Veng=3 and Takeo=5), and dry season 2013 at 6 environments (CARDI=2 and Prey Veng=5). There were effects of environment, genotype and their interaction for day to maturity, plant height and grain yield (Table 7). Stability analysis shows that there is no tested genotype performed in grain yield better than Chul'sa. However, base on the other performance, four genotypes have been identified as promising.

Table 7. Performance of tested genotypes in mean day to maturity (MDTM), mean grain yield (MGY, t/ha) and their yield stability from lowest to highest yielding environments (highlighted: promising genotypes).

Genotype	MDTM	MGY	E18	E14	E13	E19	E20	E10	E1	E6	E5	Mean
Chul'sa	96	3.86	0.21	0.17	0.20	0.54	-0.08	-0.10	0.40	0.85	1.00	0.22
IR 04N155	**99**	**3.80**	**0.00**	**0.09**	**-0.08**	**0.31**	**0.51**	**0.62**	**0.24**	**0.31**	**-0.29**	**0.16**
IR 83415	**99**	**3.75**	**0.46**	**-0.19**	**-0.02**	**0.45**	**0.20**	**-0.15**	**-0.61**	**0.22**	**-0.14**	**0.11**
IR 07L167	**100**	**3.70**	**-0.29**	**0.30**	**0.27**	**-0.19**	**0.16**	**0.55**	**0.42**	**-0.25**	**-0.36**	**0.06**
IR 06L132	97	3.69	0.36	0.08	-0.17	-0.08	0.01	-0.07	0.44	0.57	0.64	0.05
OM 2718	96	3.67	0.12	0.32	0.20	-0.19	-0.19	-0.15	0.77	0.27	-0.18	0.03
OM 3536	99	3.57	0.16	-0.44	-0.19	-0.19	0.10	-0.26	-0.86	-0.93	-0.07	-0.07
IR504	93	3.55	-0.37	0.00	-0.26	-0.37	-0.18	-0.12	0.36	0.86	0.60	-0.09
IRRI 148	96	3.55	-0.41	0.19	0.39	-0.03	-0.31	-0.14	-0.40	-0.38	-0.48	-0.09
IR 73678	97	3.47	-0.30	-0.60	-0.17	-0.12	-0.36	-0.19	0.04	-0.34	-0.04	-0.17
IR 77674	**99**	**3.39**	**0.01**	**0.08**	**-0.14**	**-0.18**	**0.15**	**0.01**	**-0.85**	**-1.23**	**-0.68**	**-0.25**
EMGY (t/ha)	97	3.64	1.92	1.98	2.20	2.79	3.19	3.95	4.17	4.78	6.91	3.64

Combined	Day to maturity (day)	Plant height (cm)	Grain yield (t/ha)
Environment (E)	1.6**	3.1**	0.34**
Genotype (G)	0.4**	1.5**	0.11**
GxE	**	**	**

Set III. This set was tested in 15 environments in wet season 2012 at 9 environments (CARDI=1, Prey Veng=3 and Takeo=5) and in dry season 2013 at 6 environments (CARD=2 and Prey Veng=4). There were 13 tested genotypes with two checks. Table 8 shows mean day to flowering and mean grain yield across environments and stability of grain yields of each genotypes in the lowest to highest yield environments. Three tested genotypes performed higher grain yield than Chul'sa, but only one was selected as promising because of it grain quality. Another genotype, performed comparable to Chul'sa was also identified as promising.

Table 8. Performance of tested genotypes in mean day to maturity (MDTM), mean grain yield (MGY, t/ha) and their yield stability from lowest to highest yielding environments (highlighted: promising genotypes).

Gen	MDTM	MGY	E9	E4	E10	E14	E2	E8	E6	Mean
IR 03L148	**99**	**3.55**	**-0.01**	**0.06**	**0.07**	**0.29**	**0.27**	**0.33**	**0.22**	**0.17**
IR 83415	98	3.54	0.44	-0.02	0.18	0.03	0.03	0.23	0.46	0.16
IR 04N155	99	3.52	-0.02	-0.08	0.49	-0.09	0.33	0.46	0.52	0.14
Chul'sa	97	3.46	0.19	0.20	-0.10	0.13	0.17	0.23	-0.01	0.08
IR 07L167	**100**	**3.45**	**-0.31**	**0.27**	**0.14**	**-0.27**	**-0.07**	**-0.04**	**-0.14**	**0.07**

IR 06L164	100	3.43	0.18	0.00	0.24	-0.37	-0.07	0.06	0.52	0.05
OM 3536	99	3.41	0.14	-0.19	0.08	-0.07	-0.20	0.16	0.17	0.03
OM 2718	97	3.36	0.10	0.20	-0.21	-0.13	0.03	0.06	-0.38	-0.02
IRRI 148	97	3.35	-0.43	0.39	-0.33	-0.33	-0.13	0.05	-0.28	-0.03
IR 06L158	100	3.35	0.05	0.04	-0.08	0.26	-0.37	-0.04	-0.04	-0.03
IR 06L132	97	3.35	0.34	-0.17	-0.01	-0.07	0.13	-0.07	0.06	-0.03
IR 77674	98	3.29	-0.01	-0.14	0.13	-0.07	0.17	-0.04	0.17	-0.09
OM 5796	98	3.27	0.03	-0.17	-0.03	0.62	-0.32	-0.57	-0.43	-0.11
IR 73678	96	3.16	-0.32	-0.17	-0.38	0.05	-0.18	0.16	-0.44	-0.22
IR504	92	3.14	-0.39	-0.26	-0.20	0.04	0.23	-0.94	-0.34	-0.24
EMGY	98	3.38	1.94	2.20	3.21	3.89	4.00	4.27	4.71	3.38
Combined			Day to maturity (day)			Plant height (cm)			Grain yield (t/ha)	
Environment (E)			0.7**			3.2**			0.29**	
Genotype (G)			0.6**			1.9**			0.15**	
GxE			**			**			**	

Set-IV. Involving 14 tested genotypes was tested with Chul'sa in 9 environments (CARDI=1, Kampot=2, Prey Veng=4 and Takeo=2) in wet season 2013. Five genotypes yielded higher and comparable to Chul'sa with good grain quality have been identified as promising genotypes (Table 9).

Table 9. Performance of tested genotypes in mean day to maturity (MDTM), mean grain yield (MGY, t/ha) and their yield stability from lowest to highest yielding environments (highlighted: promising genotypes).

Genotype	MDTM	MGY	E1	E2	E3	E4	E5	E6	E7	E8	E9	Mean
Chul'sa	95	4.45	0.1	-0.5	-0.3	-0.5	-0.3	-0.7	-0.3	-0.3	-0.7	-0.4
IR 04L186	**101**	**4.82**	**0.0**	**0.0**	**0.0**	**-0.2**	**0.3**	**-0.4**	**0.4**	**0.5**	**-0.8**	**0.0**
IR 09A102	100	4.97	-1.0	0.0	0.3	0.2	0.4	0.2	0.4	0.4	0.2	0.1
IR 09L337	**98**	**4.73**	**0.1**	**-0.2**	**-0.1**	**-0.2**	**0.1**	**-0.3**	**0.0**	**-0.5**	**0.0**	**-0.1**
IR 10L149	**99**	**4.75**	**1.0**	**-0.2**	**-0.6**	**-0.2**	**0.1**	**-0.3**	**0.2**	**-0.6**	**-0.3**	**-0.1**
IR 87741	101	4.79	0.5	-0.1	0.1	-0.3	-0.1	-0.3	-0.2	0.1	0.0	-0.1
IR 87753-5-1	**100**	**4.76**	**0.1**	**0.4**	**-0.3**	**-0.2**	**-0.2**	**-0.3**	**-0.1**	**0.0**	**0.1**	**-0.1**
IR 87753-5-2	101	4.78	-0.6	0.9	-0.5	-0.2	-0.3	-0.4	-0.3	0.5	0.3	-0.1
IR 87759-10	100	5.04	0.7	0.1	0.7	-0.1	-0.3	0.9	-0.3	0.0	0.2	0.2
IR 87759-12	100	4.73	-0.8	-0.1	0.2	0.3	-0.2	0.2	-0.2	-0.3	-0.2	-0.1
IR 87759-7	**100**	**5.15**	**0.3**	**-0.2**	**0.2**	**0.5**	**0.5**	**0.4**	**0.4**	**0.1**	**0.6**	**0.3**
IR 87760-17	100	4.97	1.1	-0.2	-0.2	0.0	0.1	-0.1	0.2	0.0	0.2	0.1
IR 87761-51	100	5.07	-1.1	0.0	0.1	0.7	0.5	0.7	0.5	0.2	0.2	0.2
IR 87761-53	100	4.89	0.4	0.1	0.3	0.0	-0.3	0.3	-0.3	-0.1	0.0	0.0
IR 87808-21	100	4.78	-0.5	0.0	0.2	0.3	-0.4	0.2	-0.5	0.0	0.1	-0.1
EMGY	100	4.85	4.4	*4.5*	*4.7*	5.3	4.2	4.9	4.3	*5.7*	*5.5*	4.8
Combined				Day to maturity (day)			Plant height (cm)			Grain yield (t/ha)		

Environment (E)	0.7**	3.1**	0.23**
Genotype (G)	0.6**	1.5**	0.28**
GxE	**	**	**

Set-V. A total of 23 genotypes were tested with two checks at 4 locations (CARDI, Kampot, Prey Veng and Takeo) in wet season 2013. There was no effect of location. There was no genotype yielded higher than IR66 (Table 10). However, base on grain quality two genotypes were selected as promising genotypes.

Table 10. Performance of tested genotypes in mean day to maturity (MDTM) and mean grain yield (MGY, t/ha) (highlighted: promising genotypes).

Genotype	MDTM	MGY	E1	E2	E3	E4
IR 09L337	96	4.39	4.45	4.37	4.21	4.54
IR 87753-5-1-6-4	93	4.38	4.80	4.80	4.21	3.71
IR 87754-42-2-2-3	96	4.34	4.37	5.07	4.35	3.58
IR 09L303	96	4.33	3.70	4.40	4.69	4.52
IR 87759-13-1-1-3	93	4.32	4.24	4.20	4.40	4.44
IR 66 (CK)	94	4.31	4.38	4.27	4.17	4.44
IR 67014-45-3-1	**92**	**4.30**	**4.49**	**5.07**	**4.27**	**3.35**
IR 87808-21-2-2-3	**93**	**4.28**	**4.07**	**4.27**	**4.08**	**4.69**
Chul'sa	90	3.60	4.18	3.93	2.71	3.58
Env. Mean	94	4.14	3.96	4.37	4.02	4.21
Combined	Day to maturity (day)			Grain yield (t/ha)		
Location (L)	0.5**			ns		
Genotype (G)	0.8**			0.37*		
GxL	**			**		

Set-VI. This set involves six genotypes selected from Aerobic lines and tested with two checks at CARDI in wet season 2013 in well watered condition (CWS13) and in dry season 2014 at CARDI under well watered (WW) and aerobic (AER) conditions and at Kampot (KPDS14) and Prey Veng (PVD14) under well watered (Table 10). One genotype (IR06L164) performed very well to the checks and also the best in highest yield in PVD14. This genotype was also performed comparable to the check in 9 environments (See Table 8). Therefore, it was selected as promising genotypes.

Table 11. Performance of aerobic genotypes in 5 environments (highlighted: most promising).

Genotype	MDTM	MGY	WW	AER	GYR (%)	KPDS14	PVDS14	CWS13
Chul'sa (CK)	103	3.81	3.99	3.63	9	3.15	4.77	3.51
IR 06L136	105	3.90	4.34	3.45	20	3.47	4.78	3.45
IR 06L141	111	3.70	4.05	3.35	17	3.35	4.63	3.12
IR 06L164	**109**	**4.13**	**4.50**	**3.77**	**16**	**3.70**	**5.41**	**3.29**
IR 06L167	105	3.83	4.05	3.62	11	3.18	5.13	3.18

IR 69502-6	111	3.44	3.68	3.20	13	3.22	4.08	3.02
IR 81040-B	106	3.54	3.91	3.17	19	3.23	4.34	3.05
Rumpe (CK)	107	3.90	4.34	3.46	20	4.40	4.21	3.09
Mean	107	3.78	4.11	3.46	16	3.46	4.67	3.21
Water (W)	0.4**			0.28**				
Location (L)	0.4**						0.35**	
Genotype (G)	0.8**	0.37*						
GxW	**	ns						
GxL	**	**						
GxWxL	**	ns						

Six promising genotypes, with two sets of genotypes, were coordinated with Project for Agricultural Development and Economic Empowerment (PADEE)" IFAD Loan No. 870-KH and Grant No. DSF 8101-KH to conduct POFAT in five provinces (PADEE: Takeo=15, Prey Veng=25 and Takeo=10; CSE05: (Kampong Chhnang=8 and Siem Reap=10) in dry season 2015. In POFAT-Set I, in average, all tested genotypes matured in 95 days which is about 5 days longer than the farmer's varieties. Genotype IR06L164 yielded 4.46 t/ha and about 0.26 t/ha higher than the farmer's varieties (Table 12). In POFAT-Set II, all introduced genotypes matured around 100 days longer than farmer varieties about 6-9 days. Averaged grain yield of IR04N155 was 3.92 t/ha compared to 3.71 t/ha of farmer varieties. Most of farmers preferred IR06L164 (26 out of 38) and IR04N155 (20 out of 30) the first not only for the yield performance but also for the grain appearance. Therefore, both varieties were released and named as CAR14 for IR06L164 and CAR15 for IR04N155.

Table 12. Day to maturity, grain yield and farmer's first preference of 6 promising genotypes.

Genotype	Day to maturity (day)	Grain yield (t/ha)	Farmer' first preference
POFAT-Set I (38 sites)			
IR 07L167	95	4.01	7
IR 03L148	95	4.04	7
IR 06L164	95	4.49	26
Farmer varieties	90	4.23	1
POFAT-Set II (30 sites)			
IR 77674-3B-8-2-2-8-2-4	102	3.28	7
IR 04N155	99	3.92	20
IR 83415-B-SDO3-3-AJY1	99	3.60	4
Farmer varieties	93	3.71	2

1) **Rice variety CAR14:** released in early 2015. This very early maturity that has developed by IRRI (IR06L164). CAR14 (CAR=Cambodian Rice) matures in 95 days, 0.9m in high, milled grain length is 6.8mm long with 1.8mm width, and has 18.6% amylose content. Average grain yield is 4.2t/ha with potential up to 7.5t/ha.
2) **Rice variety CAR15:** released in early 2015. This very early maturity that has developed by IRRI (IR05N155). CAR15 (CAR=Cambodian Rice) matures in 100 days, 1.0 m in high, milled grain length is 7.0 mm long with 2.1 mm width, and has 21.6% amylose content. Average grain yield is 4.0t/ha with potential up to 7.4t/ha.

Activity 2.3: Development and dissemination of suitable improved germplasm with desire quality and submergence tolerance.

Out of 575 progenies derived from 5 BC_2F_1 submerged in dry season 2011, only 10 progenies survived from 3 populations, and then continued development to 118 progenies of BC_3F_1 in wet season 2011. Other two populations were completed rotten in dry season 2011 and have been regenerated for $BC1F_1$ with 242 seeds in dry season 2012. During this season, 118 progenies of BC_3F_1 were also advanced for BC_3F_2 (see table below).

No	Population	2010WS-2011DS (BC2F1)		2011WS-2012DS	
		Submerged	Survival		
1	Phka Rumduol x IR64sub1	145	1	BC_3F_1 (progeny)	10
2	Phka Romeat x IR64sub1	52	0	BC_1F_1 (seed)	50
3	CAR6 x IR64sub1	175	1	BC_3F_1 (progeny)	43
4	Riang Chey x IR64sub1	93	0	BC_1F_1 (seed)	192
5	Phka Chan Sen Sar x IR64sub1	110	8	BC_3F_1 (progeny)	65

Objective 3: Understand scientific basis of sensory quality of Cambodian rice and develop capacity in Cambodia for rice quality assessment and MAS.

The sensory qualities of Cambodian rices will be determined, and QTLs for these identified. A quality evaluation program is essential to ensure adoption of the germplasm developed in this project and after. CARDI has partially equipped laboratories for assessing quality and MAS.

Activity 3.1: Determining the quality of preferred traditional rice varieties using populations segregating for quality by associating their chemical, rheological, and structural properties, and their metabolomic signatures with sensory properties, and associating all sets of phenotype data with a map developed by SNP genotyping.

Two rice varieties that have distinct quality were selected and crossed for SNP. Phka Rumduol is a prime quality with aromatic scent and Thmar Krem is traditional variety having poor quality in both grain appearance and cooking quality. Crossing was started in wet season 2010 and generation was advanced using single seed decent (SSD) up to F_5 seeds harvested in wet season 2012. In dry season 2013, 343 breeding lines were advanced for F_5 plant. F_6 seeds were harvested and sent to IRRI for phenotyping in wet season 2013. Simultaneously, seeds of all breeding lines were milled and sent to the University of Queensland for sensory profiling, metabolomic analysis and genome-wide genotyping. These activities are outside the scope of the project; however, they have become possible by the move of the PI from IRRI to UQ. The parents of the population have undergone two dimensional gas chromatography and volatile compounds were detected by mass spectroscopy (GCxGCMS). The rice grains were ground, and then cooked in a vial. The compounds that volatilised during cooking were captured and then analysed by GCxGCMS. Bioinformatic analysis was carried out to determine the compounds that differed between the two varieties, and those were likely to be detectable by humans. Meanwhile, 5-10 seeds of all breeding lines were kept at CARDI for further use.

Activity 3.2: Upgrading current facilities and capacity at CARDI for high-throughput screening of grain quality for both early and late generation materials.

Shaker (polisher), spectrophotometer and S21 (physical quality) and Udy cyclone mill machines have been purchased and installed at CARDI quality laboratory in November 2011. Meanwhile, result of amylose content tested by spectrophotometer equipped at CARDI was similar to referent laboratory at IRRI (Figure 1). Numerous good breeding lines identified by varietal testing have been tested for amylose content, gel consistency, gelatinization temperature, grain appearance, etc., and the results have been used for selection of promising breeding lines (see in varietal testing sections).

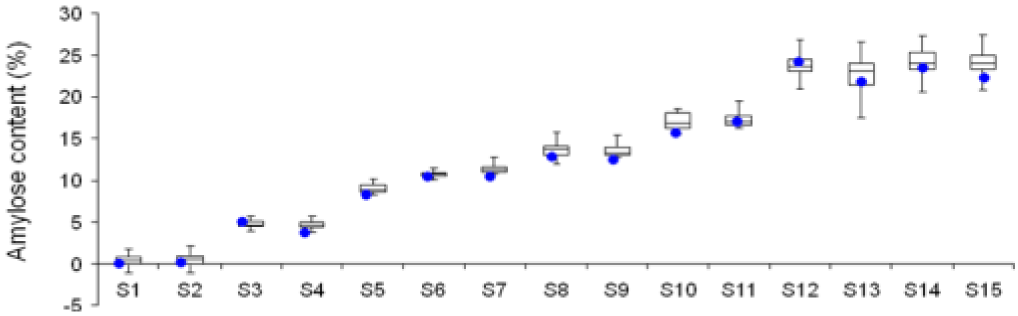


Figure 1. Result of amylose content tested by CARDI's spectrophotometer (solid blue circle) compared with IRRI's laboratory.

Activity 3.3: Upgrading current facilities and capacities at CARDI for MAS to accelerate breeding.

Chemicals has been purchased by IRRI and sent to CARDI in 2011 for testing CARDI's existing equipments for MAS. However, the team learned that PCR and gel document machines are old hence they are hard to operate and no protocols for using these machines. In 2013, a new PCR, gel documentation and fume hood have been equipped. These equipments have been testing and not been used for any experiment purpose.

Activity 3.4: Training CARDI staff to operate sustainably the future rice grain quality and MAS facilities by training CARDI staff in IRRI's quality evaluation and MAS program and then transferring that information to CARDI, for use in their upgraded quality evaluation program.

Mss OUK Sothea has been trained on grain quality testing and MAS at IRRI for two months. IRRI laboratory team lead by Dr Lorendo and other two came in November 2011 to install and train CARDI project team for MAS and operation of S21 at CARDI.

11.3 Appendix 3: GDA final report

Ngin Chhay, Pang Bora

I. Introduction

The Ministry of Agriculture, Forestry and Fisheries (MAFF) has nominated the General Directorate of Agriculture (GDA) in cooperation with the Industry and Investment NSW (NSW I&I), the International Rice Research Institute (IRRI), the Cambodian Agricultural Research and Development Institutes (CARDI) and Rice Research Australia Pty Ltd (RRAPL) to implement the project called "Improved Rice Germplasm for Cambodia and Australia" from April 2010 to the completion of the project in September 2014. The objectives of the Project are following:

- Identifying the current and future germplasm needs of Cambodian farmers and traders to determine the priorities and strategies for new germplasm development and dissemination.
- Strategic identification, development and dissemination of improved rice germplasm for different agro-ecological rice systems in Cambodia.
- Understanding sensory quality of Cambodian rice and develop capacity in Cambodia for rice quality assessment and MAS.
- Demonstration of commercially viable direct-seeding practices from tropical Australian rice production.

II. Activities and Results

2.1 Preparatory Work and Baseline Survey

In close cooperation with IRRI and CARDI, GDA has implemented the following activities:

- Organized several meetings with staff from CARDI, GDA and Research Stations for the preparation of implementation including the overall project activities and detailed operational plan each year and discussion on field trial designs.
- Undertaken travel missions to provinces namely Kampong Thom, Takeo, Kamport and Prey Veng to assess farmers' needs, select farmers and locations for field trials, study the agro ecosystem of target areas and identify main problems encountered by farmers in term of rice production and rice value chain. Several missions have also made to check and follow-up the trials in the stations and in farmer fields.
- Conducted training for staff from research stations, provincial departments of agriculture and farmers who are involved in conducting filed trials and demonstrations. During the meeting research protocols, field demonstration guidelines, training curriculum and materials were also developed and printed out for distributions.

2.2 Evaluation of Rice Varieties under Aerobic Conditions

GDA has implemented replicated field experiments in Tonle Bati Agriculture Development Center of Takeo, Prey Pdau Agriculture Research Station of Kampong Speu and Polors Plant Protection Research Station of Prey Veng province.

2.2.1 Result of the Trial in Dry Season 2011

Three replicated trials were conducted in Tonle Bati and Polors. The objective is to screen 63 IRRI and Australia aerobic and rainfed lines under non stressed aerobic soil conditions for adaptation. The trial design is Alpha Lattice 7x9 with 3 replications, 63 treatments. The plot size is 1.5m x 4m and the total plots are 189. The field was dry direct seeded in row with the seed rate of 2g/meter in 2-3cm dept.

Based on growth duration and yield potential, 10 aerobic varieties were selected. These varieties are IR80013-B-141-4-1, IR 06L129, IR 78936-B-9-B-B-B, IR 71700-247-1-1-2, IR 08L122, IR 04L186, IR 08L120, IR 06L142, IR 06G113 and IR 07L282.

2.2.2 Result of the Trial in Wet Season 2011

Three replicated trials were conducted in Tonle Bati and Prey Pdau. The objective is to screen 45 IRRI aerobic and rainfed lines under non stressed aerobic soil conditions for adaptation. The trial design is Alpha Lattice 5x9 with 3 replications and 45 treatments. The plot size is 1.5m x 4m, row spacing is 25cm and the total plots are 135. The field was dry direct seeded in row with the seed rate of 2g/meter in 2-3cm dept.

Based on growth duration and yield potential indicated that 8 aerobic varieties were good. These varieties are BP 223 E-MR-5, CT 6510-24-1-2, IR 06L136, IR 07L122, IR 07L166, IR 03L148, IR 81040-B-78-U 2-1 and IR 06L129.

2.2.3 Result of the Trial in Dry Season 2012

Three replicated trials were conducted in Tonle Bati and Prey Pdau. The objective is to screen 45 IRRI aerobic and rainfed lines under non stressed aerobic soil conditions for adaptation. The trial design is Alpha Lattice 5x9 with 3 replications and 45 treatments. The plot size is 1.5m x 4m, row spacing is 25cm and the total plots are 135. The field was dry direct seeded in row with the seed rate of 2g/meter in 2-3cm dept.

According to growth duration and yield potential, all varieties show different performances in term of 50% flowering dates and grain yields. Only two varieties produced higher yields with the 50% flowering date ranging from 70-75 days that are IR 789 36-B-9-B-B-B (4,728 kg/ha with 70 days) and IR 06G113(4,528kg/ha with 74 days).

2.2.4 Result of the Trial in Wet Season 2012

Three replicated trials were conducted in Tonle Bati and Prey Pdau. The objective is to screen 32 IRRI aerobic and rainfed lines under non stressed aerobic soil conditions for adaptation. The trial design is Alpha Lattice 4x8 with 3 replications and 32 treatments. The plot size is 1.5m x 4m, row spacing is 25cm and the total plots are 96. The field was dry direct seeded in row with the seed rate of 2g/meter in 2-3cm dept.

According to growth duration and yield potential only three varieties, IR 07L122, IR 78937-B-3-B-B-1 and CT6510-24-1-2, produced high yield with the same 50% flowering date of check ranging from 69 to 72 days.

2.2.5 Result of the Trial in Wet Season 2013

Three replicated trials were conducted in Tonle Bati and Prey Pdau. The objective is to screen 8 IRRI aerobic and rainfed lines under non stressed aerobic soil conditions for adaptation. The trial design is CRUD with 3 replications and 8 treatments.

The plot size is 1.5m x 4m, row spacing is 25cm and the total plots are 24. The field was dry direct seeded in row with the seed rate of 2g/meter in 2-3cm dept.

The result in wet season from January-June 2013 we evaluated 8 varieties under aerobic direct seeding and transplanting conditions.

- According to growth duration and yield potential, only three varieties namely IR06L164, IR06L136 and IR 81040-B-78-U 2-1 produced high yield with the similar 50% flowering date of check varieties ranging from 68 to 72 days under direct seeding condition.

- According to growth duration and yield potential, only two varieties namely IR06L167 and IR06L164 produced high yield with similar 50% flowering date of check varieties ranging from 78 to 79 days under transplanting condition.

2.2.6 Result of the Trial in Dry Season 2014

Three replicated trials were conducted in Tonle Bati and Prey Pdau stations with the objective is to screen 8 IRRI aerobic and rainfed lines under non-stressed aerobic soil conditions for adaptation. The trial design is RCBD with 3 replications and 8 treatments. The plot size is 2m x 5m, and the total plots are 24. The planting methods are dry direct seeded in row with spacing of 20cm and the seed rate of 2g/meter and transplanting with 18 days old seedlings in puddle soil with 2-3 seedlings per hill.

The results are following:

- According to growth duration and yield potential, only three varieties namely IR 06L167, IR 06L164 and IR 81040-B-78-U 2-1 produced high yield with similar 50% flowering date of check (Rumpe) which is 68 days under direct seeding condition.
- According to growth duration and yield potential, only four varieties namely IR 06L164, IR 06L136, IR 06L167 and IR 81040-B-78-U 2-1 produced high yield with similar 50% flowering of check (Rumpe) which is 81 days under transplanting condition.
-

2.3 Evaluation of Very Early Varieties under Lowland Condition

During the period from January 2011 to July 2014, GDA has implemented replicated field experiments in Tonle Bati Agriculture Development Center of Takeo, Prey Pdau Agriculture Research Station of Kampong Speu and Polors Plant Protection Research Station of Prey Veng.

2.3.1 Result of Trial in Dry Season 2011

Three replicated trials were conducted in Tonle Bati and Porlos with the objective to screen 30 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x6 with 3 replications and 30 treatments and the plot size is 4m x 1.2m or (20x6 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 17 days old seedlings in puddled soil and with 2-3 seedlings per hill.

According to growth duration and yield potential 8 very early varieties were selected. These varieties are IR 08L120, IR 06G116, IR 10T109, IR 07L270, IR 74371-3-1-1, IR 07L203, IR 08L408 and IR 08L403 for further trial.

2.3.2 Result of the Trial in Wet Season 2011

Three replicated trials were conducted in Tonle Bati and Prey Pdau with the objective is to screen 30 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x6 with 3 replications and 30 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 18 day old seedlings in puddled soil and with 2-3 seedlings per hill.

Based on maturity duration and yield potential 9 very early varieties are selected for further field testing. These varieties are IR 07L167, IR 06L132, IRRI 123, IR 06L136, OM 5796, IR 08L120, OM 2718, IR 04N155 and IR 04L186.

2.3.3 Result of the Trial in Dry Season 2012

Three replicated trials were conducted in Tonle Bati and Prey Pdau with objective to screen 30 very early IRRI aerobic, rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x6 with 3 replications and 30 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 18 days old seedlings in puddle soil and with 2-3 seedlings per hill.

Only two varieties performed high yield with 50% flowering dated ranging from 77 to 87 days that are IR 06L 132 (3,796 kg/ha with 77 days) and IR 06G113 (4,207kg/ha with 87 days). Whereas, IR 06L132, BP 223 E-MR-5, OM 2718, IR 08L403, IRRI 148, IR 73678-6-9-B, OM 5796, IR 03A151 and IR 77674-3B-8-2-2-8-2-4 showed the earlier flowering dates than other varieties.

2.3.4 Result of the Trial in Wet Season 2012

Three replicated experiments were conducted in Tonle Bati and Prey Pdau with the objective to screen 30 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x6 with 3 replications and 30 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 17 days old seedlings in puddled soil and with 2-3 seedlings per hill.

All varieties show different performance with different 50% flowering dates and grain yield, but only two varieties performed high yield with the same 50% flowering date of check that are IR 06L164 (4,549 kg/ha with 76 days) and IR 04A305 (4,236 kg/ha with 76 days).

2.3.5 Result of the Trial in Dry Season 2013

Three replicated experiments were conducted in Tonle Bati and Prey Pdau with the objective to screen 40 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x8 with 3 replications and 40 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 120. The field was transplanted with 18 days old seedlings in puddled soil and with 2-3 seedlings per hill.

Based on growth duration, it was divided into two groups of varieties that provided high yield with the same duration of check varieties. First group is compared with Chul'sa in which only four varieties performed high yield up to ≥ 5,000 kg/ha with 72-74 days of 50% flowering (Check: 4,165 kg/ha with 72 days) and second group is compared with IR66 in which only four varieties performed high yield up to ≥ 5,000 kg/ha with 75-77 days of 50% flowering (Check: 4,784 kg/ha with 79 days). These 8 varieties were selected for further evaluations are IR09L303, IR10L149, IR11A137, IR09L336, IR 09L342, IR 88864-2-1-2-4, IR 04A305 and IR 87808-21-2-2-3.

2.3.6 Result of the Trial in Wet Season 2013

Three replicated experiments were conducted in Tonle Bati and Prey Pdau with the objective to screen 25 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x5 with 3 replications and 25 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 75. The field was transplanted with 18 days old seedlings in puddled soil and with 2-3 seedlings per hill.

All varieties show different performances with different 50% flowering dates and grain yield. The fourteen varieties performed high yield with the similar 50% flowering date of Chul'sa and IR66 varieties are IR 87741-29-1-1-2, IR 10L149, IR 11A137, IR 09L337, IR 04L186, IR 87747-16-1-1-1, IR 09L303, IR 87761-51-1-3-1, IR 09L342, IR 87808-21-2-2-3, IR 09L336, IR 87747-16-3-1-4, IR 87759-13-1-1-3 and IR 87753-5-1-6-4.

2.3.7 Result of the Trial in Dry Season 2014

Three replicated experiments were conducted in Tonle Bati and Prey Pdau stations with the objective to screen 25 very early IRRI rainfed and lowland lines under irrigated lowland conditions for yield potential. The experimental design is Alpha Lattice 5x5 with 3 replications and 30 treatments and the plot size is 4m x1.2m or (20x6 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 18 days old seedlings in puddled soil with 2-3 seedlings per hill.

All varieties show different performances with different 50% flowering dates and grain yield. The two varieties performed high yield with the similar 50% flowering date of Chul'sa varieties are IR 77674-3B-8-2-2-8-2-AJY6 and IR 67014-45-3-1. The five varieties performed high yield with the similar 50% flowering date of IR66 are IR 87761-53-1-1-4, IR 10L149, IR 09L337, IR 87761-66-2-3-2 and IR 09L336.

2.3.8 Result of the Trial in Wet Season 2014

Three replicated experiments were conducted in Prey Pdau station with the objective to screen 30 IRRI NILs for Bacterial Blight tolerance. The experimental design is Alpha Lattice 5x6 with 3 replications and 30 treatments and the plot size is 1m x5m or (5x25 hills), row spacing is 20cm and the total plots are 90. The field was transplanted with 22 days old seedlings in puddled soil with 2-3 seedlings per hill.

Only four NILs were infected by Bacterial Blight with lower than 10% of leaf area. Those NILs are BB3, BB5, BB20, and BB30.

2.4 Evaluation of Medium Varieties under Lowland Condition

During the period from January 2011 to July 2014, GDA has implemented replicated field experiments in Tonle Bati Agriculture Development Center of Takeo, Prey Pdau Agriculture Research Station of Kampong Speu and Polors Plant Protection Research Station of Prey Veng.

2.4.1 Result of the Trial in Dry Season 2011

Three replicated trials were conducted Tonle Bati and Polors with the objective to screen 72 IRRI aerobic and rainfed lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 6x12 with 3 replications and 72 treatments and the plot size is 4m x 1.2m or (20x6 hills) and row spacing is 20cm and the total plots are 216. The field was transplanted with 20 days old seedlings in puddle soil with 2-3 seedlings per hill.

According to growth duration and yield potential, 10 varieties were selected for further testing. These varieties are IR 06L164, IR 07L290, IR 06L168, IR 07L332, IR 08L382, IR 06L141, IR 06G110, IR 04L186, IR 79971-B-201-2-3 and IR 03L146.

2.4.2 Result of the Trial in Wet Season 2011

Three replicated trials were conducted Tonle Bati and Prey Pdau with the objective to screen 40 IRRI rainfed and lowland lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 5x8 with 3 replications and 40 treatments and the plot size is 4m x1.2m or (20x6 hills) and row spacing is 20cm and the total plots are 120. The field was transplanted with 20 days old seedlings in puddle soil with 2-3 seedlings per hill.

According to growth duration and yield potential 15 very early varieties were selected for further field testing. These varieties are IR 04A421, IR 06L141, IR 79195-42-1-3-1, IR 04A428, OM 6049, ZX117, IR 80411-B-49-1, IR 78937-B-3-B-B-1, PSB RC 64 IR59552-21-3-2-2, IRRI 150, IR 05N444, IR 06M141, IR 05N412, IR 06M142 and IR 05A278.

2.4.3 Result of the Trial in Dry Season 2012

Three replicated trials were conducted Tonle Bati and Prey Pdau with the objective to screen 40 IRRI rainfed and lowland lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 6x12 with 3 replications and 40 treatments and the plot size is 4m x 1.2m or (20x6 hills) and row spacing is 20cm and the total plots are 120. The field was transplanted with 21 days old seedlings in puddled with 2-3 seedlings per hill.
Only two varieties performed high yields which are IR 06M139 (4,316 kg/ha with 81 days of 50% flowering date) and IR 06M141 (4,191 kg/ha with 81 days of 50% flowering date). Whereas, IR 78937-B-3-B-B-1, IR 04L180, IR 06M139, IR 06M141, HHZ 5-SAL 9-Y 3-Y 1, IR 06M142 and IR 78875-207-B-1-B have earlier flowering dates than other varieties.

2.4.4 Result of the Trial in Wet Season 2012

Three replicated trials were conducted Tonle Bati and Prey Pdau with the objective to screen 40 IRRI rainfed and lowland lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 5x8 with 3 replications and 40 treatments and the plot size is 4m x1.2m or (20x6 hills) and row spacing is 20 cm and the total plots are 120. The field was transplanted with 21 days old seedlings in puddled soil with 2-3 seedlings per hill.

Only ten varieties performed high yield up to ≥ 3,889 kg/ha with 83±1 days of 50% flowering compared with check (IR 66=3,889kg/ha with 83 days). Based on growth duration and yield potentials 10 medium varieties were selected namely IR 69502-6-SRN-3-UBN-1-B, IR 05N444, IR 80412-B-31-1, IR 61640-3B-14-3-3-2, IR 04L180, IR 87754-42-1-4-1,IR 87759-12-3-1-4 , IR 09A104IR 80411-B-49-1, and IR 87761-41-2-2-4 for further evaluation.

2.4.5 Result of the Trial in Dry Season 2013

Three replicated trials were conducted Tonle Bati and Prey Pdau with the objective to screen 56 IRRI rainfed and lowland lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 7x8 with 3 replications and 56 treatments and the plot size is 4m x 1.2m or (20x6 hills) and row spacing is 20cm and the total plots are 120. The field was transplanted with 20 days old seedlings in puddle with 2-3 seedlings per hill.

All varieties show highly significant differences on 50% flowering date and grain yield, but only six varieties namely IR 87753-5-2-1-3, IR 87754-42-1-4-1, IR 87761-53-1-1-1, IR 87759-12-3-1-4, IR 87761-53-1-1-4 and IR 87761-52-2-2-4 produced high yield (4,928-5,692 kg/ha) with the same 50% flowering date of check varieties ranging from 68 to 72 days.

2.4.6 Result of the Trial in Wet Season 2013

Three replicated trials were conducted Tonle Bati and Prey Pdau with the objective to screen 55 IRRI rainfed and lowland lines under drought stressed lowland conditions for drought tolerance. The trial design is Alpha Lattice 5x5 with 3 replications and 25 treatments and the plot size is 4m x1.2m or (20x6 hills) and row spacing is 20cm and the total plots are 120. The field was transplanted with 20 days old seedlings in puddled soil with 2-3 seedlings per hill.

All varieties show different performance on 50% flowering and grain yield, but only nine varieties performed high yield up to ≥ 4,500 kg/ha with 82±1 days of 50% flowering compared with check (IR 66=4,325 kg/ha with 81 days). Based on growing duration and yield potentials 9 medium varieties were selected for further evaluation. These varieties are IR 06L141, IR 87753-5-2-1-3, IR 87761-66-2-3-2, IR 87761-53-1-1-4, IR 87760-28-1-1-2, IR 87759-12-2-1-2, IR 87751-17-5-1-3, IR 87808-21-2-2-2 and IR 87761-52-2-2-4.

2.5 On-Farm Adapted Trial (OFAT)

2.5.1 Results of OFAT (non replicated trials) from January 2011 to December 2012

GDA in collaboration with IRRI, CARDI and 3 Provincial Departments of Agriculture (PDA) namely Kampong Thom, Takeo and Kampot has conducted On-Farm Adapted Trial (OFAT) with two early lines (lines 1 and lines 3) from January 2011 to December 2012 and IR 504 was planted as check.

- In the dry season 2011: 10 OFAT with lines 1 and lines 3 from CARDI were carried out by 10 farmers, 4 farmers in Kampot, 3 farmers in Takeo and 3 farmers in Kampong Thom provinces.
- In the wet season 2011: 9 OFAT with lines 1 and lines 3 from CARDI were carried out by 9 farmers, 3 farmers in Kampot, 3 farmers in Takeo and 3 farmers in Kampong Thom provinces
- In the dry season 2012: 9 OFAT with line1 and line 3 from CARDI were conducted by 9 farmers, 3 farmers in Kampot, 3 farmers in Takeo and 3 farmers in Kampong Thom provinces.
- In the wet season 2012, 3 OFAT with line1 and line3 from CARDI were carried out by 3 farmers, in Kampot, Takeo and Kampong Thom provinces.

The results show that IR 504 (check) is a short duration variety (mean duration= 86 days) with erect plant. The level of lodging was evaluated with score 1 indicating that the plant is strong. This variety provides the highest yield (mean yield= 4,597 kg/ha) compared with other varieties. The mean of Farmer Participatory Variety Selection (FPVS) is 14 persons, which shows that this variety is the most popular among farmers.

Line1 is also a short duration variety (mean duration=91 days) with erect plant. The level of lodging was evaluated with score 3 indicating that the plant is not strong. This variety provides lower yield (mean yield=4,133 kg/ha) than IR 504, but higher than line 3 (3,993 kg/ha). The mean of FPVS is 10 people lower than IR 504, which indicates this variety is less popular among farmers than IR 504.

Line3 has the longest duration compared to IR 504 and Line1 (mean duration=95 days). The plant is weak with lodging level of score 5. The mean yield is 3,993 kg/ha, lowers than IR 504 and Line1 and the mean of FPVS is 6 persons, which indicate that this variety is the least popular among farmers.

2.5.2 Results of OFAT with 3 Replications in Wet Season 2012

In wet season 2012, 6 OFAT to evaluate 15 very early lines from CARDI were conducted in different locations (Multi-location Trial-MLT) with 2 check varieties (Chul'sa and IR 504) with 6 farmers in Kampot, Takeo and in Kampong Thom (2 trials in each province).

All varieties show different performance on 50% flowering dates ranging from 70-74 days and grain yield up to ≥ 3,496 kg/ha compared with check varieties Chul'sa (4,511kg/ha with 73 days) and IR 504 (3,496 kg/ha with 66 days). Based on growth duration and yield potentials 11 very early varieties were selected for further evaluation. These varieties are IR 04N155, IR 06L132, IR 06L164, IR 07L167, IR 73678-6-9-B, IR 77674-3B-8-2-2-8-2-4, IR 83415-B-SDO3-3-AJY1, IRRI 148, OM 2718, OM 3535 and OM 5796.

2.5.3 Result of Evaluating 15 Very Early Varieties in Dry Season 2013

In dry season 2013, 3 OFAT by direct seeding method and 3 OFAT by transplanting method to evaluate 15 very early lines from CARDI were conducted in different locations with Chul'sa as check with 3 farmers in Kampot, Takeo and Kampong Thom provinces. The results are following:

- All varieties show highly significant differences in 50% flowering date and grain yield in which only three varieties namely IRRI148, IR06L158 and IR06L164 produced high yield (4,000-4,200 kg/ha) with the same 50% flowering date of check varieties Chul'sa (63 days) under direct seeding condition.
- All varieties show highly significant differences on 50% flowering date and grain yield. Only five varieties namely IRRI148, IR77674-3B-8-2-2-8-2-4, IR07L167, IR06L158 and IR03L148 produced high yield (5,128kg/ha-5,678kg/ha) with similar date of 50% flowering of check variety Chul'sa (68 days).

2.5.4 Result of Evaluating 15 Very Early Varieties in Wet Season 2013

In wet season 2013, 3 OFAT by direct seeding method and 3 OFAT by transplanting method to evaluate 15 early lines from CARDI were evaluated in different locations with Chul'sa (check) with 3 farmers in Kampot, Takeo and Kampong Thom provinces. The results are following:

- All varieties show different performance in 50% flowering and grain yield, but only three varieties performed high yield up to ≥ 4,500 kg/ha with 68±1 days of 50% flowering compared with Chul'sa (4,274 kg/ha with 67 days). Based on growing duration and yield potentials 3 very early varieties namely IR 87808-21-2-2-2, IR09A102 and IR10L149 were selected for further evaluation under direct seeding condition,
- All varieties show different performance on 50% flowering and grain yield, but only five varieties performed high yield up to ≥ 5,000 kg/ha with 77-78 days of 50% flowering compared with Chul'sa (4,444 kg/ha with 77 days). Based on growing duration and yield potentials 5 early varieties namely IR 87759-10-1-2-2, IR 87760-17-2-1-1, IR 87808-21-2-2-2, IR 87753-5-2-1-3 and IR 87761-51-1-3-1 were selected for further evaluation.

2.5.5 Results OFAT (non replicated trials) in dry season 2014

In dry season 2014, 6 OFAT were conducted to evaluate 5 very early lines from CARDI in different locations with 6 farmers in Kampot, Takeo and in Kampong Thom (2 trials in each province).

- 2 OFAT with lines 1 to lines 5 with IR504 as check were carried out by 2 farmers in Takeo province by transplanting method. The results show that IR 504 (check) and line 5 are the shorter duration varieties (mean duration of 50% flowering date= 65 days) and the yield of Line1 and Line5 is the highest (4,800-5,000 t/ha) and the yield of check is the lowest (mean yield=4,100 kg/ha). For L2, L3 and L4 the yield is higher than check, but not significantly different.

- 4 OFAT with lines 1 to lines 5 with Chul'sa as check were carried out by 4 farmers in Takeo, 2 farmers in Kampot and 2 farmers in Kampong Thom provinces by direct seeding method. The results show that Line 5 is a shorter duration and the yield is higher than other varieties (duration=62 days and yield=4,600 kg/ha). The duration of Line 1 to Line 5 are similar and the yield are higher than check variety Chul'sa (50% flowering duration 65 day and yield 3,875 kg/ha).

2.5.6 Results OFAT (non replicated trials) in wet season 2014

In wet season 2014, 25 OFAT were conducted to evaluate 8 very early lines from CARDI using IR 504 as check in different locations with 25 farmers in Kampot, Takeo, Kampong Thom, Svay Rieng and Kampong Spue provinces (5 trials in each province).

The result show that 3 varieties namely IR 09L337, IR 10L149 and IR 04L186 have 4 days shorter 50% flowering duration compared with Chul'sa (check) and got higher yield 4,800 to 5,700 kg /ha. The 5 varieties name IR 87759-7-1-2-2, IR 67014-45-3-1, IR 87761-66-2-3-2, IR 87753-5-1-6-4 and IR 87808-21-2-2-3 have higher yield, but same duration of 50% flowering compared with Chul'sa (3,800 kg/ha with 65 days).

2.6 On-going Activities in Dry Season 2015

In dry season from January to June 2015, GDA in collaboration with IRRI, CARDI, Toul Samrong Rice Seed Production Farm and 3 PDA namely Siem Reap, Battambang and Porsat has been conducting the following trials:

- One trial with 3 replications to evaluate 14 very early lines under lowland condition in Toul Samrong Rice Seed Production Farm
- 9 OFAT with 14 very early lines under lowland conditions in Siem Reap, Battambang and Porsat with 3 trials by transplanting and 6 trials by direct seeding (3 trials for each province).

11.4 Appendix 4: IRRI Report 1: Introgression of Sub1+AG1 Genes into Phka Rumduol

Chenie S. Zamora, Katreena Titong, Joong Hyoun Chin

1 Executive Summary

1. 1 Purpose of the study

Phka Rumduol (PRD) is a Cambodian rice variety and was named as the "World's Best Rice" by the Rice Traders World Rice Conference held in Hong Kong in November 2013. Phka Rumduol was developed through the support of Cambodia-IRRI-Australia project (1998-2001), and released in Cambodia in 1999. To date it is one of the top ten varieties promoted by the Royal Government of Cambodia and is now widely grown in the country (IRRI news).

Cambodia is one of the countries affected by flooding that usually occurs during August-October. Improvement in submergence tolerance of rice varieties is necessary to increase and/or stabilize rice production in Cambodia. With the current breeding system at IRRI, the project chose Ciherang-Sub1-AG1 (CSA) as a donor to introgress Sub1 together with AG1 (anaerobic germination) into Phka Rumduol.

1. 2 Scope of the Study

This study is limited to the introgression of Sub1 and AG1 genes into Phka Rumduol with a minimum introgression of the additional background of donors to maintain high-quality traits of Pkha Rumduol.

1. 3 Materials and Methodology

The study used near isogenic lines (NILs) from Ciherang-Sub1-AG1 to transfer Sub1 and AG1 to Phka Rumduol.

The parents were submitted to 6K Infinium™ (Illumina co.) platform for SNP polymorphism survey. In addition, both parents were also submitted for whole genome sequencing using the GIna facility in GSL.

Both F_1's and BC_1F_1's were genotyped using QTL-specific markers for submergence and anaerobic germination. Only those that were selected with hetero alleles were used to make further backcrossing.

2 Progress in Phka Rumduol (PRD) –Sub1-AG1 program

At this moment, BC_2F_1 population has been achieved and genotyped. Five selected BC_2F_1 plants are being crossed to make BC_3F_1. Markers used for this work were *ART5, GnS2* and *SC3* for Sub1 (Septiningsih et al. 2009), and *Sdhups5* and *DFR R2+LB2* for AG1 (Kretzchmar et al., unpublished).

Remaining activities for PRD-Sub1-AG1 program include:

- On-going crosses for making BC_3F_1 population
- Oktopure DNA extraction for BC_3F_1
- Fluidigm 96.96 for foreground genotyping BC_3F_1
- Oktopure DNA extraction for BC_3F_2
- Fluidigm 192.24 for BC_3F_2
- 6K Infinium™ for BC_3F_2

3 Results and Discussion

- Donor Failure at first beginning – the importance of right seed source management: Right F_1 progenies were successfully made only during the 2014 WS. This was because the donor (CSA) given in the 2014 DS was actually a segregating population of IR42-AG2. We noticed the difference in flowering stage when we observed that it was three weeks late relative to Ciherang-Sub1. Therefore, this program was one-season delayed.

- **Polymorphism between parents:** For parental polymorphism survey, both parents were submitted for 6K Infinium™. Results showed that out of 4602 SNPs, 3756 were monomorphic and only 846 SNPs (18.38%) were found polymorphic between Phka Rumduol and Ciherang-Sub1-AG1. Sixty-three SNPs were polymorphic in both parents on chromosome 9, where Sub1 and AG1 are located (Figure 1).

- **Whole-genome sequence of Phka Rumduol and Ciherang-Sub1-AG1:** The whole genome sequencing is archive in IRRI repository under the supervision of Dr. Ramil Mauleon, Dr. Michael Thomson and Dr. Joong Hyoun Chin.

- **Identification of right F_1:** From the 48 plants planted for F_1, only 14 were successfully found to have hetero allele for both Sub1 and AG1. Markers used were ART5 and Sdhups5, respectively (Table 1).

- **BC_1F_1 development:** Total of 48 plants were planted and only 16 were confirmed true BC_1F_1 (Table 2). Markers used were ART5, GnS2 and SC3 to check the Sub1 gene and Sdhups5 and DFR R2+LB2 for AG1. Newly developed markers of AG1 were firstly applied by our group.

- **BC_2F_1 and BC_3F_1 development**: BC_2F_1 seeds were harvested and genotyped in June 2015, BC_2F_1 plants are at flowering stage and being crossed to make BC_3F_1. Only selected seeds of BC_2F_2 and BC_3F_1 with the minimum background of donor segments will be passed to Dr. Dule Zhao for field screening.

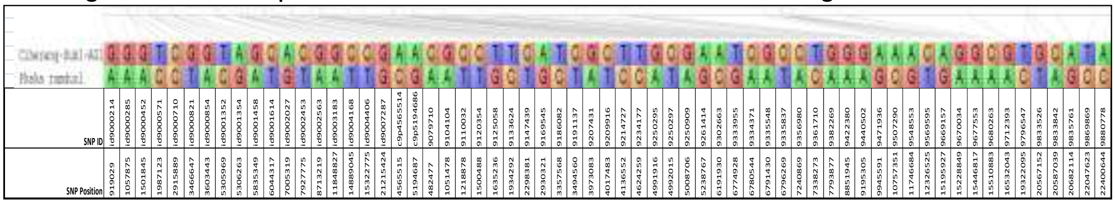


Figure 1. Polymorphic SNPs in Chromosome 9

Table 1. Successful F_1 cross between Phka Rumduol (PRD) and Ciherang-Sub1-AG1 (CSA)

Sample_code	Generation	ART5(Sub1)	Sdhups5(AG1)
Phka Rumduol	Parent	A	A
Ciherang-Sub1-AG1	Parent	B	B
MAB1-1	F_1	H	H
MAB1-2	F_1	H	H
MAB1-3	F_1	H	H
MAB1-4	F_1	H	H
MAB1-5	F_1	H	H
MAB1-6	F_1	H	H
MAB1-7	F_1	H	H
MAB1-8	F_1	H	H
MAB1-9	F_1	H	H
MAB1-10	F_1	H	H
MAB1-11	F_1	H	H
MAB1-12	F_1	H	H
MAB1-13	F_1	H	H
MAB1-14	F_1	H	H

Table 2. Successful BC_1F_1 cross between Phka Rumduol and Ciherang-Sub1-AG1

	ART5	GnS2	SC3	Sdhups5	DFR R2+LB2
Ciherang-Sub1-AG1	B	B	B	-	-
Phka Rumduol	A	B	B	-	-
MAB1-1-1	H	H	B	H	1
MAB1-2-1	H	H	B	H	1
MAB1-8-1	H	H	B	H	1
MAB1-8-4	H	H	B	H	1
MAB1-10-2	H	H	B	H	1
MAB1-10-5	H	H	B	H	1
MAB1-10-8	H	H	B	H	1
MAB1-10-9	H	H	B	H	1
MAB1-10-11	H	H	B	H	1
MAB1-13-2	H	H	B	H	1
MAB1-14-3	H	H	B	H	1
MAB1-14-4	H	H	B	H	1
MAB1-14-5	H	H	B	H	1
MAB1-14-9	H	H	B	H	1
MAB1-14-11	H	H	B	H	1
MAB1-14-13	H	H	B	H	1

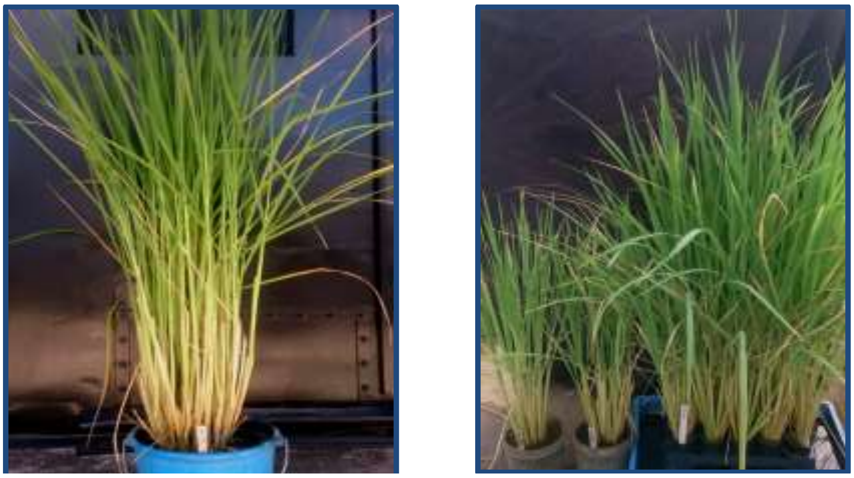


Figure 2. Phka Rumduol inside outdoor growth chamber for the rapid plant growth and photosensitivity control (Left); Phka Rumduol at greenhouse prepared for high-throughput crossing system (right).

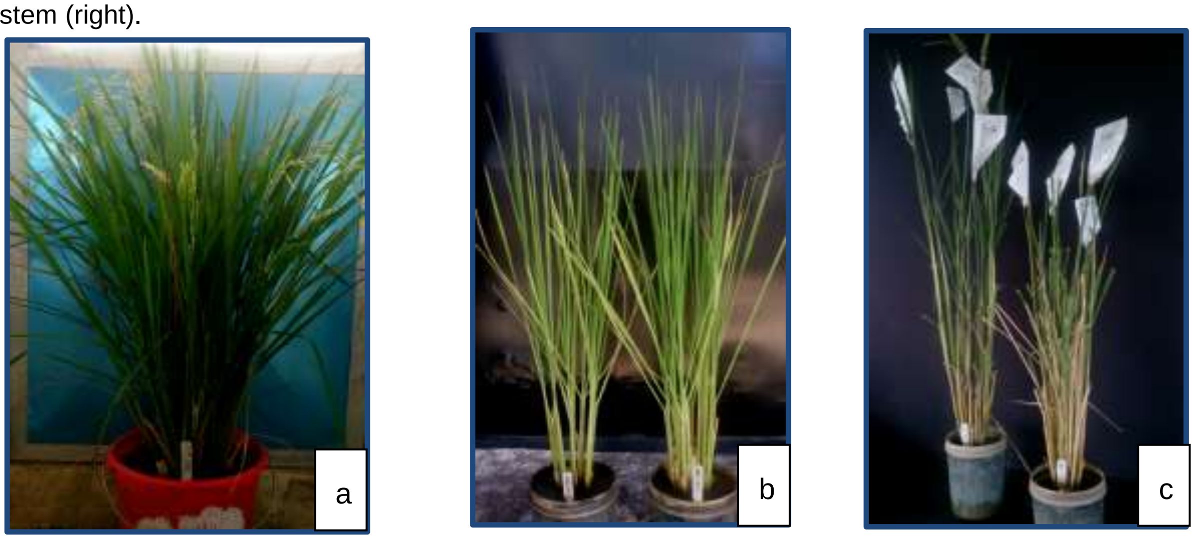


Figure 3. (a) Ciherang-Sub1-AG1 (donor) in screen house; (b) BC_1F_1 of PRD x CSA in screen house; (c) BC_2F_1 seeds are maturing as of June 10th, 2015.

11.5 Appendix 5: IRRI Report 2- Grain Quality Evaluation, Population Phenotyping and Genotyping

Adoracion Resurreccion
Grain Quality and Nutrition Center (GQNC, IRRI)

Summary
IRRI's Grain Quality and Nutrition Center (GQNC) commissioned CARDI's grain quality and molecular labs by purchasing, calibrating, and installing a number of instruments in CARDI's labs. IRRI also trained CARDI staff on grain quality measurements and marker assisted selection (MAS) both at IRRI and CARDI. GQNC measured the grain quality traits of 425 breeding lines/varieties for varietal development in Cambodia, and phenotyped a population of 384 F_6 RILs derived from a cross of Phka Rumduol x Thmar Krem in grain quality for the study on sensory quality of Cambodian rices. IRRI also genotyped the F_6 population in its molecular lab.

A. Commissioning CARDI labs, and training of CARDI staff to perform quality evaluation and MAS

The following equipment were purchased, calibrated and installed by IRRI in CARDI's labs during 2011-2013:

1) Orbital Shaker SK540 –for milling 2-5 grams of brown rice
2) Rice Statistical Analyzer LKL Brand, Model S21 – for measurement of physical characteristics of rice grains
3) Agilent Cary 60 UV-VIS Spectrophotometer – for measurement of amylose content
4) PCR Machine, G-Storm GS1- for amplifying DNA for molecular breeding
5) Gel Documentation System, Vilber Lourmat- for reading gels
6) Udy Cyclone Sample Mill – for grinding
7)

Ouk Sothea of CARDI spent two months at IRRI leaning how to perform grain quality evaluation. She also learnt how to do genotyping using IRRI's genotyping equipment. Four of IRRI's Grain Quality and Nutrition Center (GQNC) staff (Adoracion Resurreccion, Roslen Anacleto, Crystal Concepcion and Teodoro Atienza) spent one week in CARDI installing equipment 1-3 above, ensuring that they all worked and training CARDI staff on grain quality analysis, specifically measurement of amylose content, and genotyping for aroma and sub1. Crystal and Roslen made follow-up visits to troubleshoot and resolve some problems.

The proficiency of CARDI to measure amylose content was assessed in a ring test which the International Network for Quality Rice (INQR) conducted to ensure harmony of measurements around the world. A set of 45 INQR samples were sent to CARDI to test repeatability (3 replicates of 15 samples) and reproducibility of the amylose content determination there. 17 other rice quality laboratories had already measured the amylose content of the set. The data from CARDI (dots) in Figure 1 fell within the interquartile range for each sample, as calculated from the other labs, showing that CARDI has the required proficiency to measure amylose routinely.

The equipment for genotyping in CARDI were upgraded in 2013 with the purchase of a the G-Storm PCR and the Gel Documentation System, Vilber Lourmat, to effectively carry out marker-assisted selection protocols for aroma and sub1.

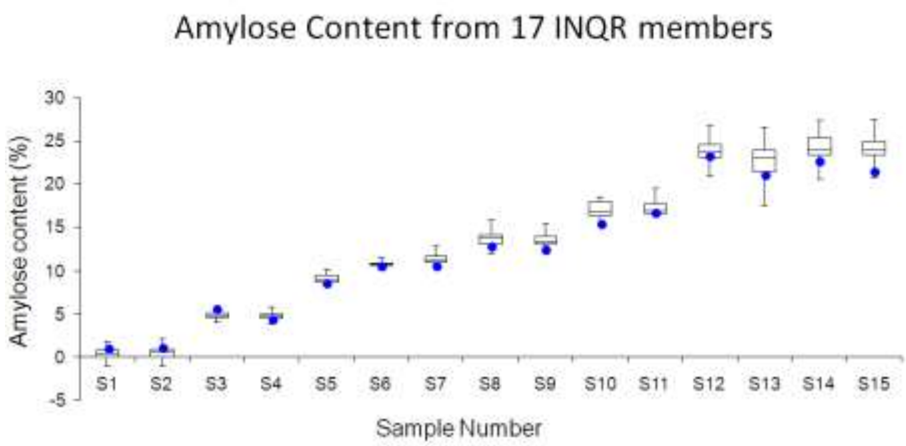


Figure 1. Amylose content of 15 samples obtained by 17 INQR member laboratories. Blue dots are those obtained by CARDI.

B. Grain Quality Evaluation

Set 1: 232 lines/varieties

The project selected 232 lines/varieties on agronomic traits from more than 900 introductions after one season field evaluation at CARDI in the 2010 WS. These lines were then sent to GQNC of IRRI for grain quality evaluation. The quality data were sent back to breeders in Cambodia for second round selection on grain quality. Quality evaluation results of early project material (232 lines /varieties) are shown in Table 1.

Among the 232 lines, Head Rice Yield (HRY) ranged from 0 – 66.5 %. There were 68 lines which showed ≥ 50% HRY values which are considered acceptable.

Chalkiness values were 0 – 52%. Chalkiness value refers to the average area of the grain that is chalky. 162 lines had 0-10% chalkiness. Only 13 lines had >25% chalkiness. A value of >25% for chalkiness can be considered as unacceptable.

Length of grain ranged from 5.55 - 7.08 mm which is medium or intermediate to long according to the size classification used. As to shape (the ratio of the length to the width of the grain), 194 lines have slender grains.

The amylose contents (AC) of the 232 lines varied from 13.0 to 32.4%. The distribution in the amylose content groups is as follows: Low AC, 26 lines; intermediate AC, 81 lines and high AC, 125 lines. It is interesting to note that 113 lines in the set have high AC (≥ 25%) and soft gel consistency (GC > 60 mm) while only 12 lines with high AC have medium-hard GC. GC is used to differentiate rice with high amylose contents.

Gelatinization temperature (GT) by Alkali Spreading Value (ASV) varied from low to intermediate to high. 124 lines were predicted by its ASV score to have an intermediate GT and 61 lines have a low GT. A high GT is usually not acceptable. GT determines cooking time, and high-GT rice takes long to cook.

Protein content of the milled rice were 5.6 -11.3% with a mean of 8.3%. A uniform degree of milling is necessary for a reliable measure and comparison of protein content values.

Table 1. Grain quality evaluation of 232 lines

No	Line / Variety	Head Rice Yield %	Chalkiness	Grain Length L, mm	Grain Width W, mm	Grain Shape L/W	Amylose Content %	Gelatinization Temperature by ASV*	Gel Consistency mm	% Protein MR
1	IR 78875-190-B-1-3	35.6	9	6.3	1.9	3.3	22.6	H/HI	77	9.0
2	IR 78878-53-2-2-2	44.4	26	6.5	2.1	3.1	21.6	HI/I	83	9.4
3	IR 78878-53-2-2-4	44.3	21	6.5	2.1	3.1	22.0	I	75	9.4
4	IR 78914-B-22-B-B-B	38.6	16	6.3	2.2	2.9	29.8	I	100	9.2
5	IR 78933-B-24-B-B-4	52.2	4	6.6	2.1	3.2	32.4	L	91	7.5
6	IR 78936-B-9-B-B-B	48.2	10	6.3	2.2	2.9	30.0	L	94	8.2
7	IR 06G112	39.5	2	6.5	1.8	3.6	23.9	HI/I	100	9.4
8	IR 79971-B-148-3-1	51.6	8	6.2	2.1	2.9	29.4	I/L	97	9.3
9	IR 06G116	41.9	2	6.6	1.9	3.5	24.3	HI/I	88	9.9
10	IR 07L241	37.7	11	6.4	2.1	3.0	29.6	L	90	9.1
11	IR 07L282	35.2	20	6.6	1.9	3.4	29.2	L	92	9.5
12	IR 07L270	43.7	23	6.6	1.9	3.4	28.9	L	82	9.3
13	IR 07L279	48.9	4	6.4	2.0	3.2	29.9	I	100	8.7
14	IR 07L203	46.8	8	6.5	2.0	3.3	30.4	L	89	8.9
15	IR 03L148	47.9	3	6.6	1.9	3.5	27.1	I	100	8.7
16	IR 72176-140-1-2-2-3	48.6	1	6.6	1.9	3.5	32.3	I	93	7.7
17	IR 08L120	37.0	4	6.5	1.9	3.4	26.1	I	93	8.2
18	IR 08L122	54.3	11	6.5	2.1	3.2	26.5	I	100	7.6
19	IR 04A265	45.2	3	6.7	1.8	3.6	24.9	HI	100	7.2
20	IR 04A305	34.9	3	6.6	1.8	3.8	23.0	H/HI	92	7.8
21	IR 04A325	35.2	14	6.6	1.8	3.6	24.8	HI/I	96	7.5
22	IR 04A393	34.8	5	6.5	1.9	3.4	24.7	I	100	8.0
23	IRRI 154	44.0	7	6.7	2.0	3.5	30.7	I	92	7.0
24	IR 05A103	20.2	31	6.4	2.1	3.1	31.2	I	96	7.3
25	IR 08L374	53.1	2	6.4	2.0	3.1	27.2	I	100	7.2
26	IR 08L375	45.9	4	6.4	2.0	3.2	27.1	I	100	7.7
27	IR 05N449	48.3	3	6.7	1.9	3.5	25.4	I	100	7.3
28	IR 06L144	46.1	5	6.5	1.9	3.4	25.8	I	88	7.6
29	IR 06L160	42.6	7	6.4	1.8	3.5	27.8	L	48	7.8
30	IR 06L167	46.7	11	6.5	2.1	3.1	28.5	I	85	7.6
31	IR 06L132	34.3	3	6.4	1.9	3.4	25.7	I	73	8.6
32	IR 07L167	55.2	2	6.9	2.0	3.5	24.7	I	78	7.4

33	IR 08L343	53.0	6	6.9	2.0	3.4	31.2	L	86	7.0
34	IR 08L408	39.1	13	6.2	2.0	3.1	31.6	I	100	8.1
35	IRRI 123	40.7	11	1.5	2.0	0.7	24.4	HI/I	95	7.8
36	RUMPE	58.3	3	6.3	1.8	3.5	29.3	I	95	8.7
37	IR 66229-243-6-2	59.7	0	6.5	1.7	3.7	14.0	L	81	10.5
38	IR 66298-15-3-3-2	49.4	12	6.4	1.7	3.7	22.6	I	52	9.6
39	IR 66696-97-4-3-1	22.7	9	6.7	1.8	3.9	23.5	I	76	10.4
40	IR 67420-189-1-3-2-1	0.0					22.9	I	80	10.2
41	IR 67420-206-1-2-3-2	51.4	2	6.5	1.7	3.7	20.7	I	74	9.7
42	IR 67420-206-3-1-3-3	55.6	0	6.5	1.7	3.7	25.3	L	46	10.2
43	IR 70421-188-2-1	43.5	8	6.7	1.8	3.7	23.3	HI/I	100	10.7
44	CAR 4	49.0	10	6.2	2.0	3.1	24.7	I	86	8.1
45	CAR 6	19.3	15	6.3	1.9	3.3	24.9	I	83	7.2
46	PHKA RUMDENG	0.0					15.2	L	81	7.9
47	PHKA RUMDUOL	41.0	4	6.9	2.0	3.5	13.8	L	90	8.0
48	PHKA RUMEAT									
49	PKHA CHAN SEN SOR	55.9	7	6.5	1.9	3.4	19.6	HI/I	50	9.6
50	RIANG CHEY	47.9	17	6.3	1.9	3.3	24.9	I	95	6.7
51	CT 16659-8-2CT-1-3-5-2-1-M	44.3	0	6.7	1.9	3.5	16.7	L	92	9.7
52	PCT 6/0/0/0>19-1-4-3-1-1-1-3-5-M	13.6	1	6.9	1.9	3.6	15.3	L	94	8.9
53	ADT (R) 48	48.3	2	6.3	1.9	3.4	19.1	HI/I	100	10.7
54	IR 71700-247-1-1-2	44.7	4	6.3	1.8	3.5	17.6	I	88	9.5
55	IR 50	16.6	2	6.3	1.7	3.6	29.2	I	95	9.5
56	BINDESHWARI	25.6	2	6.1	2.0	3.1	30.0	L	86	9.1
57	OM 5627	45.8	5	6.5	1.9	3.4	28.2	L	90	9.8
58	IR 66	34.4	5	6.3	1.8	3.4	28.9	I	97	8.5
59	IR 72	30.3	7	6.3	2.0	3.2	30.5	I	90	8.4
60	PSB RC 68	55.0	7	6.8	2.1	3.3	30.6	I	97	9.0
61	CT 15809-1-2-1-1-2SR-1-2-2-2-M	46.8	5	6.9	2.1	3.3	28.5	I	80	9.3
62	OM 6161	49.7	15	6.5	2.0	3.3	14.1	H	92	8.6
63	OM 6073	57.6	6	6.5	1.9	3.4	28.5	I	80	8.5
64	IR 71720-19-3-2-3	24.0	2	6.6	1.8	3.6	22.7	I/L	63	9.0
65	CT 15673-8-2-3-1-1-M	51.7	3	6.6	2.0	3.3	16.2	L	85	9.5
66	CIBOGO	52.7	6	6.5	1.9	3.4	22.7	HI/I	94	8.8

67	OMCS 2009	10.2	9	6.5	1.9	3.5	24.0	I/L	79	8.7
68	CT 15672-3-2-3-2-2-M	0.8					13.1	L	81	8.6
69	PCT 6/0/0/0>19-1-4-3-1-1-1-1-1-M	18.9	3	6.9	1.9	3.6	15.8	L	90	8.0
70	SEN PIDAO	10.2	4	6.5	1.8	3.6	19.8	L	62	8.1
71	IR 75288-144-1-3	20.3	9	6.3	1.8	3.5	24.2	I	84	8.2
72	OM 7938	59.3	1	6.4	1.8	3.5	18.2	L	83	9.0
73	CT 9509-17-3-1-1-M-1-3P-M	13.4	5	6.5	1.9	3.4	29.6	L	83	8.0
74	IR 77512-128-2-1-2	19.8	2	6.5	1.9	3.4	25.4	I	90	9.0
75	PR 26645-B-7	58.1	8	6.5	2.0	3.2	26.3	L	89	7.5
76	IR 77542-560-1-1-1-1-2	35.6	2	6.9	1.8	3.8	26.8	L	57	8.5
77	PSB RC 2 (IR 32809-26-3-3)	51.5	5	6.4	1.9	3.3	30.9	I	98	8.0
78	IR 77542-112-1-1-1-1-3	24.8	16	6.8	1.7	3.9	15.8	H/HI	86	9.3
79	IR 78545-49-2-2-2	60.2	5	6.6	1.9	3.5	23.3	HI/I	86	9.4
80	IR 77734-93-2-3-2	43.0	2	6.4	1.8	3.7	30.7	I	84	9.3
81	IR 76993-49-1-1	49.3	4	6.5	1.9	3.4	25.0	I/L	81	9.2
82	IR 78554-145-1-3-2	58.5	4	6.7	1.9	3.5	23.6	I	81	8.7
83	IR 81352-65-2-1-3-3	61.2	3	6.7	2.0	3.3	24.3	I	94	9.0
84	PSB RC 64(IR59552-21-3-2-2)	45.2	10	6.7	1.9	3.5	24.7	I	78	9.0
85	CT 6775-5-17-4-2-7P	45.3	12	6.7	2.0	3.4	23.9	I/L	56	9.6
86	IR 78555-68-3-3-3	61.0	9	6.5	2.0	3.2	28.1	I	48	9.3
87	IR 79478-67-3-3-2	30.1	7	6.9	1.9	3.7	30.0	I	92	8.1
88	A69-1	43.8	42	6.4	2.2	2.9	28.9	I	90	8.8
89	IR 75395-2B-B-19-2-1-1	21.7	39	6.6	1.8	3.7	22.9	I	76	8.6
90	IR 83415-B-SDO3-3-AJY1	47.5	8	6.5	1.9	3.4	30.5	I	88	8.1
91	IR 72046-B-R-3	45.8	20	5.6	2.3	2.5	30.7	I	100	7.0
92	IR 77674-3B-8-2-2-8-2-AJY10	15.4	4	6.7	1.8	3.7	26.4	L	89	7.8
93	IR 77674-3B-8-2-2-8-2-4	3.8	5	7.1	1.8	3.9	26.3	L	78	8.1
94	IR 73678-6-9-B	35.4	15	6.5	1.9	3.5	24.9	I	92	7.6
95	IR 61640-3B-14-3-3-2	43.3	7	6.6	2.0	3.4	29.4	I	100	6.6
96	BC-10	45.9	4	6.2	1.9	3.3	29.1	L	97	8.4
97	IR 64	45.5	7	6.6	1.9	3.4	21.3	HI/I	96	9.3
98	IR 31917-45-3-2	49.0	5	6.4	2.1	3.0	21.6	I	93	8.7
99	IR 71033-4-1-127-B	55.3	5	6.7	2.0	3.4	22.1	I/L	95	8.6
100	IR 71033-62-15-B	33.9	24	6.8	2.0	3.4	25.4	I	100	8.0

101	IR 71033-121-15-B	28.9	23	6.9	2.1	3.4	24.3	I	100	7.8
102	IR 65483-118-25-31-7-1-5-B	46.5	1	6.5	1.8	3.5	30.4	L	75	8.5
103	IR 75870-5-8-5-B-5-B	31.5	9	6.6	1.9	3.5	31.0	I	88	6.5
104	IR 80310-12-B-1-3-B	49.4	28	5.7	2.3	2.5	22.2	I	76	7.3
105	IR 80314-4-B-1-3-B	37.8	16	6.4	2.0	3.3	23.9	HI/I	80	7.4
106	IR 80340-23-B-12-6-B	53.5	6	6.5	2.1	3.1	21.3	H/HI	85	7.5
107	IR 80340-12-B-B-1-2-B-B	56.0	18	6.7	2.1	3.1	28.6	I	94	7.0
108	IR 80340-23-B-4-1-1-B-B	63.6	4	6.5	2.1	3.2	21.1	I	82	8.5
109	IR 80352-10-B-24-1-B-B	49.8	8	6.5	2.0	3.2	23.2	I	88	8.1
110	IR 71146-97-1-2-1-3	43.6	11	6.8	2.0	3.4	20.6	I/L	90	7.2
111	IR 04N155	25.7	28	6.8	2.1	3.3	25.7	I	100	6.6
112	IR 06M145	24.9	39	6.5	2.2	2.9	24.0	I	87	5.6
113	IR 06M139	60.9	1	6.7	2.0	3.3	18.2	L	90	6.8
114	IR 06M142	45.8	17	6.8	2.0	3.5	19.9	I/L	85	6.7
115	IR 03A568	54.1	4	6.7	1.9	3.6	30.3	I	74	6.9
116	IR 04N106	64.7	7	6.9	2.0	3.4	28.1	I	98	7.2
117	IR 04A390	38.2	11	6.6	1.9	3.4	24.1	I	73	7.3
118	IR 06N154	65.5	1	6.5	2.1	3.1	14.8	L	87	6.8
119	IR 73546-20-2-2-2	39.1	16	6.7	1.9	3.6	23.4	HI/I	76	7.5
120	IR 03A151	36.3	9	6.5	2.0	3.3	25.9	L	68	6.8
121	IR 05A278	39.8	7	6.8	2.0	3.4	25.4	I/L	66	7.4
122	IR 73000-70-2-2-2	35.9	20	6.5	2.0	3.3	23.2	I	85	7.8
123	IR 02A477	49.6	11	6.5	1.9	3.3	19.9	HI	80	8.2
124	IR 68058-71-2-1	33.6	21	6.7	2.0	3.4	24.3	I	85	7.3
125	IR 00A105	14.6	49	6.7	2.1	3.3	29.8	I	85	6.9
126	IR 68450-36-3-2-2-3	49.6	9	6.4	2.0	3.2	24.2	I	80	8.2
127	IR 69726-116-1-3	41.2	26	6.5	2.0	3.2	22.9	I	85	7.8
128	IR 72875-94-3-3-2	20.1	24	6.6	2.0	3.4	21.7	I	74	7.1
129	IR 73439-11-1-3-1	34.2	28	6.7	2.2	3.1	20.5	I	69	6.2
130	IR 73459-120-2-2-3	47.8	17	6.7	2.1	3.2	24.7	I	75	6.7
131	IR 80411-B-49-1	52.9	15	6.9	2.1	3.2	29.2	I	81	8.0
132	IR 80412-B-31-1	56.3	2	6.4	1.9	3.4	29.5	I/L	92	8.0
133	IR 79195-42-1-3-1	46.5	9	6.6	1.9	3.4	24.1	HI	70	6.8
134	IR 79233-1-2-1-2	51.6	23	6.5	2.2	3.0	24.5	I	71	6.7

135	IRYN 1005-105-B	51.5	2	6.7	2.0	3.4	25.1	HI/I	80	7.5
136	IRYN 1068-4-B	39.3	11	6.4	2.1	3.0	31.3	I	73	7.4
137	OM 5796	21.0	7	6.6	2.0	3.3	24.6	HI/I	100	7.9
138	PR 34727-3-1-1-1-1	42.0	4	6.6	2.0	3.3	25.0	I	100	7.8
139	IR 83140-B-11-B	46.0	5	6.7	2.0	3.4	24.5	I	100	7.8
140	IR 83142-B-20-B	36.1	7	6.6	2.0	3.4	23.2	HI/I	98	8.4
141	IR 83142-B-7-B-B	30.1	7	6.7	2.0	3.4	24.2	I	100	8.7
142	HHZ 5-SAL 9-Y 3-Y 1	62.0	5	6.7	2.0	3.4	27.4	L	51	8.0
143	HHZ 15-SUB 1-Y 3-Y 1	43.0	32	6.8	2.3	3.0	28.9	L	39	6.2
144	ZHONGHUA1	63.2	1	5.7	2.0	2.8	29.3	L	55	8.1
145	ZX117	30.0	3	6.7	2.1	3.2	18.3	L	96	7.6
146	IRRI 119	56.2	2	6.8	2.0	3.4	28.0	I	100	8.4
147	PSB RC 82-SUB1	39.5	6	6.8	1.9	3.6	23.7	I	90	8.9
148	IR 70174-14-SRN-4-UBN-2-B-1-2	66.5	0	6.9	2.0	3.5	28.1	L	74	8.1
149	CT 6510-24-1-2	8.3	8	6.4	2.1	3.0	22.2	L	70	7.9
150	IR 82870-57	61.7	10	6.4	2.1	3.1	23.8	I	73	7.3
151	IR 55423-01	62.9	29	6.2	2.2	2.8	22.0	I	64	7.8
152	BP 223 E-MR-5	52.4	2	6.3	2.2	2.8	19.8	L	77	8.9
153	IR 03L111	30.1	5	6.2	2.2	2.8	24.4	L	73	8.9
154	IR 74371-3-1-1	33.3	10	6.2	2.3	2.7	27.6	L	70	10.3
155	IRRI 148	45.9	11	6.2	2.1	2.9	23.9	L	63	9.0
156	IR 06U101	22.7	29	6.5	2.3	2.8	21.4	I	84	8.1
157	IR 78875-176-B-2-B	37.0	17	6.4	2.0	3.2	23.7	I	84	8.9
158	IR 78875-207-B-1-B	50.4	16	5.7	2.2	2.5	23.2	I	72	7.8
159	IR 08L103	44.1	8	6.7	2.0	3.3	25.0	L	85	7.9
160	IR 78877-208-B-1-2	21.9	19	6.4	2.2	3.0	22.1	I	68	9.2
161	IR 08L403	36.0	6	6.5	1.9	3.5	24.2	I	98	8.6
162	IR 78937-B-20-B-B-4	43.8	11	6.3	2.2	2.9	28.5	I	90	7.7
163	IR 78937-B-3-B-B-1	37.9	10	6.2	2.1	2.9	29.3	L	85	7.8
164	IR 79899-B-179-2-3	15.0	6	6.8	2.0	3.4	28.3	I	85	8.7
165	IR 06G110	38.8	6	6.5	2.0	3.3	23.9	I	85	7.7
166	IR 79907-B-389-B-1	39.6	2	6.5	1.9	3.5	28.4	L	85	8.1
167	IR 79907-B-425-B-3	45.3	8	6.3	1.8	3.5	24.1	HI/I	85	8.2
168	IR 79907-B-425-B-4	53.6	3	6.3	1.9	3.3	29.3	I	91	8.2

169	IR 79913-B-176-B-4	38.7	6	6.3	2.2	2.8	29.4	I	96	9.3
170	IR 79913-B-20-B-2	40.0	4	6.2	2.1	2.9	29.3	L	64	9.1
171	IR 79913-B-238-B-3	48.6	9	6.2	2.2	2.8	28.3	L	91	8.4
172	IR 79913-B-362-B-3	43.3	10	6.1	2.1	2.9	29.2	I	75	8.6
173	IR 06G113	37.1	3	6.8	1.9	3.5	23.1	I	96	8.2
174	IR 79971-B-201-2-3	20.7	52	5.6	2.2	2.5	28.4	I	87	8.5
175	IR 80013-B-141-4-1	54.7	16	6.3	2.1	3.0	22.6	I	92	7.8
176	IR 80014-B2-25-B-B-B	52.8	22	5.6	2.2	2.5	21.7	I	72	8.1
177	IR 07L290	55.0	6	5.7	2.2	2.6	22.0	I	75	8.2
178	IR 07L332	48.9	7	6.3	2.0	3.1	27.9	I	90	8.1
179	IR 07L330	35.7	13	6.3	2.1	3.1	27.8	L	90	8.1
180	IR 81040-B-78-U 2-1	38.6	1	6.7	2.0	3.4	29.0	L	45	9.0
181	IR 07L256	43.3	15	6.5	1.9	3.4	23.6	I	85	8.5
182	IR 07L205	40.8	10	6.3	2.0	3.1	19.1	HI/I	78	9.1
183	IR 07L277	42.4	11	6.6	1.9	3.5	27.2	L	89	8.6
184	IR 08L141	39.1	4	6.2	2.1	2.9	27.8	I	90	8.0
185	IR 08L382	49.1	6	6.2	2.2	2.8	27.3	L	98	8.2
186	IR 08L337	52.8	1	6.2	2.1	2.9	27.6	L	97	8.7
187	IR 04L180	40.3	5	6.9	2.0	3.4	25.6	Segregating	98	9.6
188	IR 04L186	48.3	2	6.8	1.9	3.5	27.1	L	90	8.6
189	IR 03L146	42.6	2	6.8	1.8	3.8	25.7	L	77	8.2
190	IR 06L104	54.0	3	6.3	2.0	3.1	29.6	L	65	7.1
191	IR 06L119	35.6	4	6.2	2.1	2.9	27.9	L	53	6.8
192	IR 03L120	47.8	2	6.5	1.9	3.5	23.4	I	95	7.6
193	IR 05A139	38.4	7	6.9	1.9	3.7	23.0	HI/I	95	7.3
194	IR 05A233	63.0	2	6.9	1.9	3.6	13.0	HI/I	90	7.7
195	IR 05A235	39.8	5	6.9	1.9	3.6	28.0	I	72	7.8
196	IR 05N386	61.4	2	7.0	2.1	3.3	28.8	I	80	7.7
197	IR 05N412	60.1	3	6.7	2.0	3.3	23.3	H/I	89	7.3
198	IR 05N419	64.7	9	6.5	2.0	3.3	21.5	I	94	7.7
199	IR 05N444	59.8	2	6.7	2.0	3.3	21.8	I	94	7.9
200	IR 05N496	58.3	1	6.8	2.0	3.5	22.8	I	87	7.7
201	IR 06L142	51.5	1	6.6	1.9	3.5	23.6	L	64	7.9
202	IR 06L158	44.5	1	6.5	1.9	3.5	17.2	H/HI	90	7.7

203	IR 06L141	56.5	1	6.6	1.9	3.4	29.4	I	91	7.9
204	IR 06L139	54.1	9	6.6	2.1	3.1	29.6	I	89	7.9
205	IR 06L165	53.0	7	6.7	2.0	3.3	28.4	L	85	8.6
206	IR 06L136	49.1	0	6.4	1.8	3.6	28.4	I	89	8.4
207	IR 06L129	50.0	4	6.4	1.9	3.4	25.8	I	76	8.3
208	IR 06L168	54.3	4	6.5	1.9	3.4	24.6	I	79	8.0
209	IR 06L164	48.4	6	6.4	1.9	3.4	25.6	I	95	7.6
210	IR 07L166	46.0	1	6.6	1.9	3.4	24.9	I	85	8.4
211	IR 07L122	47.2	9	6.7	2.1	3.2	29.2	L	80	8.6
212	IR 07L163	49.7	12	6.7	2.1	3.2	29.8	I	79	8.7
213	IR 08L318	20.0	2	6.9	1.8	3.8	31.1	L	44	8.2
214	IR 08L410	47.1	16	6.3	2.0	3.1	30.0	I	98	7.7
215	IR 08L407	22.1	15	6.4	1.7	3.9	25.9	I	90	7.0
216	IR 08L105	53.3	3	6.3	1.9	3.3	29.7	I	98	7.9
217	CHUL'SA	41.6	8	6.4	1.8	3.5	22.2	HI/L	60	9.0
218	IR 80342-11-B-18-1-B-B	53.9	6	6.6	1.9	3.5	23.6	I	81	8.8
219	IR 77379-6-1-17-14-B-B	22.7	12	7.0	1.8	3.8	28.7	I	75	11.3
220	IR 69502-6-SRN-3-UBN-1-B	59.5	10	6.5	2.1	3.2	19.9	I	65	10.1
221	IR 04A421	49.2	9	6.8	2.0	3.3	27.1	I	56	8.4
222	IR 06M141	60.7	2	6.8	2.1	3.3	16.7	L	82	8.6
223	IR 05A272	34.9	16	7.0	1.9	3.7	26.8	I	73	7.8
224	IR 08A176	60.5	14	6.6	2.1	3.2	22.3	I	80	8.2
225	IR 04A428	52.5	14	6.9	2.0	3.4	24.1	I	90	9.4
226	IR 03A262	58.0	12	6.8	2.0	3.4	24.4	I/L	60	8.8
227	IRRI 150	45.2	7	6.8	2.0	3.4	27.2	I	76	8.4
228	IR 10T109	15.7	4	6.8	1.8	3.8	28.2	L	73	9.7
229	IR 10T113	28.6	10	6.9	1.7	3.9	21.6	I	70	8.1
230	OM 4495	51.4	2	6.5	2.0	3.3	20.7	HI/I	70	9.5
231	OM 6049	38.3	3	6.2	2.0	3.1	27.9	L	30	9.0
232	OM 2718	45.3	3	6.5	1.9	3.5	20.4	HI/I	62	9.8

Set 2: 94 lines/varieties

Set 2 included 54 breeding lines and 40 local varieties. The grain quality evaluation results are presented in Table 2a.

HRY ranged from 11 – 68% with only 17 lines having values ≥ 50%. The chalkiness obtained was 2 – 61%. The number of lines/varieties having ≤ 25% chalkiness was 62. About a third of the samples in the set had unacceptable chalkiness (≥ 25%).

The length of the grain ranged from 5.17 – 7.00 mm. Four lines including Thmar Krem have short grains; 60 lines have medium or intermediate length while 29 lines had long grains. As to the shape classification, majority of the samples (82 lines/varieties) had slender grains.

Amylose content (AC) ranged from 3.6 – 29.2%. Classification of the samples based on amylose content were as follows: very low (1 line), low (36 lines), intermediate (32 lines) and high (24 lines) AC.

About half of the samples exhibited an intermediate GT according to the ASV score.

Most of the samples (91 lines) showed soft gel consistency (> 61 mm length of gel).

The analysis of rice flour samples in a Rapid Visco Analyzer (RVA) shows viscosity changes as flour is cooked and cooled to 50^{o}C. The RVA data obtained are shown in Table 2b. Gelatinization and paste viscosity characteristics of milled rice flour predict cooking properties. The pasting properties that characterize rice and measured in the RVA are as follows: (Ref. AACC Method 61-02)

- Pasting temperature – temperature of the initial viscosity increase; directly related to gelatinization temperature (GT), equal to GT + 3 degrees
- Peak – maximum viscosity recorded during the heating and holding cycles; usually occurs soon after temperature reaches 95^{o}C
- Peak time – time required to reach peak
- Trough – minimum viscosity after peak
- Final viscosity – viscosity achieved at the end of the run
- Breakdown – the difference between peak and trough; an indication of the breakdown in viscosity of the paste during the 95^{o}C holding period. Breakdown is related to stability of the starch to heat and shear stress
- Setback – the difference between final viscosity and peak viscosity; an indication of the starch to retrograde
- Retrogradation – the difference between final viscosity and trough; an indication of the starch to retrograde

Both setback and retrogradation give an indication for cooked rice to retrograde or harden on cooling. In this second set of 94 samples, setback and retrogadation values correlate with R^2 = 0.701. In general, rice with setback values that are negative or close to zero are preferred because they remain soft after the cooked rice is cooled.

The diversity in grain quality traits is demonstrated in the Principal Component Analysis (PCA) of the data obtained as shown in Figure 2. The plot was presented by Dr. Melissa Fitzgerald in the final meeting of the project in July 2013 in CARDI.

Table 2a. Quality evaluation results of second set of 94 lines/varieties

No	Line / Variety	% Head Rice	Chalkiness	Grain Length L, mm	Grain Width W, mm	Grain Shape L/W	% Amylose	Gelatinization Temperature by ASV*	Gel Consistency
1	IR 04L186	37.3	14	6.8	1.9	3.5	26.7	L	95
2	IR 06L136	40.2	23	6.5	1.9	3.5	28.3	I	100
3	IR 08L152	28.0	46	6.3	2.0	3.1	19.4	I	79
4	IR 08L269	29.2	45	6.2	2.1	3.0	17.4	HI	93
5	IR 09L303	39.6	14	6.5	1.9	3.4	23.0	I/L	100
6	IR 09L336	38.0	22	6.4	1.9	3.4	21.1	L	100
7	IR 09L337	47.5	6	6.7	1.9	3.5	20.1	HI/I	100
8	IR 09L342	28.1	17	6.4	1.9	3.4	22.3	I/L	100
9	IR 10L149	28.8	7	6.7	1.8	3.7	25.4	L	100
10	IR 11A137	40.5	20	6.6	2.0	3.3	21.0	I/L	95
11	IR 67014-45-3-1	11.0	43	6.5	1.7	3.8	19.4	HI	90
12	IR 70421-188-2-1	12.9	31	6.5	1.8	3.6	18.0	I	74
13	IR 77674-3B-8-2-2-8-2-AJY6	14.6	7	6.8	1.8	3.8	19.5	I/L	84
14	IR 87741-29-1-1-2	42.0	17	6.4	1.8	3.5	16.5	HI/I	99
15	IR 87747-16-1-1-1	40.9	22	6.4	1.8	3.6	19.1	HI	79
16	IR 87747-16-3-1-4	37.1	18	6.4	1.8	3.5	19.7	HI/I	100
17	IR 87753-15-1-2-1	33.5	21	6.4	1.8	3.6	17.6	HI/I	99
18	IR 87753-15-1-2-4	50.0	17	6.4	1.8	3.5	19.4	HI/I	98
19	IR 87753-5-1-6-4	38.2	17	6.5	1.8	3.5	19.0	HI/I	97
20	IR 87754-42-2-2-3	49.3	16	6.4	1.8	3.5	19.2	HI/I	95
21	IR 87759-13-1-1-3	42.8	16	6.4	1.8	3.6	20.0	I	92
22	IR 87761-51-1-3-1	39.9	25	6.5	1.8	3.5	19.9	HI	94
23	IR 87808-21-2-2-3	48.4	21	6.4	1.8	3.6	20.0	HI/I	96
24	IR 06L141	45.3	18	6.5	1.9	3.4	28.2	I	97
25	IR 09A102	42.8	40	6.3	1.9	3.2	20.0	HI	94
26	IR 69502-6-SRN-3-UBN-1-B	44.4	41	6.4	1.9	3.3	19.5	I	94
27	IR 80411-B-49-1	44.9	31	6.7	2.1	3.2	26.8	I	84
28	IR 87741-29-1-1-4								
29	IR 87751-16-2-1-2	48.4	16	6.3	1.8	3.5	20.1	HI/I	95
30	IR 87751-17-5-1-3	38.6	14	6.4	1.8	3.5	19.7	HI/I	95
31	IR 87753-5-2-1-3	35.1	7	6.6	1.9	3.6	19.1	I	75
32	IR 87754-40-2-1-4	43.8	16	6.4	1.8	3.6	20.0	I	100
33	IR 87754-42-1-4-1	51.0	14	6.3	1.8	3.5	19.3	I	95
34	IR 87759-10-1-2-2	40.1	21	6.4	1.8	3.5	20.1	I	94
35	IR 87759-12-2-1-2	48.2	28	6.3	1.8	3.5	19.7	I	100
36	IR 87759-12-2-1-3	46.8	31	6.4	1.8	3.5	19.5	I	100
37	IR 87759-12-3-1-4	38.7	24	6.4	1.8	3.6	20.0	HI	94
38	IR 87759-7-1-2-2	36.7	4	6.7	1.8	3.6	20.2	I	90
39	IR 87760-17-2-1-1	39.7	6	6.7	1.8	3.7	20.3	I	95
40	IR 87760-28-1-1-2	46.0	21	6.4	1.8	3.5	19.2	HI/I	95
41	IR 87761-41-2-2-4	49.1	18	6.3	1.8	3.5	19.2	I	95
42	IR 87761-52-2-2-4	47.7	24	6.3	1.8	3.5	20.5	I	95
43	IR 87761-53-1-1-1	34.6	33	6.4	1.8	3.5	28.8	I	94
44	IR 87761-53-1-1-4	33.8	29	6.4	1.8	3.5	29.2	I	90
45	IR 87761-55-3-1-4	47.4	15	6.4	1.8	3.6	20.5	HI	95
46	IR 87761-66-2-3-2	41.4	8	6.4	1.8	3.6	20.6	HI	70
47	IR 87808-21-2-2-2	29.5	4	6.7	1.8	3.7	20.4	HI	100
48	IR 81040-B-78-U 2-1	37.7	19	6.7	2.1	3.2	26.9	L	69
49	IR 07L167	27.8	46	6.8	2.0	3.4	18.4	I	100
50	IR 77674-3B-8-2-2-8-2-4	14.7	23	6.7	1.9	3.6	20.7	I/L	75
51	IR 03L148	40.3	26	6.8	1.9	3.5	21.2	I/L	100
52	IR 04N155	34.2	29	6.7	2.0	3.3	21.6	HI/I	98
53	IR 06L164	39.4	19	6.6	1.9	3.6	18.9	HI/I	90
54	IR 83415-B-SDO3-3-AJY1	43.8	32	6.5	1.9	3.4	27.0	I	100
55	BARAY	20.6	45	6.3	1.8	3.4	16.8	I	85
56	CAR 1	36.3	29	6.2	1.8	3.4	27.8	I	94
57	CAR 11	53.2	6	6.9	2.0	3.4	22.9	L	98
58	CAR 12	65.8	18	5.6	2.1	2.6	27.6	I	93
59	CAR 13	67.9	11	5.5	2.1	2.7	21.5	I	100
60	CAR 2	39.7	53	5.2	2.3	2.2	18.7	I	90
61	CAR 3	44.0	38	6.3	2.2	2.9	20.9	I	98
62	CAR 4	59.3	38	6.2	2.0	3.1	20.3	I	100
63	CAR 5	58.2	16	6.3	1.9	3.3	21.5	I	100
64	CAR 6	62.6	17	6.3	1.9	3.3	20.9	I	95
65	CAR 7	52.6	30	5.5	2.4	2.3	26.0	I	90
66	CAR 8	52.1	36	5.4	2.3	2.4	20.9	I	95
67	CAR 9	52.3	26	6.3	2.1	2.9	28.1	I	94
68	CHUL'SA	47.1	9	6.5	1.9	3.4	21.6	HI/I	90
69	DON	51.1	5	6.9	2.1	3.4	25.8	I	96
70	GLUTINOUS-6	38.8	2	6.8	1.9	3.5	3.6	I	70
71	IR 66	47.5	29	6.4	1.9	3.4	26.4	I	96
72	IR 72	20.2	55	6.4	2.0	3.2	28.2	I	91
73	IR KESAR	24.1	39	6.3	2.0	3.2	17.8	I	75
74	KHAO TAH PETCH	50.4	16	6.7	2.1	3.2	21.7	I	97
75	KRU	22.8	31	6.5	1.9	3.5	16.1	I	92
76	PHKA CHAN SEN SAR	34.6	16	6.3	1.9	3.4	18.5	I	70
77	PHKA ROMEAT	43.6	6	6.9	2.0	3.4	13.2	I/L	89
78	PHKA RUMCHANG	43.7	2	6.9	2.0	3.5	12.6	L	85
79	PHKA RUMCHEK	49.6	3	7.0	2.0	3.5	13.2	L	75
80	PHKA RUMDUOL	42.2	5	6.9	2.0	3.4	12.1	L	84
81	PKHA ROMDENG	45.6	3	6.8	2.0	3.5	12.9	L	86
82	POPOUL	39.3	13	6.9	2.3	3.0	27.3	L	50
83	RIANG CHEY	46.5	38	6.2	1.9	3.3	20.8	HI/I	90

84	RIMKE	32.0	24	6.7	2.3	2.9	19.6	I	75
85	ROHAT	45.0	17	6.5	1.9	3.3	25.0	L	80
86	RUMPE	23.9	30	6.3	1.9	3.4	26.0	I	90
87	SANTEPHEAP 1	58.0	10	6.5	2.2	3.0	23.5	L	86
88	SANTEPHEAP 2	59.4	9	6.7	2.1	3.2	28.1	I	89
89	SANTEPHEAP 3	64.2	44	6.4	2.6	2.5	27.1	I	95
90	SARIKA	32.8	21	6.9	2.2	3.1	26.9	L	30
91	SEN PIDAO	49.9	6	6.5	1.9	3.4	17.3	L	60
92	SITA	41.5	61	5.5	2.5	2.2	15.9	I	68
93	TEWADA	53.8	24	6.9	2.1	3.3	26.3	I	80
94	THMAR KREM	52.3	25	5.5	2.0	2.7	26.0	I	100

Table 2b. Viscosity profile of 94 lines/varieties obtained by the Rapid Visco Analyzer

No	Line / Variety	Pasting Temp ºC	Peak Time min	Peak Viscosity cP	Trough cP	Final Viscosity cP	Breakdown cP	Setback cP	Retrogradation
1	IR 04L186	72.1	5.67	1975	1459	3151	516	1176	1692
2	IR 06L136	76.8	5.47	2243	1397	3158	846	915	1761
3	IR 08L152	77.6	5.67	2590	1419	2885	1171	295	1466
4	IR 08L269	79.0	5.73	2547	1458	2865	1089	318	1407
5	IR 09L303	69.7	5.80	2713	1522	3085	1191	372	1563
6	IR 09L336	68.8	5.80	2716	1533	3030	1183	314	1497
7	IR 09L337	77.5	5.67	2203	1456	2954	747	751	1498
8	IR 09L342	69.7	5.73	2635	1495	3063	1140	428	1568
9	IR 10L149	70.5	5.73	1966	1288	2599	678	633	1311
10	IR 11A137	72.9	5.60	3014	1530	3083	1484	69	1553
11	IR 67014-45-3-1	78.4	5.60	3351	1590	3053	1761	-298	1463
12	IR 70421-188-2-1	77.5	5.67	3115	1545	2992	1570	-123	1447
13	IR 77674-3B-8-2-2-8-2-AJY6	71.3	5.93	2559	1600	3265	959	706	1665
14	IR 87741-29-1-1-2	77.5	5.60	2782	1411	2883	1371	101	1472
15	IR 87747-16-1-1-1	78.2	5.60	2901	1430	2888	1471	-13	1458
16	IR 87747-16-3-1-4	77.6	5.53	2792	1406	2846	1386	54	1440
17	IR 87753-15-1-2-1	78.2	5.47	2812	1429	2925	1383	113	1496
18	IR 87753-15-1-2-4	77.5	5.53	2767	1377	2832	1390	65	1455
19	IR 87753-5-1-6-4	77.4	5.60	2722	1353	2805	1369	83	1452
20	IR 87754-42-2-2-3	77.5	5.47	2845	1421	2868	1424	23	1447
21	IR 87759-13-1-1-3	78.3	5.60	2941	1473	2960	1468	19	1487
22	IR 87761-51-1-3-1	78.3	5.60	2886	1465	2927	1421	41	1462
23	IR 87808-21-2-2-3	78.3	5.60	2897	1418	2849	1479	-48	1431
24	IR 06L141	76.0	5.40	2671	1453	3225	1218	554	1772
25	IR 09A102	77.5	5.67	3098	1592	3038	1506	-60	1446
26	IR 69502-6-SRN-3-UBN-1-B	77.5	5.60	3043	1474	2890	1569	-153	1416
27	IR 80411-B-49-1	75.2	5.53	2579	1441	3366	1138	787	1925
28	IR 87741-29-1-1-4								
29	IR 87751-16-2-1-2	78.3	5.53	2925	1457	2919	1468	-6	1462
30	IR 87751-17-5-1-3	77.6	5.53	2942	1431	2855	1511	-87	1424
31	IR 87753-5-2-1-3	78.3	5.60	1979	1412	2974	567	995	1562
32	IR 87754-40-2-1-4	77.5	5.53	3011	1465	2960	1546	-51	1495
33	IR 87754-42-1-4-1	77.5	5.53	2949	1468	2910	1481	-39	1442
34	IR 87759-10-1-2-2	78.3	5.60	2885	1490	2954	1395	69	1464
35	IR 87759-12-2-1-2	77.5	5.67	2978	1500	2936	1478	-42	1436
36	IR 87759-12-2-1-3	77.5	5.53	3025	1456	2892	1569	-133	1436
37	IR 87759-12-3-1-4	77.5	5.53	2881	1430	2886	1451	5	1456
38	IR 87759-7-1-2-2	79.8	5.60	2106	1490	3072	616	966	1582
39	IR 87760-17-2-1-1	80.0	5.67	1973	1473	3076	500	1103	1603
40	IR 87760-28-1-1-2	78.3	5.53	2956	1479	2988	1477	32	1509
41	IR 87761-41-2-2-4	77.5	5.67	2968	1461	2928	1507	-40	1467
42	IR 87761-52-2-2-4	77.5	5.60	3003	1482	2944	1521	-59	1462
43	IR 87761-53-1-1-1	76.0	5.73	3193	2103	4113	1090	920	2010
44	IR 87761-53-1-1-4	75.9	5.53	3215	2046	4122	1169	907	2076
45	IR 87761-55-3-1-4	77.5	5.47	3046	1481	2927	1565	-119	1446
46	IR 87761-66-2-3-2	78.4	5.60	2937	1486	2930	1451	-7	1444
47	IR 87808-21-2-2-2	78.4	5.67	2124	1414	2987	710	863	1573
48	IR 81040-B-78-U 2-1	72.8	5.73	2251	1924	3757	327	1506	1833
49	IR 07L167	76.9	5.53	3132	1529	2920	1603	-212	1391
50	IR 77674-3B-8-2-2-8-2-4	74.4	5.93	2878	1780	3509	1098	631	1729
51	IR 03L148	77.5	5.47	2847	1347	2718	1500	-129	1371
52	IR 04N155	77.6	5.53	3018	1454	2887	1564	-131	1433
53	IR 06L164	78.3	5.53	2612	1456	2974	1156	362	1518
54	IR 83415-B-SDO3-3-AJY1	76.8	5.60	2493	1526	3415	967	922	1889
55	BARAY	78.4	5.80	3221	1653	2983	1568	-238	1330
56	CAR 1	75.2	5.53	3383	2101	4044	1282	661	1943
57	CAR 11	65.8	5.60	2120	1327	2808	793	688	1481
58	CAR 12	74.4	5.47	2760	1955	3723	805	963	1768
59	CAR 13	74.4	5.20	2221	1222	2362	999	141	1140
60	CAR 2	76.0	5.40	3173	1345	2614	1828	-559	1269
61	CAR 3	73.6	5.40	3185	1402	2642	1783	-543	1240
62	CAR 4	76.1	5.40	3246	1365	2563	1881	-683	1198
63	CAR 5	75.2	5.40	2692	1368	2618	1324	-74	1250
64	CAR 6	76.0	5.40	2704	1476	2884	1228	180	1408
65	CAR 7	75.2	5.67	3531	2225	4155	1306	624	1930
66	CAR 8	73.5	5.53	3158	1413	2760	1745	-398	1347
67	CAR 9	74.4	5.47	3447	1904	3794	1543	347	1890
68	CHUL'SA	76.8	5.67	2965	1585	3249	1380	284	1664
69	DON	74.3	5.53	2673	1676	3237	997	564	1561
70	GLUTINOUS-6	68.2	4.07	2833	1580	2116	1253	-717	536

71	IR 66	75.2	5.40	2068	1232	2939	836	871	1707
72	IR 72	76.0	5.80	2626	1725	3600	901	974	1875
73	IR KESAR	77.6	5.87	3051	1676	3180	1375	129	1504
74	KHAO TAH PETCH	72.9	5.40	2344	1257	2476	1087	132	1219
75	KRU	76.8	5.67	2794	1344	2612	1450	-182	1268
76	PHKA CHAN SEN SAR	75.2	5.60	3204	1573	2828	1631	-376	1255
77	PHKA ROMEAT	69.6	5.47	4121	1613	2597	2508	-1524	984
78	PHKA RUMCHANG	68.9	5.47	3693	1756	2870	1937	-823	1114
79	PHKA RUMCHEK	72.1	5.40	3157	1823	3009	1334	-148	1186
80	PHKA RUMDUOL	72.0	5.60	4180	1747	2640	2433	-1540	893
81	PKHA ROMDENG	71.3	5.40	4243	1637	2642	2606	-1601	1005
82	POPOUL	68.1	5.87	2882	2428	4781	454	1899	2353
83	RIANG CHEY	75.9	5.47	3306	1425	2700	1881	-606	1275
84	RIMKE	75.3	5.73	2999	1647	3083	1352	84	1436
85	ROHAT	73.5	5.87	1749	1227	2479	522	730	1252
86	RUMPE	76.8	5.60	2089	1317	3050	772	961	1733
87	SANTEPHEAP 1	67.4	5.80	2528	1598	3350	930	822	1752
88	SANTEPHEAP 2	75.2	5.40	2562	1967	3938	595	1376	1971
89	SANTEPHEAP 3	75.8	5.40	2933	1915	3680	1018	747	1765
90	SARIKA	68.9	5.87	2924	2545	5046	379	2122	2501
91	SEN PIDAO	69.7	5.60	3427	1587	3136	1840	-291	1549
92	SITA	77.6	5.73	3238	1735	2994	1503	-244	1259
93	TEWADA	74.3	5.53	2605	1809	3607	796	1002	1798
94	THMAR KREM	75.2	5.60	2118	1298	2806	820	688	1508

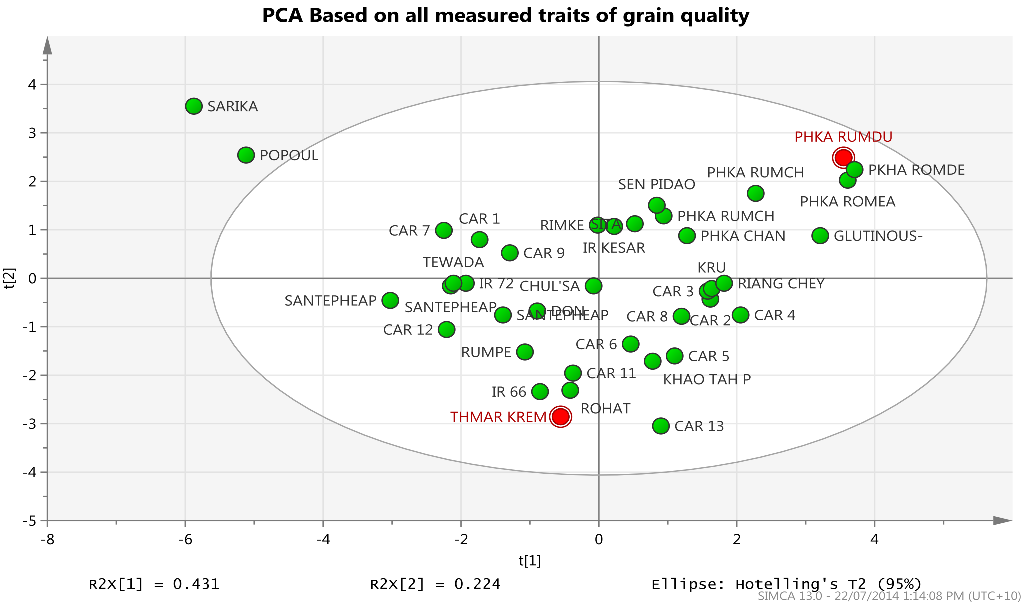


Figure 2. PCA based on all quality traits measured for Sets 1 and 2 as shown in Tables 1 and 2 (Fitzgerald, M. 2014, Project Final Meeting, CARDI, 22 July 2014).

Set 3: 99 breeding lines

These 99 lines were new breeding lines developed by the project at CARDI. Quality evaluation results are presented in Table 3. HRY ranged from 8-53% with a mean of 40. 81 of the 99 lines/varieties had chalkiness ≤ 25. Amylose content varied from 11-28% with a mean of 18%. 14 lines or varieties had a high AC of ≥ 25%. Grain length varied from 5.52-7.03 which is classified as intermediate to long. A number of the lines are still segregating in GT. All lines/varieties have soft gel consistency.

PCA graphs are shown in Figure 3a and 3b. Five clusters are formed in Figure 3a while there are three clusters in Figure 3b. The graph in Figure 4 of group sum squares vs number of clusters justifies the grouping into three clusters.

Table 3. Grain quality evaluation results of last batch of samples consisting of 99 lines/varieties (2015)

No.	*Line / Variety*	*Head Rice Yield %*	*Chalkiness*	*Grain Length L, mm*	*Grain Width W, mm*	*Grain Shape L/W*	*Amylose Content %*	*Gelatinization Temperature by ASV**	*Gel Consistency mm*
1	*CAR 3*	*34*	*40*	*5.5*	*2.4*	*2.3*	*22.9*	*I*	*100*
2	*CIR 792-19-3-3-105-1-B*	*42*	*34*	*5.6*	*2.3*	*2.4*	*14.1*	*HI*	*95*
3	*CIR 792-19-3-3-105-21-B-2*	*37*	*31*	*5.6*	*2.3*	*2.4*	*14.7*	*HI*	*100*
4	CIR 792-6-2-5-57-119-B	41	33	5.6	2.3	2.4	13.9	H/HI	100
5	CIR 792-6-2-5-57-16-B-2	44	33	5.6	2.4	2.3	13.6	HI	80
6	CIR 827-13-15-B-3-3-1-29-1-1	53	1	6.7	2.1	3.1	12.8	L	78
7	CIR 827-13-15-B-3-3-1-29-1-5	44	2	6.6	2.0	3.3	15.7	L	100
8	CIR 827-13-15-B-3-3-1-29-3-4	40	4	6.7	2.1	3.2	14.0	L	100
9	CIR 827-15-17-B-4-4-1-32-2-3	38	5	6.7	2.2	3.0	16.7	L	89
10	CIR 827-16-18-B-3-5-30-2-10-1-1	48	5	6.6	2.0	3.4	15.3	L	76
11	CIR 827-16-18-B-3-5-30-2-10-1-2	48	1	6.7	2.0	3.4	15.3	L	100
12	CIR 827-16-18-B-3-5-30-2-10-1-3	38	7	6.8	2.0	3.4	15.4	L	100
13	CIR 827-16-18-B-3-5-30-2-10-2-4	48	6	6.5	2.0	3.3	13.8	L	98
14	CIR 827-21-23-B-2-6-1-36-1-2	51	6	6.5	2.0	3.3	12.5	HI	100
15	CIR 827-21-23-B-5-7-47-1-13-1-4	47	2	6.6	2.0	3.3	14.7	L	98
16	CIR 827-21-23-B-5-7-47-1-13-2-2	16	13	6.7	1.9	3.5	13.4	L	95
17	CIR 827-21-23-B-5-7-47-1-13-2-4	42	9	6.5	1.9	3.4	11.9	HI/L	100
18	CIR 827-21-23-B-5-7-47-1-13-3-1	47	0	6.8	2.0	3.5	13.2	I	78
19	CIR 827-21-23-B-5-7-47-1-13-4-1	8	4	6.8	2.0	3.4	11.7	L	78
20	CIR 827-21-23-B-5-7-47-1-13-4-3	48	3	6.7	2.0	3.3	14.6	L	91
21	CIR 827-23-25-B-4-8-53-1-15-1-3	26	40	6.5	2.0	3.2	20.1	I	100
22	CIR 827-2-4-B-5-1-1-27-1-2	34	6	6.6	2.1	3.2	14.9	L	85
23	CIR 827-25-27-B-2-9-56-1-18-1-4	41	1	6.6	1.9	3.4	13.2	L	96
24	CIR 827-25-27-B-2-9-56-6-23-1-3	37	2	6.6	2.0	3.3	12.5	L	74
25	CIR 827-25-27-B-2-9-56-6-23-1-4	50	19	6.7	2.1	3.3	11.1	L	100
26	CAR 3	34	40	5.5	2.4	2.3	22.9	I	100
27	CIR 792-19-3-3-105-1-B	42	34	5.6	2.3	2.4	14.1	HI	95
28	CIR 792-19-3-3-105-21-B-2	37	31	5.6	2.3	2.4	14.7	HI	100
29	CIR 792-6-2-5-57-119-B	41	33	5.6	2.3	2.4	13.9	H/HI	100
30	CIR 792-6-2-5-57-16-B-2	44	33	5.6	2.4	2.3	13.6	HI	80
31	CIR 827-13-15-B-3-3-1-29-1-1	53	1	6.7	2.1	3.1	12.8	L	78
32	CIR 827-13-15-B-3-3-1-29-1-5	44	2	6.6	2.0	3.3	15.7	L	100
33	CIR 827-13-15-B-3-3-1-29-3-4	40	4	6.7	2.1	3.2	14.0	L	100
34	CIR 827-15-17-B-4-4-1-32-2-3	38	5	6.7	2.2	3.0	16.7	L	89
35	CIR 827-16-18-B-3-5-30-2-10-1-1	48	5	6.6	2.0	3.4	15.3	L	76
36	CIR 827-16-18-B-3-5-30-2-10-1-2	48	1	6.7	2.0	3.4	15.3	L	100
37	CIR 827-16-18-B-3-5-30-2-10-1-3	38	7	6.8	2.0	3.4	15.4	L	100
38	CIR 827-16-18-B-3-5-30-2-10-2-4	48	6	6.5	2.0	3.3	13.8	L	98
39	CIR 827-21-23-B-2-6-1-36-1-2	51	6	6.5	2.0	3.3	12.5	HI	100
40	CIR 827-21-23-B-5-7-47-1-13-1-4	47	2	6.6	2.0	3.3	14.7	L	98
41	CIR 827-21-23-B-5-7-47-1-13-2-2	16	13	6.7	1.9	3.5	13.4	L	95
42	CIR 827-21-23-B-5-7-47-1-13-2-4	42	9	6.5	1.9	3.4	11.9	HI/L	100
43	CIR 827-21-23-B-5-7-47-1-13-3-1	47	0	6.8	2.0	3.5	13.2	I	78
44	CIR 827-21-23-B-5-7-47-1-13-4-1	8	4	6.8	2.0	3.4	11.7	L	78
45	CIR 827-21-23-B-5-7-47-1-13-4-3	48	3	6.7	2.0	3.3	14.6	L	91
46	CIR 827-23-25-B-4-8-53-1-15-1-3	26	40	6.5	2.0	3.2	20.1	I	100
47	CIR 827-2-4-B-5-1-1-27-1-2	34	6	6.6	2.1	3.2	14.9	L	85
48	CIR 827-25-27-B-2-9-56-1-18-1-4	41	1	6.6	1.9	3.4	13.2	L	96
49	CIR 827-25-27-B-2-9-56-6-23-1-3	37	2	6.6	2.0	3.3	12.5	L	74
50	CIR 827-25-27-B-2-9-56-6-23-1-4	50	19	6.7	2.1	3.3	11.1	L	100
51	CIR 848-22-4-1-B	45	9	6.6	2.0	3.3	21.5	L	100
52	CIR 848-22-4-2-B	45	8	6.7	2.0	3.4	26.4	L	100
53	CIR 848-22-6-1-B	32	28	6.5	1.9	3.5	26.7	I/L	100
54	CIR 848-7-1-1-B	33	22	6.5	2.0	3.3	20.0	I/L	100
55	CIR 848-9-4-1-B	35	21	6.6	1.9	3.6	24.7	L	85
56	CIR 848-9-4-3-B	32	21	6.6	1.9	3.4	27.0	I/L	100
57	CIR 848-9-4-6-B	41	14	6.6	1.9	3.4	22.3	L	100
58	CIR 848-9-4-7-B	38	19	6.6	1.9	3.4	20.8	I/L	100
59	CIR 850-1-1-2-B	48	3	6.7	2.0	3.3	16.8	I/L	78
60	CIR 850-1-2-1-B	48	14	6.6	2.0	3.3	15.3	I	97
61	CIR 850-1-2-2-B	45	20	6.7	2.0	3.4	15.3	I	89
62	CIR 850-1-2-4-B	39	16	6.8	2.0	3.4	22.3	I/L	85
63	CIR 850-1-3-1-B	37	12	6.9	2.0	3.5	22.0	I/L	78
64	CIR 850-1-3-3-B	40	8	6.7	1.9	3.4	16.1	I/L	76
65	CIR 850-4-2-1-B	27	46	6.7	1.9	3.5	25.6	I/L	68
66	CIR 850-4-2-3-B	33	50	6.7	1.9	3.5	26.6	L	66
67	CIR 850-6-5-1-B	41	10	7.0	2.0	3.5	16.7	I	75
68	CIR 850-6-6-1-B	37	29	6.8	2.1	3.3	26.2	L	76
69	CIR 850-7-2-1-B	43	22	6.9	2.0	3.5	26.9	L	75
70	CIR 850-7-2-2-B	43	20	6.9	2.0	3.4	27.9	L	68
71	CIR 850-7-6-1-B	38	26	6.8	2.0	3.5	28.0	L	85
72	CIR 851-17-3-2-B	51	15	6.5	1.9	3.5	15.4	HI/L	75
73	CIR 851-26-1-1-B	41	18	6.6	1.8	3.6	15.0	HI/L	78
74	CIR 851-27-4-1-B	47	13	6.8	1.9	3.5	21.6	I/L	65
75	CIR 851-3-2-3-B	41	17	6.6	1.8	3.6	27.8	I/L	81
76	CIR 851-3-2-4-B	40	16	6.7	1.9	3.6	22.3	Segregating	75
77	CIR 851-4-3-1-B	47	10	6.6	1.9	3.4	15.9	I/L	80
78	CIR 851-6-5-1-B	48	13	6.5	2.0	3.3	16.3	I/L	68
79	CIR 851-7-3-1-B	38	25	6.4	1.9	3.3	21.1	Segregating	73
80	CIR 851-8-5-1-B	45	10	6.5	1.9	3.4	21.0	L	68

81	CIR 852-1-2-2-B	26	24	6.8	1.8	3.8	24.2	I/L	68
82	CIR 852-5-1-1-B	39	6	6.4	1.9	3.4	14.3	L	76
83	CIR 852-5-1-2-B	49	3	6.5	1.9	3.5	14.9	I/L	66
84	CIR 853-14-3-1-B	39	9	6.6	1.9	3.5	22.0	Segregating	75
85	CIR 853-18-1-1-B	44	10	6.7	1.9	3.6	20.5	I/L	73
86	CIR 853-7-1-1-B	17	4	6.8	1.7	3.9	13.9	I/L	77
87	CIR 853-7-1-2-B	24	1	6.7	1.8	3.8	14.2	L	68
88	CIR 853-7-2-1-B	39	0	6.7	1.8	3.7	14.6	I/L	72
89	CIR 853-8-2-2-B	31	21	6.9	2.0	3.4	18.8	Segregating	72
90	CIR 853-8-3-1-B	53	4	6.5	1.9	3.5	14.7	I/L	70
91	CIR 853-8-5-1-B	46	2	6.5	1.9	3.4	20.1	L	76
92	CIR 853-9-4-1-B	37	2	6.5	1.9	3.4	15.4	I/L	85
93	CIR 853-9-5-1-B	30	2	6.7	1.8	3.7	21.1	L	86
94	CIR 855-14-2-1-B	34	6	6.9	2.0	3.5	16.5	I/L	83
95	CIR 855-4-2-1-B	36	22	6.7	2.0	3.4	27.4	L	67
96	CIR 855-4-2-2-B	43	10	6.9	2.0	3.5	14.8	I/L	69
97	CIR 855-9-2-1-B	40	18	6.7	1.9	3.5	12.8	L	74
98	IR 66	28	45	6.5	1.9	3.4	27.2	I	100
99	SEN PIDAO	36	17	6.4	1.8	3.5	16.1	I/L	82

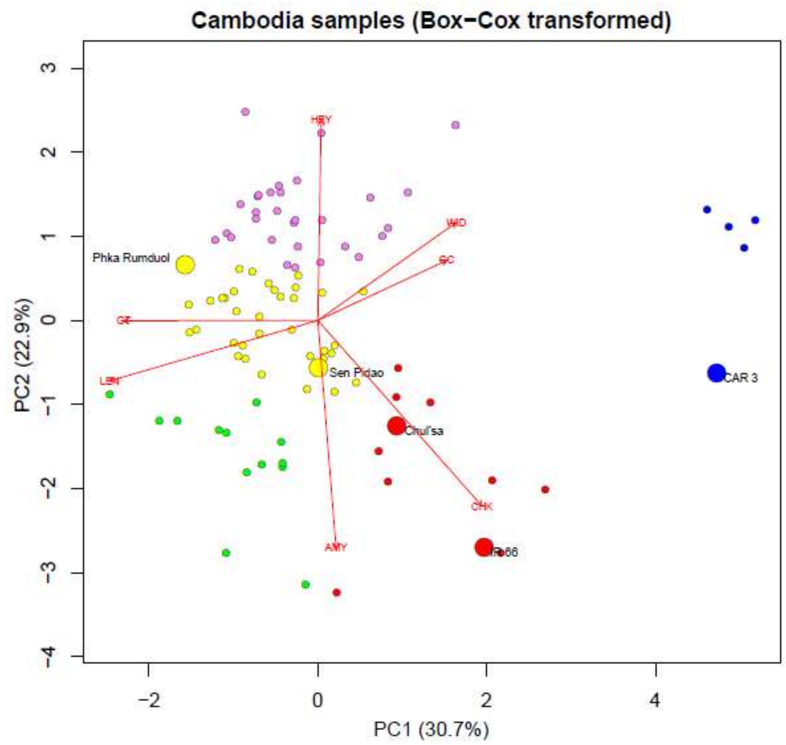


Figure 3a. PCA based on quality traits of the last batch of samples received in 2015 showing five clusters. The contribution to PC1 which has the higher variation followed the order: 1-length, 2-GT (gelatinization temperature), 3-chalk, 4-width, 5-gel consistency (GC), 6-amylose content (AC) and 7-HRY (head rice yield). The order of contribution of the traits to PC2 was as follows: 1-amylose content, 2-HRY, 3-chalk, 4-width, 5-length, 6-GC and 7-GT

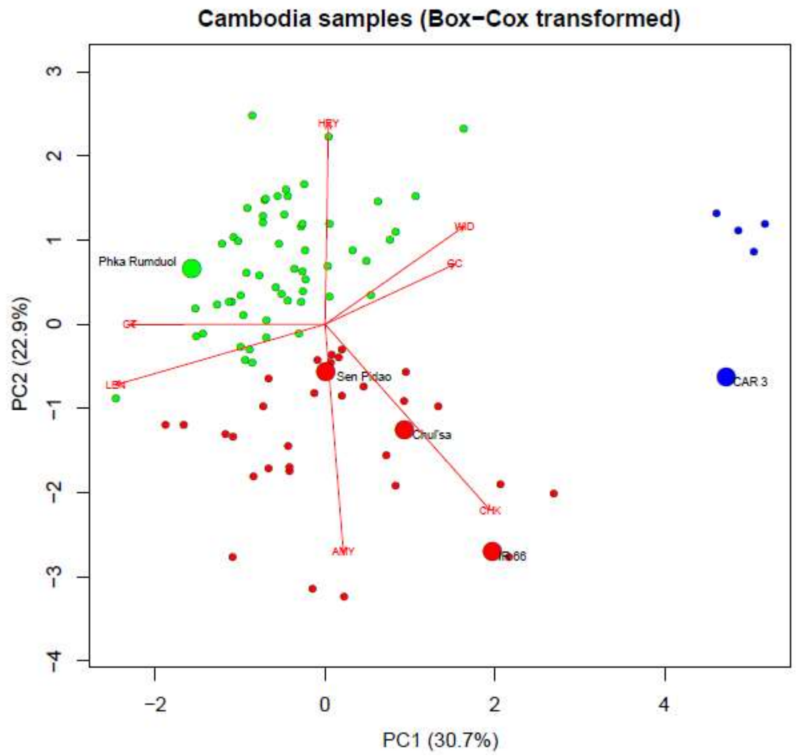


Figure 3b. PCA based on quality traits of the last batch of samples received in 2015 showing three clusters. The justification for forming three clusters is shown in Figure 8.

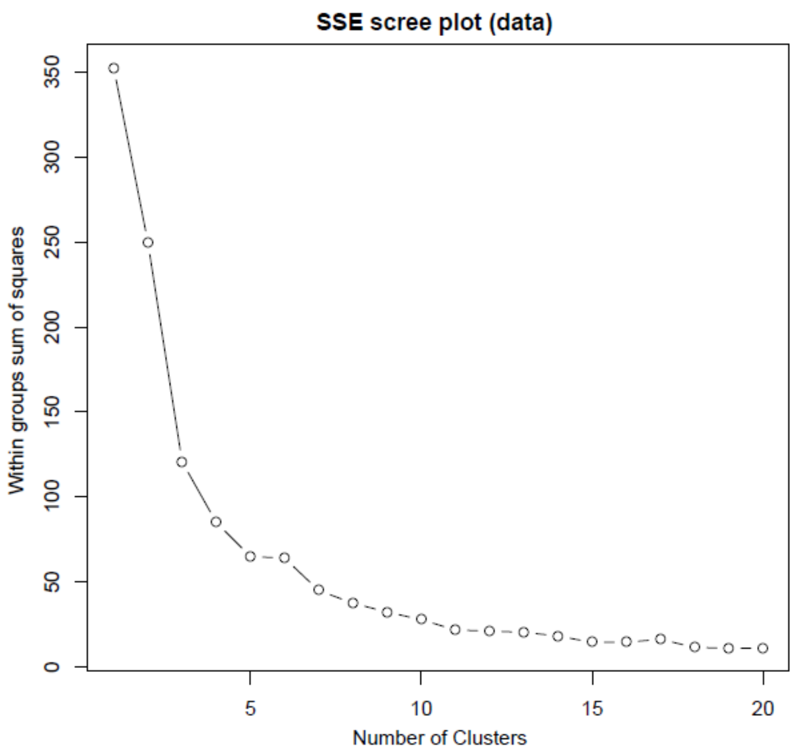


Figure 4. Group sum of squares plot against number of clusters. The graph justifies the grouping into three clusters shown in Figure 7b

C. Phenotyping Population Derived from Phka Rumduol (PRD) x Thmar Krem (TK)

C1. Quality Evaluation Results of the Population

Amylose content, gelatinization temperature by DSC, gel consistency, grain length, grain width, chalkiness and RVA traits were measured. The results are shown in Tables 4a and 4b.

Both parents, PRD and TK have low chalkiness scores of less than 25%. Similarly, 63% of the population showed low chalkiness like the parents.

21% had long grains similar to PRD in contrast to 77% which had medium grains like TK. As to shape, 74% of the population had slender grains like PRD while 26% had medium grains similar to TK.

The distribution in AC were as follows: 31% had low AC similar to PRD, 58% had intermediate AC like TK, 10% had high AC and 1%, very low AC. All lines showed soft gel consistency

PRD and TK showed Intermediate and high GT, respectively. 14% of the population exhibited intermediate GT similar to PRD, 56% showed high GT as TK and 30%, low GT.

Table 4a. Grain quality evaluation results of the Phka Rumduol x Thmar Krem population

No	Line/Variety	Chalkiness	Grain Length L, mm	Grain Width W, mm	Grain Shape L/W	Amylose Content %	Gelatinization Temperature by DSC*	Gel Consistency mm
1	CIR840-1	28	5.46	2.15	2.54	25.6	76.0	57
2	CIR840-2	15	5.66	2.33	2.43	26.3	67.0	68
3	CIR840-3	65	6.23	2.10	2.97	24.4	71.6	87
4	CIR840-4	36	6.37	2.02	3.15	22.3	78.5	75
5	CIR840-5	18	6.61	2.03	3.26	26.0	75.3	85
6	CIR840-6	22	6.66	1.96	3.40	22.0	66.7	62
7	CIR840-7	19	6.35	2.04	3.11	12.3	81.2	61
8	CIR840-8	13	6.47	1.92	3.37	12.5	2 peaks	83
9	CIR840-9	58	6.27	2.27	2.76	24.2	78.0	90
10	CIR840-10	2	6.18	2.03	3.04	22.1	60.3	53
11	CIR840-11	5	6.27	1.88	3.34	22.3	77.2	56
12	CIR840-12	41	6.78	2.05	3.31	21.4	76.8	76
13	CIR840-13	13	6.37	2.12	3.00	20.8	78.5	76
14	CIR840-14	2	6.17	1.82	3.39	22.4	76.2	66
15	CIR840-15	5	6.14	1.86	3.30	23.1	78.0	80
16	CIR840-16	14	6.76	1.91	3.54	23.1	77.5	85
17	CIR840-17	9	6.37	1.80	3.54	22.6	76.5	80
18	CIR840-18	7	6.75	2.00	3.38	19.2	69.4	35
19	CIR840-19	26	6.73	2.21	3.05	21.7	76.8	70
20	CIR840-20	2	6.85	1.96	3.49	13.9	70.2	81
21	CIR840-21	9	5.65	1.98	2.85	23.8	76.8	91
22	CIR840-22	45	6.60	1.91	3.46	24.6	76.2	82
23	CIR840-23	21	6.66	2.04	3.26	24.0	68.1	81
24	CIR840-24	31	6.53	1.76	3.71	24.7	76.2	88
25	CIR840-25	54	6.24	2.15	2.90	24.4	76.3	87
26	CIR840-26	36	6.82	2.11	3.23	22.5	77.8	64
27	CIR840-27	5	6.52	1.80	3.62	26.2	76.5	91
28	CIR840-28	3	6.54	2.06	3.17	14.6	70.2	82
29	CIR840-29	35	5.71	1.94	2.94	23.5	76.3	86
30	CIR840-30	11	6.77	1.92	3.53	24.2	68.2	71
31	CIR840-31	12	5.54	2.09	2.65	18.9	76.3	82
32	CIR840-32	17	6.42	1.96	3.28	21.9	67.5	79
33	CIR840-33	29	6.68	2.13	3.14	26.4	66.4	81
34	CIR840-34	25	6.29	1.98	3.18	25.1	76.2	83
35	CIR840-35	12	6.34	1.89	3.35	23.8	67.3	81
36	CIR840-36	57	6.44	2.04	3.16	12.7	81.0	85
37	CIR840-37	4	6.18	2.16	2.86	21.7	66.8	69
38	CIR840-38	3	6.95	1.89	3.68	23.8	66.2	76
39	CIR840-39	23	6.21	1.96	3.17	24.0	76.2	77
40	CIR840-40	13	6.32	2.10	3.01	21.4	76.9	83
41	CIR840-41	38	6.87	2.23	3.08	23.3	76.7	81
42	CIR840-42	31	6.73	2.25	2.99	22.5	75.9	88
43	CIR840-43	1	6.45	1.92	3.36	22.1	67.3	74
44	CIR840-44-G1	23	6.29	1.99	3.16	21.2	69.8	93
45	CIR840-44-G2	41	6.37	1.89	3.37	14.4	79.2	89
46	CIR840-45	66	6.54	2.09	3.13	12.3	80.5	89
47	CIR840-46	17	6.81	1.97	3.46	13.5	72.0	88
48	CIR840-47	48	6.29	1.86	3.38	11.3	81.3	84
49	CIR840-48	65	6.07	1.85	3.28	23.0	77.3	83

50	CIR840-49	6	6.14	2.00	3.07	22.6	68.2	82
51	CIR840-50	8	6.22	2.07	3.00	21.3	68.0	78
52	CIR840-53	66	6.78	2.07	3.28	23.8	77.3	82
53	CIR840-54	58	6.36	2.23	2.85	23.7	78.4	81
54	CIR840-55	35	6.20	1.98	3.13	21.4	78.1	79
55	CIR840-56	27	6.23	2.08	3.00	24.6	67.5	73
56	CIR840-57	70	6.14	2.01	3.05	21.9	77.1	77
57	CIR840-58	41	6.33	2.16	2.93	24.1	77.2	80
58	CIR840-59	54	6.22	2.19	2.84	9.5	80.3	82
59	CIR840-60	3	6.16	1.90	3.24	22.0	66.9	77
60	CIR840-63	28	6.36	1.96	3.24	11.9	82.1	80
61	CIR840-64	2	6.46	1.86	3.47	23.3	66.8	81
62	CIR840-65-G1	2	6.18	1.93	3.20	21.8	67.7	81
63	CIR840-65-G2	0	6.20	1.96	3.16	14.8	70.2	78
64	CIR840-66	42	6.20	2.25	2.76	12.7	71.6	76
65	CIR840-67	5	6.85	1.95	3.51	21.7	67.1	71
66	CIR840-68	54	6.38	2.01	3.17	11.0	80.6	83
67	CIR840-69	5	6.34	2.03	3.12	23.6	67.7	83
68	CIR840-70	21	6.66	1.95	3.42	12.2	70.4	86
69	CIR840-71	16	5.63	2.16	2.61	23.1	76.3	87
70	CIR840-72	13	6.17	2.10	2.94	22.9	67.1	80
71	CIR840-73-G1	53	6.30	2.18	2.89	23.3	76.6	89
72	CIR840-73-G2	40	6.19	2.13	2.91	23.1	77.0	88
73	CIR840-74	50	6.48	2.18	2.97	11.0	81.7	85
74	CIR840-75-G1	28	6.38	2.00	3.19	22.9	67.0	82
75	CIR840-75-G2	23	6.26	1.93	3.24	25.2	66.9	84
76	CIR840-76-G1	15	6.37	2.22	2.87	21.9	77.0	84
77	CIR840-76-G2	15	5.55	2.26	2.46	11.4	80.4	81
78	CIR840-77	8	6.19	2.13	2.91	20.2	69.8	73
79	CIR840-78	53	6.21	2.20	2.82	13.1	77.5	96
80	CIR840-79	62	6.56	1.96	3.35	18.0	69.2	100
81	CIR840-80	7	6.59	1.82	3.62	12.6	76.6	96
82	CIR840-81	52	6.28	2.25	2.79	23.7	76.3	100
83	CIR840-82	52	6.18	2.21	2.80	10.9	70.9	91
84	CIR840-83	43	6.42	2.04	3.15	22.3	77.5	100
85	CIR840-84	19	6.25	2.23	2.80	22.6	76.9	97
86	CIR840-85	13	6.86	1.90	3.61	12.4	2 peaks	84
87	CIR840-86-G1	51	6.39	2.22	2.88	13.5	67.7	95
88	CIR840-86-G2	3	5.54	2.09	2.65	23.5	72.2	84
89	CIR840-87	29	6.67	2.21	3.02	22.2	80.8	87
90	CIR840-88	31	6.63	2.14	3.10	22.3	68.0	87
91	CIR840-89-G1	16	6.51	2.04	3.19	18.7	80.9	81
92	CIR840-89-G2	16	6.45	2.04	3.16	19.9	67.5	89
93	CIR840-90	23	5.74	2.31	2.48	16.8	77.0	91
94	CIR840-91	33	5.73	2.31	2.48	13.5	71.9	93
95	CIR840-92	31	6.88	1.81	3.80	20.4	68.4	84
96	CIR840-93	50	6.28	2.08	3.02	22.6	78.1	76
98	CIR840-95	5	6.22	1.89	3.29	23.9	77.4	100
99	CIR840-96	62	6.42	1.96	3.28	23.2	76.1	98
100	CIR840-97	27	6.29	2.04	3.08	24.9	76.1	90
101	CIR840-98	17	6.25	1.81	3.45	22.5	76.9	87
102	CIR840-99	2	6.25	1.96	3.19	23.1	66.4	87
103	CIR840-100	34	6.24	1.97	3.17	23.4	2 peaks	97
104	CIR840-101	9	6.22	1.85	3.36	12.9	71.9	86
105	CIR840-102	31	6.19	2.17	2.85	13.6	72.0	89
106	CIR840-103	15	6.30	2.07	3.04	20.7	77.1	91
107	CIR840-104	42	6.27	2.04	3.07	23.0	76.6	92
108	CIR840-105-G1	71	6.68	1.94	3.44	10.9	80.6	91
109	CIR840-105-G2	9	6.15	1.92	3.20	22.5	76.6	95
110	CIR840-106	53	6.55	2.20	2.98	12.3	80.5	92
111	CIR840-107	56	6.15	2.19	2.81	10.4	81.6	86
112	CIR840-108	2	6.32	1.94	3.26	22.4	66.0	81
113	CIR840-109	18	6.49	2.14	3.03	22.8	66.9	75
114	CIR840-110	8	6.18	2.00	3.09	22.4	72.2	90
115	CIR840-111	43	6.64	1.98	3.35	9.9	80.5	75
116	CIR840-112	20	6.26	2.04	3.07	21.4	67.1	76
117	CIR840-113	24	6.88	2.22	3.10	20.9	67.8	72
118	CIR840-114	44	6.31	2.00	3.16	24.7	76.3	99
119	CIR840-115	31	6.58	2.16	3.05	23.0	77.9	82
120	CIR840-116	49	6.77	2.05	3.30	11.2	2 peaks	81
121	CIR840-117	41	6.60	2.11	3.13	20.8	78.3	86
122	CIR840-118	1	6.31	1.95	3.24	22.2	66.6	90
123	CIR840-119	7	5.61	2.00	2.81	22.2	66.4	83
124	CIR840-120	16	6.16	1.98	3.11	20.3	77.5	79
125	CIR840-121	6	6.76	1.90	3.56	22.8	66.3	74
126	CIR840-122	67	6.58	2.08	3.16	11.8	80.7	94
127	CIR840-124	12	6.65	1.89	3.52	19.5	68.1	86
128	CIR840-125	6	6.84	2.01	3.40	9.9	70.4	70
129	CIR840-126	6	6.51	1.90	3.43	18.6	2 peaks	88
130	CIR840-127	5	6.41	1.81	3.54	20.5	77.7	92
131	CIR840-128	6	6.17	2.07	2.98	21.5	67.0	75
132	CIR840-129-G1	10	6.19	2.25	2.75	20.4	78.2	74
133	CIR840-129-G2	19	6.60	2.07	3.19	19.7	78.4	83
134	CIR840-130	12	6.27	1.87	3.35	20.5	68.3	69
135	CIR840-131	42	6.54	2.11	3.10	23.7	76.8	91
136	CIR840-132	20	6.62	1.86	3.56	21.3	77.2	76
137	CIR840-133	16	6.25	1.95	3.21	24.0	76.1	100

138	CIR840-134	39	5.57	1.98	2.81	8.2	80.9	85
139	CIR840-135	1	6.12	1.95	3.14	20.8	66.9	81
140	CIR840-136	32	6.08	1.95	3.12	10.8	81.3	94
141	CIR840-137	5	5.76	2.29	2.52	20.0	68.2	66
142	CIR840-138	22	5.53	2.05	2.70	12.9	72.2	79
143	CIR840-139	5	6.22	1.98	3.14	20.3	66.7	77
144	CIR840-140	63	6.80	2.03	3.35	12.7	80.7	79
145	CIR840-141	12	5.61	2.01	2.79	12.8	71.8	79
146	CIR840-142	38	6.45	1.76	3.66	25.4	76.6	85
147	CIR840-143	13	6.38	1.85	3.45	20.4	2 peaks	88
148	CIR840-144	8	6.60	1.85	3.57	23.8	66.3	96
149	CIR840-145	47	6.37	2.07	3.08	17.1	76.9	100
150	CIR840-146	11	6.52	1.91	3.41	22.4	67.4	100
151	CIR840-147	54	6.50	1.90	3.42	25.8	76.5	100
152	CIR840-148	50	6.29	1.94	3.24	17.3	2 peaks	95
153	CIR840-149	11	6.16	1.80	3.42	25.7	76.7	100
154	CIR840-150	49	6.20	2.06	3.01	25.1	76.8	100
155	CIR840-151	53	6.20	2.10	2.95	28.0	76.6	100
156	CIR840-152	19	6.60	2.02	3.27	27.7	77.0	100
157	CIR840-153	26	5.68	2.29	2.48	15.1	68.2	90
158	CIR840-154	19	6.62	1.95	3.39	23.6	68.3	96
159	CIR840-155	5	5.60	2.00	2.80	27.5	81.5	100
160	CIR840-156	16	6.19	1.93	3.21	23.7	80.3	100
161	CIR840-157	48	6.29	1.91	3.29	28.6	77.1	100
162	CIR840-158	45	6.25	2.08	3.00	26.5	78.2	100
163	CIR840-159	36	6.24	2.10	2.97	14.1	77.5	91
164	CIR840-160-G1	44	6.43	1.98	3.25	23.5	80.8	100
165	CIR840-160-G2	56	6.42	1.89	3.40	23.4	2 peaks	99
166	CIR840-161	38	6.28	2.17	2.89	24.5	2 peaks	88
167	CIR840-162-G1	14	6.28	1.97	3.19	23.7	68.3	87
168	CIR840-162-G2	26	6.52	2.01	3.24	13.7	71.8	82
169	CIR840-163-G1	20	6.23	2.09	2.98	12.8	80.6	88
170	CIR840-163-G2	39	6.90	1.91	3.61	23.4	67.7	83
171	CIR840-164	76	6.54	1.93	3.39	11.6	81.3	98
172	CIR840-165	1	5.70	1.93	2.95	22.7	67.5	74
173	CIR840-166	4	6.58	1.83	3.60	22.2	77.4	94
174	CIR840-167	4	6.75	2.05	3.29	11.0	72.2	82
175	CIR840-168	7	6.29	2.03	3.10	23.7	67.4	85
176	CIR840-169	16	5.56	2.06	2.70	20.6	76.5	97
177	CIR840-170	30	6.16	1.98	3.11	23.4	76.2	83
178	CIR840-171-G1	18	6.18	2.26	2.73	24.3	66.6	81
179	CIR840-171-G2	8	5.57	2.30	2.42	24.4	66.5	80
180	CIR840-172	10	6.31	2.05	3.08	10.3	81.3	96
181	CIR840-173	12	6.59	1.76	3.74	15.0	80.6	81
182	CIR840-174-G1	27	5.71	2.13	2.68	23.2	76.3	88
183	CIR840-174-G2	22	6.22	2.04	3.05	21.5	77.8	83
184	CIR840-175	10	6.28	2.10	2.99	22.3	76.1	81
185	CIR840-176	41	5.31	2.07	2.57	12.6	80.3	91
186	CIR840-177	16	6.53	1.99	3.28	20.3	2 peaks	50
187	CIR840-178	7	6.53	1.79	3.65	14.7	70.9	67
188	CIR840-179	2	6.20	1.97	3.15	20.9	66.5	67
189	CIR840-180	39	6.59	2.02	3.26	22.3	2 peaks	89
190	CIR840-181	3	6.41	1.88	3.41	24.4	77.6	89
191	CIR840-182	12	6.20	1.95	3.18	24.0	2 peaks	92
192	CIR840-183	37	6.30	1.99	3.17	14.0	70.3	88
193	CIR840-184	38	6.35	2.11	3.01	24.9	76.0	90
194	CIR840-185	2	6.87	1.98	3.47	12.5	72.3	74
196	CIR840-188	7	5.47	2.03	2.69	12.5	2 peaks	79
197	CIR840-189	2	6.51	1.93	3.37	10.9	70.7	73
198	CIR840-190	8	6.55	1.99	3.29	21.5	76.7	78
199	CIR840-191	20	5.70	2.27	2.51	11.0	80.9	85
200	CIR840-192	8	6.25	2.03	3.08	20.9	68.3	79
201	CIR840-193	13	6.95	2.00	3.48	20.9	78.4	86
202	CIR840-194	4	6.41	1.78	3.60	21.7	76.8	80
203	CIR840-195	5	6.51	1.88	3.46	22.4	76.5	86
204	CIR840-196	34	6.61	1.84	3.59	22.5	76.9	97
205	CIR840-197	9	6.59	2.17	3.04	12.1	80.9	87
206	CIR840-198	3	6.32	2.02	3.13	21.1	68.5	67
207	CIR840-199	25	6.88	2.18	3.16	23.6	67.9	75
208	CIR840-200	3	6.25	2.08	3.00	13.4	72.0	69
209	CIR840-201	40	6.31	2.05	3.08	20.1	77.2	68
210	CIR840-202	27	6.76	2.09	3.23	12.1	80.2	79
211	CIR840-203	43	5.45	2.02	2.70	12.9	80.9	
212	CIR840-204	4	6.68	1.81	3.69	24.9	66.8	81
213	CIR840-205	5	6.19	1.98	3.13	22.7	68.3	75
214	CIR840-206	20	5.63	2.02	2.79	21.4	78.3	80
215	CIR840-207	1	6.53	1.86	3.51	23.6	76.8	81
216	CIR840-208	10	6.32	2.02	3.13	21.2	76.6	82
217	CIR840-209	8	6.97	2.01	3.47	21.6	77.5	77
218	CIR840-210	5	5.67	2.08	2.73	26.7	76.8	99
219	CIR840-211	11	6.76	1.85	3.65	13.0	81.2	85
220	CIR840-212-G1	33	6.16	2.18	2.83	25.1	76.0	95
221	CIR840-212-G2	15	5.60	2.23	2.51	23.7	77.5	97
222	CIR840-213	63	6.27	1.94	3.23	11.5	80.5	100
223	CIR840-214	11	6.42	2.09	3.07	21.5	68.7	81
224	CIR840-215	12	6.74	1.96	3.44	12.9	72.5	95
225	CIR840-216-G1	34	6.37	2.02	3.15	13.1	80.5	100

226	CIR840-216-G2	11	5.65	1.98	2.85	22.3	78.3	97
227	CIR840-217	35	6.45	1.88	3.43	12.2	81.3	100
228	CIR840-218	35	6.85	2.09	3.28	24.5	67.0	97
229	CIR840-219	6	6.34	2.01	3.15	19.0	2 peaks	67
230	CIR840-220	12	6.19	2.15	2.88	21.2	67.9	83
231	CIR840-221	5	6.20	1.94	3.20	21.2	75.0	86
232	CIR840-222	25	6.99	2.03	3.44	14.3	70.7	98
233	CIR840-223	11	6.88	1.94	3.55	21.5	67.2	88
234	CIR840-224	1	6.25	1.91	3.27	21.7	76.9	92
235	CIR840-225	10	6.30	1.74	3.62	24.5	76.4	100
236	CIR840-226	25	6.67	2.04	3.27	24.4	66.6	92
237	CIR840-227	14	6.89	2.17	3.18	23.2	77.3	91
238	CIR840-228	6	5.63	2.06	2.73	21.1	68.4	78
239	CIR840-229	3	6.43	1.78	3.61	24.7	76.5	90
240	CIR840-230	2	5.51	2.05	2.69	22.2	77.0	87
241	CIR840-231	4	6.22	1.90	3.27	22.8	77.6	87
242	CIR840-232	30	6.29	2.06	3.05	17.8	80.6	80
243	CIR840-233-G1	34	6.57	1.88	3.49	13.2	71.6	83
244	CIR840-233-G2	2	6.49	1.79	3.63	18.8	68.4	64
245	CIR840-234	1	6.44	1.87	3.44	11.8	72.4	82
246	CIR840-235	7	6.24	2.06	3.03	21.3	77.8	85
247	CIR840-236	26	5.63	2.11	2.67	27.3	76.7	99
248	CIR840-237	31	6.14	2.16	2.84	20.7	2 peaks	67
249	CIR840-238	5	6.24	1.82	3.43	23.9	67.0	84
250	CIR840-239	18	6.67	1.77	3.77	22.6	77.3	92
251	CIR840-240	8	6.21	2.07	3.00	26.3	66.8	89
252	CIR840-241	21	6.22	2.04	3.05	23.2	76.7	87
253	CIR840-242	10	6.83	1.90	3.59	23.5	66.8	76
254	CIR840-243	78	6.48	1.86	3.48	11.7	80.8	91
255	CIR840-244	5	5.64	1.97	2.86	24.9	66.4	79
256	CIR840-245	31	6.34	2.05	3.09	22.4	76.8	84
257	CIR840-246-G1	2	6.42	1.93	3.33	23.3	66.3	75
258	CIR840-246-G2	2	6.36	1.88	3.38	25.3	66.4	85
260	CIR840-247	5	6.57	1.83	3.59	23.3	76.0	81
261	CIR840-249	1	6.44	1.98	3.25	24.8	68.0	85
263	CIR840-252-G1	17	6.15	2.01	3.06	24.6	67.2	88
264	CIR840-252-G2	23	6.18	2.08	2.97	23.5	67.6	81
265	CIR840-253-G1	27	6.19	2.18	2.84	21.3	2 peaks	79
266	CIR840-253-G2	32	6.90	2.01	3.43	25.1	67.9	80
267	CIR840-254	25	6.63	2.13	3.11	23.4	67.8	78
268	CIR840-255	34	6.59	2.00	3.30	12.1	82.1	81
269	CIR840-256	17	6.41	1.92	3.34	23.1	77.5	89
270	CIR840-257	24	5.73	2.16	2.65	11.9	81.5	84
271	CIR840-258	2	6.97	1.87	3.73	20.6	66.6	66
272	CIR840-259	1	6.73	1.89	3.56	21.9	67.7	79
273	CIR840-260	23	6.77	1.96	3.45	18.6	77.8	75
275	CIR840-262	5	6.53	1.94	3.37	19.9	68.6	65
276	CIR840-263	10	6.91	1.99	3.47	17.3	2 peaks	66
277	CIR840-264	1	5.67	2.06	2.75	22.4	76.8	85
278	CIR840-265	5	6.53	1.98	3.30	20.5	77.4	87
279	CIR840-266	29	6.47	2.05	3.16	22.7	67.7	68
280	CIR840-267	6	6.24	1.90	3.28	22.9	66.7	79
281	CIR840-268	7	6.31	2.11	2.99	21.5	2 peaks	82
282	CIR840-269	5	6.36	2.16	2.94	22.6	76.5	82
283	CIR840-270	0	6.48	2.03	3.19	14.4	70.3	78
284	CIR840-271	7	6.16	1.95	3.16	22.7	78.4	81
285	CIR840-272-G1	1	5.62	1.83	3.07	25.0	66.7	89
286	CIR840-272-G2	45	6.77	2.20	3.08	12.2	81.1	86
287	CIR840-273	4	6.33	1.95	3.25	23.1	66.8	
288	CIR840-274	21	6.29	2.09	3.01	11.8	80.3	
289	CIR840-275	9	6.72	1.87	3.59	24.0	76.6	91
290	CIR840-276	12	5.61	2.21	2.54	22.3	77.1	88
291	CIR840-277	14	5.75	2.22	2.59	22.4	76.4	85
292	CIR840-278	1	6.25	1.91	3.27	24.0	66.3	88
293	CIR840-279	14	6.35	1.83	3.47	23.4	67.8	97
294	CIR840-280	7	6.19	1.87	3.31	22.3	66.5	70
295	CIR840-281	16	6.28	1.80	3.49	23.7	76.3	95
296	CIR840-282	18	6.22	2.15	2.89	21.6	78.2	98
297	CIR840-283	9	6.17	2.01	3.07	21.6	76.9	90
298	CIR840-284	44	6.46	2.16	2.99	22.9	77.4	87
299	CIR840-285	22	6.61	2.09	3.16	24.2	68.3	80
300	CIR840-286	30	6.38	2.02	3.16	22.0	69.3	80
301	CIR840-287	2	5.74	1.91	3.01	21.3	78.0	90
302	CIR840-288	44	7.01	2.05	3.42	24.2	76.5	83
303	CIR840-289	14	6.24	2.09	2.99	12.6	72.3	78
304	CIR840-290	28	6.91	2.25	3.07	23.1	76.4	82
305	CIR840-291	30	6.88	2.08	3.31	18.4	78.1	77
306	CIR840-292	27	6.74	2.07	3.26	24.0	67.5	73
307	CIR840-293	8	6.46	1.89	3.42	14.6	71.8	87
308	CIR840-294	33	6.56	1.86	3.53	26.7	76.4	87
309	CIR840-295	5	6.60	1.87	3.53	14.1	72.1	79
310	CIR840-296-G1	13	6.51	1.97	3.30	14.1	71.8	76
311	CIR840-296-G2	4	6.48	2.03	3.19	13.2	72.6	73
312	CIR840-297-G1	51	6.36	2.21	2.88	13.6	81.2	79
313	CIR840-297-G2	39	6.30	2.04	3.09	12.1	81.7	84
314	CIR840-298	5	5.58	2.05	2.72	24.4	75.9	83
315	CIR840-299	3	6.26	2.05	3.05	24.6	77.8	87

316	CIR840-300	21	6.77	2.06	3.29	15.7	70.3	80
317	CIR840-301	30	5.70	2.00	2.85	23.7	77.3	86
318	CIR840-302-G1	24	6.21	2.24	2.77	25.1	66.7	80
319	CIR840-302-G2	12	6.77	2.13	3.18	21.7	68.2	60
320	CIR840-303	2	6.48	1.88	3.45	14.2	72.0	70
321	CIR840-304	42	6.22	1.93	3.22	27.4	77.1	95
322	CIR840-305	26	6.22	1.97	3.16	26.0	77.4	83
323	CIR840-306	9	6.26	1.89	3.31	13.3	71.5	78
324	CIR840-307	8	6.20	1.84	3.37	13.4	2 peaks	66
325	CIR840-308	23	6.25	2.24	2.79	22.9	67.5	89
326	CIR840-309	30	6.53	1.91	3.42	13.1	80.9	83
327	CIR840-310	21	6.30	1.84	3.42	17.1	2 peaks	67
328	CIR840-311	49	6.46	2.07	3.12	12.4	81.2	82
329	CIR840-312	8	6.37	1.90	3.35	13.6	71.6	75
330	CIR840-313	40	6.28	1.82	3.45	8.2	71.6	78
334	CIR840-317	5	6.18	2.02	3.06	23.6	66.4	85
335	CIR840-318	10	6.63	1.95	3.40	21.6	77.3	77
336	CIR840-319	6	5.50	2.08	2.64	24.2	68.5	79
337	CIR840-320	21	6.08	1.94	3.13	26.6	67.1	80
338	CIR840-321	9	6.70	1.84	3.64	17.1	71.5	83
340	CIR840-323	10	5.50	1.80	3.06	22.8	76.7	92
341	CIR840-324	50	6.26	1.96	3.19	23.6	77.2	85
342	CIR840-325	3	6.37	1.97	3.23	12.4	70.3	76
343	CIR840-326	49	6.75	1.77	3.81	20.6	77.8	86
344	CIR840-327	29	5.40	2.02	2.67	26.7	76.7	87
346	CIR840-329	7	5.70	1.99	2.86	23.2	67.4	76
347	CIR840-330	4	5.41	2.05	2.64	26.8	68.3	88
349	CIR840-332	9	5.71	2.01	2.84	24.9	66.7	80
350	CIR840-333	28	6.14	2.02	3.04	11.7	81.1	78
351	CIR840-334	11	5.58	2.10	2.66	24.2	76.6	86
352	CIR840-335	34	6.88	1.97	3.49	12.6	71.0	82
353	CIR840-336	62	6.20	1.93	3.21	25.5	76.0	88
354	CIR840-337	19	6.74	1.85	3.64	13.0	72.1	79
355	CIR840-338	41	6.56	1.74	3.77	20.9	77.8	85
357	CIR840-340	76	6.30	1.93	3.26	12.8	81.4	87
358	CIR840-341	45	6.38	1.88	3.39	26.9	76.4	87
359	CIR840-342	11	5.52	2.20	2.51	26.1	66.6	82
360	CIR840-343	19	6.24	1.94	3.22	20.7	78.7	86
361	CIR840-344	13	6.37	1.96	3.25	13.3	70.4	75
362	CIR840-345	63	6.93	2.10	3.30	23.8	77.4	78
363	CIR840-346	28	6.64	1.96	3.39	12.4	71.1	78
364	CIR840-348	14	6.31	2.15	2.93	12.4	81.5	77
366	CIR840-349	21	5.59	2.05	2.73	22.6	77.6	63
368	CIR840-351	48	6.72	2.03	3.31	25.0	2 peaks	83
369	CIR840-352	21	6.18	1.82	3.40	21.5	2 peaks	79
370	CIR840-353	13	6.70	1.73	3.87	13.1	71.8	84
372	CIR840-355	5	6.62	1.86	3.56	12.3	72.6	75
373	CIR840-356	46	6.30	2.20	2.86	12.0	81.6	79
375	CIR840-358	51	6.23	2.18	2.86	10.4	80.9	78
376	CIR840-359	20	6.20	1.80	3.44	23.8	76.1	89
377	CIR840-360	18	6.58	2.05	3.21	11.8	71.4	76
378	CIR840-261	48	6.56	2.08	3.15	12.8	80.2	75
379	CIR840-362	4	5.59	1.87	2.99	22.7	67.5	80
380	CIR840-363	18	6.39	1.91	3.35	25.9	69.1	77
381	CIR840-364	5	6.62	1.93	3.43	24.8	67.3	80
382	CIR840-365	12	6.66	1.88	3.54	13.3	72.1	80
383	PHKA RUMDUOL	18	6.71	1.96	3.42	12.7	71.8	76
384	THMAR KREM	23	5.54	2.18	2.54	24.7	76.4	91

Table 4b. RVA results of the Phka Rumduol x Thmar Krem population

Line / Variety	Peak Time min	Pasting Temperature ºC	Peak Viscosity cP	Trough cP	Final Viscosity cP	Breakdown cP	Setback cP	Retrogradation cP
CIR840-1	5.33	74.4	2115	1209	906	2699	584	1490
CIR840-2	5.67	68.1	1725	1224	501	2326	601	1102
CIR840-3	5.33	73.6	2279	1188	1091	2692	413	1504
CIR840-4	5.60	75.9	3036	1459	1577	2989	-47	1530
CIR840-5	5.73	72.8	1952	1152	800	2384	432	1232
CIR840-6	5.67	66.7	1369	955	414	1895	526	940
CIR840-7	5.40	78.3	3528	1355	2173	2213	-1315	858
CIR840-8	5.73	75.2	3649	1600	2049	2576	-1073	976
CIR840-9	5.33	75.9	2296	1059	1237	2457	161	1398
CIR840-10	5.80	66.6	1519	1191	328	2216	697	1025
CIR840-11	5.40	75.2	1746	955	791	2267	521	1312
CIR840-12	5.67	75.2	2105	1350	755	3089	984	1739
CIR840-13	5.40	76.1	2673	1313	1360	3052	379	1739
CIR840-14	5.40	72.8	1594	920	674	2115	521	1195
CIR840-15	5.47	75.3	1881	959	922	2467	586	1508
CIR840-16	5.60	75.2	1986	1181	805	2706	720	1525
CIR840-17	5.53	74.5	2033	1107	926	2803	770	1696
CIR840-18	5.73	68.8	1900	1082	818	2635	735	1553
CIR840-19	5.60	74.3	2157	1228	929	2856	699	1628
CIR840-20	5.60	67.3	3705	1420	2285	2528	-1177	1108
CIR840-21	5.33	74.5	1926	960	966	2414	488	1454
CIR840-22	5.47	73.7	2228	1303	925	2950	722	1647
CIR840-23	5.73	68.1	1467	1085	382	2162	695	1077

CIR840-24	5.53	75.2	1868	1093	775	2536	668	1443
CIR840-25	5.33	74.5	2277	1333	944	3041	764	1708
CIR840-26	5.67	75.2	2274	1371	903	3121	847	1750
CIR840-27	5.47	74.4	2181	1127	1054	2629	448	1502
CIR840-28	5.80	68.1	3831	1697	2134	2850	-981	1153
CIR840-29	5.60	73.7	2137	1274	863	2767	630	1493
CIR840-30	5.67	68.1	1316	986	330	2005	689	1019
CIR840-31	5.47	74.4	1751	1042	709	2488	737	1446
CIR840-32	5.73	68.1	1352	1025	327	1938	586	913
CIR840-33	5.73	66.6	2137	1530	607	3088	951	1558
CIR840-34	5.53	74.4	2280	1333	947	2985	705	1652
CIR840-35	5.67	67.3	1595	1132	463	2285	690	1153
CIR840-36	5.60	79.0	3496	1501	1995	2475	-1021	974
CIR840-37	5.80	68.2	1508	1171	337	2252	744	1081
CIR840-38	5.73	67.3	1478	1178	300	2135	657	957
CIR840-40	5.47	72.8	2429	1304	1125	2895	466	1591
CIR840-41	5.60	72.8	2082	1306	776	2861	779	1555
CIR840-42	5.40	72.8	1985	1129	856	2681	696	1552
CIR840-43	5.80	66.6	1317	1139	178	2023	706	884
CIR840-44-G1	5.53	67.3	2205	1295	910	2782	577	1487
CIR840-44-G2	5.60	76.0	4040	1722	2318	2876	-1164	1154
CIR840-45	5.33	78.3	3992	1643	2349	2661	-1331	1018
CIR840-46	5.73	70.4	3691	1644	2047	2764	-927	1120
CIR840-47	5.53	78.3	3584	1598	1986	2581	-1003	983
CIR840-48	5.47	75.2	1847	1188	659	2688	841	1500
CIR840-49	5.67	68.2	1903	1196	707	2486	583	1290
CIR840-50	5.67	67.3	2171	1356	815	2863	692	1507
CIR840-53	5.47	75.1	2198	1278	920	2791	593	1513
CIR840-54	5.13	74.4	2209	948	1261	2198	-11	1250
CIR840-55	5.47	75.1	2937	1487	1450	3319	382	1832
CIR840-56	5.73	66.6	2213	1556	657	3250	1037	1694
CIR840-57	5.33	74.4	2228	1266	962	2927	699	1661
CIR840-58	5.60	75.2	2507	1371	1136	3044	537	1673
CIR840-59	5.53	77.6	2928	1478	1450	2408	-520	930
CIR840-60	5.87	68.1	1352	1149	203	2025	673	876
CIR840-63	5.40	77.6	3058	1290	1768	2175	-883	885
CIR840-64	5.67	67.3	1457	1092	365	2055	598	963
CIR840-65-G1	5.67	68.2	1698	1228	470	2565	867	1337
CIR840-65-G2	5.87	67.3	3173	1377	1796	2423	-750	1046
CIR840-66	5.53	68.9	3694	1526	2168	2465	-1229	939
CIR840-67	5.67	67.4	1546	1116	430	2355	809	1239
CIR840-68	5.40	77.6	3765	1582	2183	2447	-1318	865
CIR840-69	5.60	66.6	1452	1004	448	1998	546	994
CIR840-70	5.80	68.1	4012	1804	2208	3033	-979	1229
CIR840-71	5.27	74.4	1977	1087	890	2572	595	1485
CIR840-72	5.73	68.8	1548	1207	341	2235	687	1028
CIR840-73-G1	5.40	73.7	2399	1336	1063	3024	625	1688
CIR840-73-G2	5.60	74.5	2431	1345	1086	3008	577	1663
CIR840-74	5.40	78.2	3645	1457	2188	2384	-1261	927
CIR840-75-G1	5.87	66.6	1591	1279	312	2333	742	1054
CIR840-75-G2	5.80	67.4	1378	1123	255	2162	784	1039
CIR840-76-G1	5.53	74.4	2350	1415	935	3040	690	1625
CIR840-77	5.87	68.1	1615	1306	309	2595	980	1289
CIR840-78	5.40	76.0	3861	1549	2312	2665	-1196	1116
CIR840-79	5.53	72.8	3159	1580	1579	3424	265	1844
CIR840-80	5.60	69.6	4153	1733	2420	2924	-1229	1191
CIR840-81	5.27	75.2	2329	1141	1188	2616	287	1475
CIR840-82	5.33	79.0	3802	1646	2156	2804	-998	1158
CIR840-83	5.47	75.1	2191	1320	871	3031	840	1711
CIR840-84	5.40	72.9	2001	1078	923	2458	457	1380
CIR840-85	5.60	70.5	3758	1639	2119	2834	-924	1195
CIR840-86-G1	5.60	78.2	3546	1606	1940	2729	-817	1123
CIR840-86-G2	5.67	68.1	1483	1070	413	1983	500	913
CIR840-87	5.67	73.6	2098	1173	925	2600	502	1427
CIR840-88	5.80	68.2	1645	1167	478	2419	774	1252
CIR840-89-G1	5.47	75.1	2497	1143	1354	2695	198	1552
CIR840-89-G2	5.60	73.5	2775	1454	1321	3062	287	1608
CIR840-90	5.87	67.3	2411	1446	965	2799	388	1353
CIR840-91	5.27	77.6	3798	1427	2371	2446	-1352	1019
CIR840-92	5.53	75.2	2472	1501	971	3136	664	1635
CIR840-93	5.80	68.1	2126	1502	624	3008	882	1506
CIR840-95	5.27	74.3	2207	1018	1189	2409	202	1391
CIR840-96	5.47	74.4	2447	1367	1080	3219	772	1852
CIR840-97	5.53	74.4	2530	1467	1063	3395	865	1928
CIR840-98	5.53	75.2	2353	1390	963	3133	780	1743
CIR840-99	5.80	67.4	1236	968	268	1787	551	819
CIR840-100	5.80	73.6	2355	1531	824	3205	850	1674
CIR840-101	5.60	68.9	3630	1433	2197	2423	-1207	990
CIR840-102	5.80	69.6	3575	1623	1952	2603	-972	980
CIR840-103	5.47	75.0	2609	1269	1340	2822	213	1553
CIR840-104	5.33	74.4	2206	1066	1140	2543	337	1477
CIR840-105-G1	5.53	78.3	3922	1633	2289	2558	-1364	925
CIR840-105-G2	5.47	75.3	1962	1183	779	2664	702	1481
CIR840-106	5.40	78.2	4180	1724	2456	2837	-1343	1113
CIR840-107	5.27	77.6	3946	1501	2445	2369	-1577	868
CIR840-108	5.67	66.6	1003	855	148	1579	576	724
CIR840-109	5.73	66.6	1383	1029	354	2010	627	981

CIR840-110	5.33	74.4	2366	1234	1132	2856	490	1622
CIR840-111	5.40	78.3	4213	1613	2600	2417	-1796	804
CIR840-112	5.73	67.4	1819	1349	470	2819	1000	1470
CIR840-115	5.67	75.2	2206	1376	830	3025	819	1649
CIR840-116	5.53	76.0	3969	1590	2379	2572	-1397	982
CIR840-117	5.47	76.0	2934	1379	1555	2966	32	1587
CIR840-118	5.87	69.7	1080	903	177	1654	574	751
CIR840-119	5.80	67.3	1242	1015	227	1952	710	937
CIR840-120	5.53	76.0	2349	1241	1108	3079	730	1838
CIR840-121	5.67	69.7	1363	1052	311	2074	711	1022
CIR840-124	5.73	69.7	1283	967	316	2214	931	1247
CIR840-125	5.93	68.8	3038	1512	1526	2696	-342	1184
CIR840-126	5.60	74.4	2617	1452	1165	3325	708	1873
CIR840-127	5.60	75.2	2071	1175	896	2991	920	1816
CIR840-128	5.80	67.3	1832	1427	405	2785	953	1358
CIR840-129-G1	5.47	75.9	2549	1334	1215	3128	579	1794
CIR840-129-G2	5.53	75.9	2555	1417	1138	3101	546	1684
CIR840-130	5.67	68.1	2215	1424	791	3011	796	1587
CIR840-131	5.20	74.4	2320	1176	1144	2838	518	1662
CIR840-132	5.40	74.4	1963	1244	719	2873	910	1629
CIR840-133	5.33	74.4	2159	1239	920	3038	879	1799
CIR840-134	5.40	78.3	3113	1503	1610	2385	-728	882
CIR840-135	5.73	68.2	1486	1139	347	2250	764	1111
CIR840-136	5.27	78.3	3968	1508	2460	2493	-1475	985
CIR840-137	5.47	66.7	1917	1122	795	2500	583	1378
CIR840-138	5.67	69.7	4454	1755	2699	2784	-1670	1029
CIR840-139	5.53	67.3	2206	1393	813	3026	820	1633
CIR840-140	5.33	77.6	4148	1599	2549	2703	-1445	1104
CIR840-141	5.60	69.7	4250	1679	2571	2829	-1421	1150
CIR840-142	5.53	74.4	2447	1304	1143	2954	507	1650
CIR840-143	5.47	73.6	2376	1342	1034	2993	617	1651
CIR840-144	5.60	66.7	1595	1130	465	2315	720	1185
CIR840-145	5.53	75.1	3343	1557	1786	2960	-383	1403
CIR840-146	5.67	68.1	1725	1009	716	2179	454	1170
CIR840-147	5.47	73.5	2596	1335	1261	3363	767	2028
CIR840-149	5.47	74.5	2012	1186	826	2727	715	1541
CIR840-150	5.73	75.2	2167	1310	857	3028	861	1718
CIR840-151	5.40	74.4	2328	1094	1234	2648	320	1554
CIR840-152	5.40	74.4	2076	1134	942	2669	593	1535
CIR840-153	5.53	70.5	3841	1656	2185	3043	-798	1387
CIR840-154	5.53	68.8	2087	1319	768	2858	771	1539
CIR840-155	5.13	73.7	2278	1081	1197	2721	443	1640
CIR840-156	5.47	67.4	2081	1196	885	2566	485	1370
CIR840-157	5.20	73.6	2619	1359	1260	3228	609	1869
CIR840-158	5.53	74.5	2341	1276	1065	2957	616	1681
CIR840-159	5.60	68.9	4022	1708	2314	3050	-972	1342
CIR840-160-G1	5.53	76.9	2458	1567	891	3185	727	1618
CIR840-160-G2	5.80	75.9	2644	1751	893	3356	712	1605
CIR840-161	5.67	72.8	2340	1586	754	3349	1009	1763
CIR840-162-G1	5.80	66.5	2344	1467	877	3092	748	1625
CIR840-162-G2	5.73	68.8	3538	1586	1952	2733	-805	1147
CIR840-163-G1	5.40	78.3	3863	1717	2146	2905	-958	1188
CIR840-163-G2	5.80	68.1	1806	1219	587	2554	748	1335
CIR840-164	5.33	78.3	4248	1686	2562	2732	-1516	1046
CIR840-166	5.47	74.4	2213	1174	1039	2896	683	1722
CIR840-167	5.73	68.8	2736	1230	1506	2357	-379	1127
CIR840-169	5.67	75.2	2281	1449	832	3189	908	1740
CIR840-170	5.47	75.2	2184	1329	855	2982	798	1653
CIR840-171-G1	5.47	66.6	1595	1057	538	2162	567	1105
CIR840-171-G2	5.73	67.3	1461	1029	432	1922	461	893
CIR840-172	5.67	78.3	2739	1473	1266	2469	-270	996
CIR840-173	5.67	75.2	2776	1395	1381	2801	25	1406
CIR840-174-G1	5.47	74.5	2344	1247	1097	3320	976	2073
CIR840-174-G2	5.53	75.2	2294	1222	1072	3054	760	1832
CIR840-175	5.67	74.4	2081	1314	767	3028	947	1714
CIR840-176	5.47	78.3	3876	1612	2264	2600	-1276	988
CIR840-177	5.80	75.2	1703	1161	542	2976	1273	1815
CIR840-178	5.73	72.0	2674	1310	1364	2689	15	1379
CIR840-179	5.73	68.2	1588	1201	387	2413	825	1212
CIR840-180	5.73	72.8	1849	1235	614	2796	947	1561
CIR840-181	5.40	74.4	2491	1396	1095	3184	693	1788
CIR840-182	5.47	72.8	1624	911	713	2189	565	1278
CIR840-183	5.67	69.7	3671	1604	2067	2888	-783	1284
CIR840-184	5.47	74.5	2498	1364	1134	3271	773	1907
CIR840-185	5.67	72.9	2774	1383	1391	3057	283	1674
CIR840-188	5.73	74.4	2438	1244	1194	2598	160	1354
CIR840-189	6.07	69.7	1880	941	939	1814	-66	873
CIR840-190	5.60	74.3	1760	1079	681	2934	1174	1855
CIR840-191	5.40	78.4	2723	1214	1509	2266	-457	1052
CIR840-192	5.73	68.9	1911	1175	736	2526	615	1351
CIR840-193	5.53	76.0	2264	1079	1185	2755	491	1676
CIR840-194	5.60	75.2	1850	1088	762	2861	1011	1773
CIR840-195	5.47	73.6	1644	944	700	2464	820	1520
CIR840-196	5.33	75.1	1801	984	817	2399	598	1415
CIR840-197	5.53	77.6	2968	1341	1627	2389	-579	1048
CIR840-198	5.67	67.3	2049	1238	811	2762	713	1524
CIR840-199	5.60	67.3	1845	1344	501	3111	1266	1767

CIR840-200	5.80	69.7	2911	1357	1554	2464	-447	1107
CIR840-201	5.67	75.1	1913	1072	841	2983	1070	1911
CIR840-202	5.53	75.2	3210	1372	1838	2383	-827	1011
CIR840-203	5.40	78.4	4016	1471	2545	2393	-1623	922
CIR840-204	5.67	67.3	1529	1066	463	2062	533	996
CIR840-205	5.73	68.1	1889	1273	616	2727	838	1454
CIR840-206	5.53	75.9	2057	1128	929	2695	638	1567
CIR840-207	5.67	72.9	2078	1291	787	2808	730	1517
CIR840-208	5.67	74.3	2144	1372	772	3149	1005	1777
CIR840-209	5.60	73.6	2763	1414	1349	3196	433	1782
CIR840-210	5.27	74.4	2350	1092	1258	2680	330	1588
CIR840-211	5.47	78.3	3632	1573	2059	2700	-932	1127
CIR840-212-G2	5.33	74.4	2565	1356	1209	3081	516	1725
CIR840-213	5.47	78.4	3486	1710	1776	2786	-700	1076
CIR840-214	5.73	68.9	1465	975	490	2239	774	1264
CIR840-215	5.60	69.7	3819	1670	2149	2886	-933	1216
CIR840-216-G1	5.33	76.9	4130	1529	2601	2515	-1615	986
CIR840-216-G2	5.47	74.3	2029	1085	944	2620	591	1535
CIR840-217	5.33	78.3	3930	1640	2290	2722	-1208	1082
CIR840-218	5.73	66.6	2201	1617	584	3139	938	1522
CIR840-219	5.80	73.7	2233	1397	836	3045	812	1648
CIR840-220	5.67	66.6	1828	1331	497	2654	826	1323
CIR840-221	5.60	73.7	1626	1089	537	2447	821	1358
CIR840-222	5.33	68.0	4447	1689	2758	2920	-1527	1231
CIR840-223	5.67	66.7	1480	1058	422	2261	781	1203
CIR840-224	5.27	74.4	2334	1282	1052	3022	688	1740
CIR840-225	5.47	74.4	2505	1407	1098	3312	807	1905
CIR840-226	5.73	68.1	1915	1450	465	2993	1078	1543
CIR840-227	5.47	74.4	2627	1577	1050	3680	1053	2103
CIR840-228	5.60	68.1	1609	1187	422	2445	836	1258
CIR840-229	5.47	74.4	2343	1312	1031	3015	672	1703
CIR840-230	5.47	74.5	1849	1082	767	2549	700	1467
CIR840-231	5.53	75.2	1897	1169	728	2520	623	1351
CIR840-232	5.33	75.2	2515	1197	1318	2759	244	1562
CIR840-233-G1	5.53	69.0	4234	1588	2646	2678	-1556	1090
CIR840-233-G2	5.87	69.7	1656	1139	517	2545	889	1406
CIR840-234	5.80	69.6	3329	1595	1734	2973	-356	1378
CIR840-235	5.40	75.2	2297	1273	1024	2864	567	1591
CIR840-236	5.27	74.4	2259	971	1288	2378	119	1407
CIR840-237	5.60	73.6	1704	1044	660	2583	879	1539
CIR840-239	5.47	75.1	3037	1473	1564	3303	266	1830
CIR840-240	5.60	67.3	1476	935	541	1982	506	1047
CIR840-241	5.53	74.4	2465	1378	1087	3280	815	1902
CIR840-242	5.67	68.2	1373	985	388	2064	691	1079
CIR840-243	5.27	78.3	4522	1573	2949	2593	-1929	1020
CIR840-244	5.67	66.6	1361	1059	302	2141	780	1082
CIR840-245	5.73	75.3	2156	1268	888	3035	879	1767
CIR840-246-G1	5.60	67.3	1529	1074	455	2242	713	1168
CIR840-246-G2	5.47	66.5	1612	1100	512	2254	642	1154
CIR840-247	5.47	74.5	2105	1154	951	2831	726	1677
CIR840-249	5.53	68.1	1861	1135	726	2440	579	1305
CIR840-252-G1	5.53	67.3	1698	1142	556	2440	742	1298
CIR840-252-G2	5.80	68.1	1955	1330	625	2711	756	1381
CIR840-253-G1	5.47	72.8	2262	1399	863	3198	936	1799
CIR840-254	5.80	67.4	2058	1326	732	2751	693	1425
CIR840-255	5.53	78.2	3117	1357	1760	2419	-698	1062
CIR840-256	5.53	75.2	2371	1114	1257	2526	155	1412
CIR840-257	5.33	78.4	3904	1663	2241	2813	-1091	1150
CIR840-258	5.60	66.6	1511	1146	365	2420	909	1274
CIR840-259	5.80	68.1	1297	1032	265	2002	705	970
CIR840-260	5.67	75.9	2567	1330	1237	2943	376	1613
CIR840-262	5.53	67.3	1982	1156	826	2530	548	1374
CIR840-263	5.53	71.2	2497	1331	1166	2928	431	1597
CIR840-264	5.33	73.6	1900	1030	870	2492	592	1462
CIR840-265	5.40	76.1	2376	1319	1057	2942	566	1623
CIR840-266	5.87	68.8	1378	1077	301	2010	632	933
CIR840-267	5.67	67.4	1544	1050	494	2195	651	1145
CIR840-268	5.40	72.1	2218	1328	890	3058	840	1730
CIR840-269	5.33	73.6	2219	1108	1111	2686	467	1578
CIR840-270	5.73	68.1	3810	1624	2186	2864	-946	1240
CIR840-271	5.27	75.2	2714	1113	1601	2676	-38	1563
CIR840-272-G1	5.60	68.1	1555	1091	464	2216	661	1125
CIR840-272-G2	5.33	78.2	3570	1496	2074	2504	-1066	1008
CIR840-273	5.87	68.1	1555	1262	293	2348	793	1086
CIR840-275	5.40	75.1	2417	1295	1122	3053	636	1758
CIR840-276	5.33	74.4	1819	978	841	2552	733	1574
CIR840-277	5.33	74.4	2151	1093	1058	2783	632	1690
CIR840-278	5.60	68.1	1219	952	267	1853	634	901
CIR840-279	5.53	69.6	1521	1059	462	2257	736	1198
CIR840-280	5.60	67.3	1499	1085	414	2231	732	1146
CIR840-281	5.40	75.2	2158	1294	864	3090	932	1796
CIR840-283	5.27	74.4	1908	999	909	2473	565	1474
CIR840-284	5.60	74.4	2454	1464	990	3215	761	1751
CIR840-285	5.60	66.6	1506	1061	445	2246	740	1185
CIR840-286	5.67	68.0	1923	1296	627	2980	1057	1684
CIR840-287	5.40	76.0	1818	1055	763	2563	745	1508
CIR840-288	5.27	73.6	2556	1342	1214	3087	531	1745

CIR840-289	5.47	69.6	3471	1305	2166	2292	-1179	987
CIR840-290	5.40	73.6	2723	1470	1253	3472	749	2002
CIR840-291	5.40	75.9	2651	1327	1324	3012	361	1685
CIR840-292	5.60	66.6	1908	1447	461	3136	1228	1689
CIR840-293	5.60	70.4	4156	1755	2401	2984	-1172	1229
CIR840-294	5.40	74.3	2062	1228	834	2773	711	1545
CIR840-295	5.47	70.4	3687	1535	2152	2767	-920	1232
CIR840-296-G1	5.73	69.8	3539	1568	1971	2767	-772	1199
CIR840-296-G2	5.73	69.6	3171	1391	1780	2507	-664	1116
CIR840-297-G1	5.40	77.6	3385	1325	2060	2305	-1080	980
CIR840-297-G2	5.40	78.3	3746	1501	2245	2485	-1261	984
CIR840-298	5.27	72.1	2070	1095	975	2695	625	1600
CIR840-299	5.33	75.2	2211	1155	1056	2777	566	1622
CIR840-300	5.53	68.9	3275	1514	1761	2982	-293	1468
CIR840-301	5.13	74.3	2549	1131	1418	2775	226	1644
CIR840-302-G1	5.60	67.4	1925	1210	715	2630	705	1420
CIR840-302-G2	5.80	67.4	1959	1248	711	2751	792	1503
CIR840-303	5.67	69.7	3607	1631	1976	2897	-710	1266
CIR840-304	5.40	74.3	2254	1109	1145	2563	309	1454
CIR840-305	5.27	73.7	2384	1190	1194	2965	581	1775
CIR840-306	5.60	69.7	3757	1636	2121	2748	-1009	1112
CIR840-307	5.73	76.0	3579	1556	2023	2656	-923	1100
CIR840-308	5.73	67.3	1920	1338	582	2742	822	1404
CIR840-309	5.47	77.5	3604	1470	2134	2478	-1126	1008
CIR840-310	5.80	72.1	2536	1447	1089	2913	377	1466
CIR840-311	5.40	78.3	4234	1628	2606	2521	-1713	893
CIR840-312	5.73	70.5	3638	1746	1892	3028	-610	1282
CIR840-313	5.60	70.4	3771	1749	2022	2885	-886	1136
CIR840-317	6.00	68.0	1590	1346	244	2422	832	1076
CIR840-318	5.67	75.2	2407	1278	1129	2813	406	1535
CIR840-325	5.53	68.0	4168	1685	2483	2900	-1268	1215
CIR840-329	5.93	69.6	1485	1182	303	2269	784	1087
CIR840-330	5.60	67.4	1536	1056	480	2111	575	1055
CIR840-333	5.67	79.1	3267	1767	1500	2864	-403	1097
CIR840-334	5.47	74.4	2107	1236	871	2921	814	1685
CIR840-335	5.60	69.6	3694	1638	2056	2895	-799	1257
CIR840-338	5.53	76.0	2648	1771	877	3493	845	1722
CIR840-345	5.60	75.9	2401	1431	970	3225	824	1794
CIR840-348	5.60	78.2	3205	1483	1722	2547	-658	1064
CIR840-351	5.60	73.7	2119	1271	848	3005	886	1734
CIR840-356	5.67	78.3	3357	1710	1647	2852	-505	1142
CIR840-358	5.47	78.2	3494	1597	1897	2614	-880	1017
CIR840-360	5.80	69.6	3310	1681	1629	2907	-403	1226
CIR840-261	5.53	78.3	3678	1703	1975	2936	-742	1233
CIR840-362	5.80	67.3	1384	1040	344	2011	627	971
CIR840-363	5.80	68.9	1837	1223	614	2465	628	1242
CIR840-364	5.53	66.6	1702	1150	552	2468	766	1318
CIR840-365	5.80	70.5	3340	1696	1644	3040	-300	1344
PHKA RUMDUOL	5.60	69.6	4215	1736	2479	2925	-1290	1189
THMAR KREM	5.53	74.5	2292	1181	1110	2756	465	1576

PCA was done by Mr. Roslen Anacleto, Senior Associate Scientist of the Grain Quality and Nutrition Center of IRRI, using all the quality traits to illustrate any groupings of the progeny relative to the parents (Figure 5). PCA involves a dimension reduction operation to convert all measured parameters to comparable values. In this analysis, the following equation was used to get the variation:

Variance = (x - μ) / δ

where x = variable, measurement of a trait

μ = mean value of the trait of population

δ = standard deviation

Three clusters or groupings are shown in the plot: blue, PRD-like; green, TK-like and red are the intermediates between the two parents. The quality traits that highly contribute to the difference between the PRD-like lines and TK-like lines are the following: amylose content and RVA parameters such as peak viscosity, final viscosity, setback, trough and retrogradation, measurements that predict the cooking quality of rice.

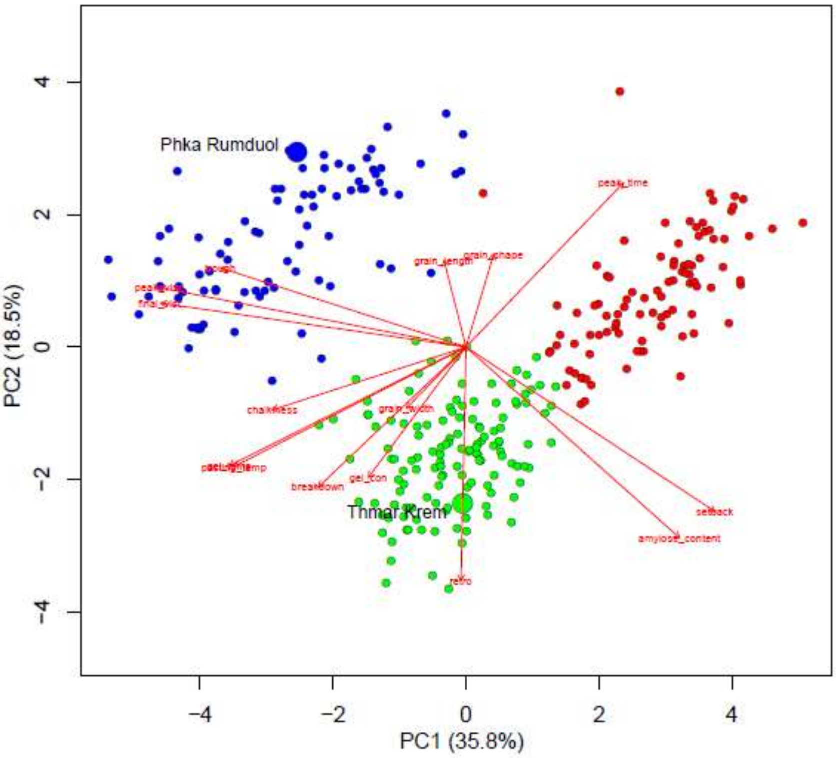


Figure 5. PCA based on quality traits of the PRD x TK population which are shown in Tables 3a and 3b. Three clusters formed using k-means clustering: blue, PRD-like lines; green, TK-like and red are the intermediates. The arrow indicates the direction of increasing value of the trait. Length of the arrow indicates the magnitude of the variation in a given trait. The major contributions to PC1 are 1-peak viscosity, 2- final viscosity, 3-setback, 4-trough, 5-gelatinization temperature and 6-pasting temperature. To PC2, the following traits contribute in the order of decreasing magnitude: 1-retrogradation, 2-amylose, 3-setback, 4-peak time, 5-breakdown and 6-gel consistency.

C2. Texture Analysis

Cooked rice texture was evaluated using the TA.XTplus Texture Analyser by Stable Micro System, UK. The textural attributes measured were the following: (Reference for definitions: Juliano, BO. Rice Chemistry and Quality. 2007. Philippine Rice Research Institute, p. 92.)

- Hardness - force required to bite through the sample with the molars
- Adhesiveness - force required to separate individual grains adhering to each other (manual adhesiveness); degree to which the grains stick together in a mass (visual adhesiveness)
- Cohesiveness – degree to which the grains deform rather than crumble, crack or break when biting with molars
- Springiness – degree to which the grains return to original shape after partial compression

Hardness, adhesiveness, cohesiveness and springiness measurements of freshly cooked and retrograded rice samples are presented in Tables 5a and 5b and Scatter Plots in Figure 6. Retrogradation was done by keeping the cooked rice in the refrigerator for 24 hours.

Figures 7 and 8 are the PCA graphs representing the variation in the textural attributes. Three clusters or groups formed in both graphs for freshly cooked and retrograded rice of the population. The three clusters represent the PRD-like lines, TK-like lines and the intermediates.

Table 5a. Textural attributes of freshly cooked PRD x TK lines

Freshly Cooked	Hardness g	Adhesiveness g·sec	Cohesiveness	Springiness
1	1861.30	-38.049	0.395	0.109
3	1949.53	-38.084	0.444	0.132
4	1656.00	-69.601	0.455	0.104
5	1911.86	-38.972	0.386	0.099
6	1977.80	-26.170	0.407	0.113
7	1220.81	-91.718	0.470	0.135
8	983.29	-95.845	0.409	0.089
9	2068.95	-33.245	0.467	0.123
10	1756.47	-15.639	0.371	0.118
11	1175.71	-15.259	0.345	0.114
18	1618.35	-49.178	0.423	0.100
19	2134.43	-28.960	0.438	0.115
20	1041.31	-111.373	0.445	0.107
21	1200.11	-18.013	0.360	0.096
22	1780.61	-14.997	0.422	0.105
23	1950.41	-16.027	0.364	0.112
24	1547.25	-23.673	0.362	0.118
25	2476.88	-28.540	0.419	0.124
26	3086.51	-50.685	0.457	0.124
27	1732.75	-39.543	0.366	0.103
28	1242.45	-107.109	0.468	0.090
29	1345.39	-19.412	0.387	0.106
30	1783.20	-22.924	0.356	0.098
31	1527.03	-19.614	0.336	0.122
32	1586.56	-19.495	0.325	0.117
33	2597.62	-24.228	0.463	0.117
34	1805.36	-18.144	0.418	0.114
35	1489.35	-13.530	0.309	0.111
36	1261.52	-110.341	0.430	0.102
37	1614.12	-15.126	0.323	0.105
38	1964.99	-21.644	0.353	0.090
39	1541.10	-16.402	0.364	0.105
40	1741.25	-34.760	0.397	0.121
41	2922.89	-30.033	0.483	0.145
42	2762.33	-32.495	0.502	0.107
43	2058.83	-14.527	0.396	0.109
44	1728.49	-42.060	0.390	0.117
45	1124.36	-113.437	0.450	0.124
46	1368.41	-102.872	0.419	0.099
47	1269.29	-112.613	0.384	0.098
48	923.51	-77.343	0.435	0.093
49	1431.02	-20.654	0.366	0.096
50	1647.08	-41.252	0.417	0.101
51	1825.34	-46.489	0.431	0.105
52	2474.49	-15.104	0.504	0.139
53	2710.92	-25.616	0.495	0.129
54	1753.69	-31.939	0.408	0.114
55	2155.91	-25.239	0.442	0.132
56	1808.82	-12.388	0.377	0.121
57	2300.57	-23.777	0.406	0.118
58	2079.13	-97.572	0.471	0.130

59	1629.85	-7.887	0.377	0.097
60	1378.81	-44.567	0.439	0.142
61	1659.35	-10.078	0.379	0.105
62	1573.91	-14.170	0.378	0.104
63	668.42	-70.165	0.436	0.093
64	1131.32	-88.531	0.447	0.095
65	1902.49	-17.101	0.372	0.111
66	987.52	-75.849	0.433	0.084
67	1962.62	-37.379	0.368	0.104
68	1131.86	-100.994	0.448	0.098
69	1609.56	-9.840	0.380	0.125
70	1617.40	-13.195	0.329	0.101
71	2064.12	-24.528	0.491	0.106
72	1714.00	-43.102	0.458	0.148
73	1404.84	-78.937	0.434	0.096
74	1771.56	-16.130	0.417	0.103
75	1447.05	-11.950	0.361	0.098
76	2088.71	-19.091	0.401	0.128
77	1314.59	-79.681	0.448	0.112
78	2249.65	-7.469	0.399	0.106
79	1239.62	-94.602	0.456	0.095
80	1732.72	-14.873	0.425	0.101
81	1095.05	-70.266	0.418	0.104
82	2225.00	-17.888	0.481	0.181
83	1062.13	-70.316	0.412	0.103
84	1997.37	-7.597	0.472	0.121
85	2135.37	-11.626	0.435	0.117
86	981.43	-69.260	0.399	0.093
95	2197.19	-26.856	0.453	0.108
96	1963.50	-15.725	0.346	0.116
97	1080.38	-18.163	0.319	0.107
98	1741.83	-17.553	0.360	0.102
99	2023.52	-16.053	0.368	0.115
100	1464.94	-15.593	0.354	0.093
101	1768.87	-18.034	0.345	0.123
102	1741.85	-11.412	0.372	0.120
103	823.54	-70.542	0.422	0.089
104	1318.75	-101.225	0.399	0.094
105	2136.10	-32.248	0.422	0.110
106	2151.72	-18.714	0.423	0.118
107	1245.22	-116.190	0.439	0.101
108	1554.74	-20.835	0.328	0.091
109	1596.87	-133.629	0.450	0.123
110	1201.26	-100.151	0.447	0.107
111	1667.50	-23.349	0.320	0.096
112	2147.86	-30.193	0.395	0.102
113	1616.12	-25.161	0.373	0.091
114	1132.03	-94.909	0.444	0.129
115	1983.79	-25.589	0.374	0.113
116	2553.03	-20.096	0.409	0.143
117	1817.84	-22.873	0.348	0.108
118	2342.90	-11.832	0.412	0.119
119	1447.29	-121.771	0.406	0.082

120	2120.46	-34.664	0.468	0.105
121	1658.63	-11.074	0.337	0.101
122	1701.23	-6.970	0.375	0.107
131	2558.76	-26.008	0.464	0.115
132	1909.80	-31.234	0.430	0.109
133	1395.37	-42.417	0.345	0.096
134	2056.25	-24.623	0.436	0.111
135	1630.10	-11.787	0.342	0.125
136	1253.24	-17.990	0.330	0.106
137	1106.43	-62.370	0.414	0.097
138	1440.17	-27.668	0.315	0.091
139	800.44	-83.761	0.407	0.089
140	2083.62	-35.179	0.425	0.101
141	1103.95	-93.958	0.451	0.076
142	1631.42	-40.724	0.341	0.105
143	1371.98	-120.084	0.461	0.105
144	838.56	-76.506	0.441	0.067
145	1444.11	-26.202	0.398	0.113
146	1651.99	-28.109	0.390	0.125
147	1242.64	-14.198	0.327	0.098
148	1754.68	-52.912	0.451	0.101
149	1659.05	-27.404	0.388	0.100
150	1589.00	-16.469	0.445	0.123
151	1354.07	-32.368	0.465	0.103
152	1265.82	-7.461	0.368	0.095
153	1591.22	-23.216	0.346	0.095
154	2137.02	-31.893	0.410	0.122
155	2746.20	-59.102	0.451	0.116
156	1633.24	-104.740	0.423	0.103
157	1750.26	-28.853	0.389	0.092
158	1523.35	-13.836	0.353	0.116
159	1475.52	-38.994	0.403	0.095
160	1607.07	-13.717	0.421	0.106
161	1550.40	-14.942	0.419	0.098
162	1042.97	-83.214	0.427	0.103
163	1806.23	-26.871	0.433	0.114
164	1574.70	-26.758	0.444	0.128
165	2460.80	-19.600	0.399	0.122
166	2006.71	-30.041	0.412	0.101
167	1495.86	-97.758	0.423	0.098
168	1552.92	-100.475	0.444	0.125
169	1993.79	-24.704	0.400	0.107
170	1481.99	-109.577	0.432	0.086
171	1669.82	-20.830	0.302	0.087
172	1730.12	-14.772	0.353	0.114
173	1541.63	-103.911	0.386	0.113
174	2224.28	-20.507	0.379	0.116
175	1441.02	-17.626	0.350	0.097
176	1661.36	-7.974	0.379	0.115
177	2385.74	-4.053	0.471	0.153
178	2175.58	-6.388	0.410	0.143
179	1181.57	-51.114	0.443	0.099
180	1119.95	-24.065	0.414	0.109

181	1388.53	-9.309	0.435	0.146
182	1014.48	-13.768	0.382	0.117
183	1419.54	-5.471	0.406	0.114
184	522.83	-21.438	0.363	0.128
185	2186.08	-10.623	0.328	0.123
186	1460.52	-36.141	0.369	0.095
187	2010.84	-33.935	0.306	0.114
188	2360.86	-16.342	0.386	0.113
189	1939.67	-11.468	0.420	0.105
190	2112.05	-8.186	0.425	0.124
191	2023.47	-41.121	0.478	0.128
192	2370.57	-14.186	0.514	0.123
193	1705.38	-91.620	0.395	0.080
194	1356.17	-51.308	0.368	0.103
195	1080.06	-87.199	0.433	0.085
196	2199.54	-10.665	0.383	0.134
197	1252.20	-67.773	0.393	0.089
198	1630.41	-20.945	0.389	0.108
199	2073.86	-15.962	0.402	0.113
200	1509.56	-8.104	0.349	0.101
201	1676.96	-8.916	0.399	0.143
202	1839.48	-4.751	0.415	0.141
203	1592.82	-42.857	0.420	0.089
204	1908.60	-7.984	0.412	0.121
205	2721.83	-15.614	0.386	0.128
206	1525.94	-22.652	0.368	0.098
207	1760.25	-17.796	0.380	0.097
208	1206.01	-82.406	0.413	0.116
209	746.80	-62.819	0.423	0.085
210	1595.83	-20.540	0.336	0.133
211	1579.25	-18.680	0.349	0.098
212	1406.43	-18.541	0.355	0.151
213	1502.25	-8.255	0.384	0.120
214	1902.93	-6.811	0.424	0.121
227	1695.56	-19.392	0.338	0.096
228	2221.60	-10.528	0.351	0.110
229	1616.77	-18.064	0.306	0.123
230	1747.71	-82.033	0.398	0.111
231	1961.70	-24.978	0.349	0.087
232	1615.07	-14.837	0.324	0.096
233	1473.68	-15.438	0.345	0.090
234	2446.03	-18.935	0.396	0.133
235	2559.30	-14.118	0.419	0.141
236	1884.16	-23.676	0.316	0.148
237	1334.67	-18.009	0.399	0.119
238	1215.14	-11.061	0.336	0.107
239	1201.60	-9.638	0.339	0.097
240	1380.06	-21.796	0.379	0.106
241	1108.99	-72.140	0.422	0.087
242	1314.68	-9.701	0.356	0.087
243	967.00	-25.234	0.398	0.087
244	1326.38	-6.451	0.370	0.119
245	1362.80	-43.310	0.344	0.092

247	1378.93	-15.936	0.312	0.101
248	1691.38	-40.183	0.417	0.130
249	1878.69	-24.407	0.336	0.107
250	1773.47	-16.660	0.374	0.109
251	1782.61	-15.599	0.353	0.092
252	1171.97	-65.481	0.489	0.098
253	1907.50	-4.533	0.427	0.100
254	1607.22	-10.794	0.403	0.121
255	1637.64	-17.407	0.358	0.100
256	1543.97	-13.312	0.362	0.109
257	1485.32	-11.013	0.384	0.131
258	2024.38	-25.804	0.380	0.123
259	1576.47	-20.449	0.338	0.102
260	1615.69	-23.983	0.350	0.127
261	2405.33	-7.302	0.405	0.120
262	2756.57	-10.867	0.437	0.118
263	2415.90	-21.561	0.433	0.096
264	1576.78	-62.200	0.438	0.104
265	1845.21	-6.451	0.412	0.110
266	1297.19	-71.457	0.373	0.063
267	2221.25	-11.032	0.384	0.093
268	1267.88	-13.524	0.282	0.070
269	1838.54	-13.053	0.395	0.092
270	1992.91	-11.370	0.414	0.102
271	2354.54	-18.558	0.471	0.128
272	1942.20	-4.427	0.414	0.107
273	1875.25	-9.925	0.447	0.102
274	1849.05	-20.011	0.340	0.101
275	1555.35	-17.166	0.335	0.096
276	2140.12	-15.704	0.404	0.155
277	1944.77	-13.275	0.402	0.122
278	815.49	-27.548	0.451	0.078
279	847.55	-12.320	0.362	0.087
280	904.92	-5.476	0.346	0.098
281	967.33	-29.491	0.422	0.085
282	975.98	-7.154	0.344	0.114
283	673.65	-23.577	0.367	0.069
284	1256.76	-5.703	0.425	0.120
285	1324.54	-4.093	0.463	0.095
286	1323.60	-5.208	0.428	0.096
287	1089.16	-7.789	0.331	0.101
288	1058.25	-5.929	0.364	0.102
289	941.33	-4.668	0.326	0.111
290	1511.93	-10.534	0.412	0.108
291	1870.97	-18.530	0.399	0.101
292	1553.62	-10.302	0.351	0.095
293	2413.96	-12.148	0.462	0.094
294	2265.62	-14.169	0.394	0.109
295	2071.69	-5.596	0.456	0.114
296	1523.46	-3.236	0.375	0.131
297	2568.85	-5.570	0.500	0.125
298	1221.01	-62.575	0.382	0.073
299	2949.11	-9.065	0.534	0.146

300	2408.71	-18.352	0.440	0.115
301	2576.09	-4.358	0.448	0.112
302	942.13	-51.025	0.372	0.090
303	1791.20	-5.888	0.435	0.125
304	993.38	-24.234	0.355	0.084
305	939.60	-22.543	0.399	0.078
306	861.88	-28.955	0.356	0.061
307	965.50	-25.191	0.378	0.066
308	853.60	-20.124	0.375	0.060
309	1198.37	-4.331	0.366	0.106
310	1555.15	-21.504	0.366	0.105
311	1786.59	-54.167	0.423	0.102
312	1536.24	-18.991	0.371	0.095
313	2667.02	-13.589	0.456	0.121
314	2608.87	-30.779	0.451	0.116
315	1368.84	-37.420	0.405	0.086
317	1620.03	-13.524	0.383	0.090
318	1012.94	-67.264	0.340	0.070
319	886.43	-33.805	0.349	0.060
320	2129.20	-15.882	0.375	0.088
321	1228.76	-54.451	0.396	0.057
322	1136.66	-16.038	0.322	0.061
323	1408.53	-45.816	0.424	0.066
324	1211.54	-33.445	0.369	0.065
325	804.49	-48.316	0.336	0.059
326	1465.77	-19.265	0.282	0.093
327	1405.08	-34.565	0.379	0.090
328	1152.39	-11.438	0.342	0.093
330	987.23	-36.825	0.367	0.089
331	817.53	-11.776	0.350	0.101
333	792.95	-33.799	0.374	0.090
336	1491.17	-3.525	0.419	0.119
337	1358.68	-4.081	0.382	0.094
339	1081.92	-16.134	0.378	0.077
340	1600.93	-2.369	0.417	0.119
341	1801.46	-108.375	0.420	0.093
344	1992.61	-19.942	0.433	0.105
345	1221.86	-61.160	0.412	0.108
347	1757.32	-10.143	0.342	0.107
348	1648.80	-18.117	0.408	0.110
349	1406.70	-60.880	0.336	0.086
350	2447.02	-24.539	0.410	0.105
351	1369.41	-91.371	0.347	0.083
352	1495.72	-76.340	0.383	0.088
353	1677.30	-25.397	0.355	0.120
355	1350.76	-26.100	0.370	0.100
356	1093.92	-71.405	0.372	0.106
358	1451.39	-59.898	0.381	0.070
359	1234.21	-45.352	0.404	0.097
360	1427.72	-7.286	0.320	0.196
361	1459.49	-51.043	0.364	0.084
362	1595.54	-74.744	0.368	0.092
363	1363.88	-35.999	0.323	0.089

364	1444.94	-14.996	0.300	0.119
365	2066.46	-8.851	0.390	0.103
366	1295.83	-46.486	0.339	0.085
367-PRD	1185.65	-78.629	0.463	0.081
368-TK	1265.44	-19.859	0.361	0.105

Table 5b. Textural attributes of retrograded PRD x TK lines

Retrograded	Hardness g	Adhesiveness g:sec	Cohesiveness	Springiness
1	1907.97	-17.054	0.313	0.134
3	2058.26	-14.269	0.351	0.153
4	2076.72	-39.583	0.366	0.121
5	1879.92	-18.600	0.313	0.131
6	1994.05	-17.349	0.323	0.127
7	1574.47	-71.224	0.362	0.113
8	908.73	-95.367	0.353	0.118
9	2641.18	-12.160	0.363	0.138
10	1798.49	-14.652	0.305	0.116
11	1465.60	-9.093	0.288	0.145
12	3238.56	-8.737	0.418	0.155
13	2919.58	-13.742	0.382	0.144
14	1464.56	-9.980	0.320	0.147
15	1273.11	-12.396	0.260	0.124
16	2280.85	-7.871	0.357	0.131
17	1890.55	-11.142	0.315	0.145
18	1713.53	-52.533	0.348	0.128
19	2339.25	-17.096	0.326	0.151
20	948.17	-101.416	0.395	0.092
21	1571.71	-9.918	0.282	0.123
22	2186.76	-8.490	0.361	0.137
23	2181.87	-12.999	0.327	0.116
24	1761.55	-8.413	0.316	0.134
25	2326.16	-11.743	0.335	0.149
26	2327.54	-14.525	0.336	0.139
27	1885.27	-20.933	0.304	0.146
28	1308.31	-118.006	0.447	0.096
29	1647.39	-11.606	0.312	0.115
30	1952.53	-21.367	0.310	0.118
31	1966.51	-12.894	0.304	0.131
32	1637.84	-14.876	0.290	0.120
33	2475.37	-19.803	0.391	0.137
34	2164.30	-10.342	0.345	0.169
35	2132.48	-16.081	0.317	0.126
36	2038.97	-61.746	0.340	0.129
37	1881.47	-10.784	0.298	0.143
38	2500.55	-13.476	0.344	0.139
39	2130.10	-11.190	0.319	0.135
40	2757.50	-26.390	0.370	0.158
41	3729.76	-15.187	0.412	0.136
42	3040.28	-12.623	0.396	0.154
43	2112.39	-11.912	0.330	0.148
44	1891.42	-43.087	0.352	0.133
45	1268.01	-110.286	0.356	0.098
46	2323.07	-79.445	0.365	0.124

47	1300.49	-120.712	0.363	0.118
48	812.09	-60.929	0.355	0.095
49	1455.22	-10.076	0.296	0.122
50	1446.35	-42.028	0.372	0.129
51	1710.62	-51.025	0.357	0.117
52	2974.55	-9.453	0.409	0.141
53	3114.44	-10.373	0.392	0.163
54	1768.78	-16.948	0.323	0.135
55	2015.11	-13.183	0.456	0.148
56	2107.00	-10.202	0.337	0.154
57	2967.48	-11.672	0.353	0.135
58	1476.47	-65.808	0.334	0.102
59	1829.18	-9.105	0.317	0.138
60	1492.57	-34.436	0.314	0.103
61	1635.70	-15.109	0.305	0.112
62	1565.82	-13.488	0.292	0.126
63	569.55	-72.673	0.394	0.091
64	1007.69	-103.408	0.418	0.105
65	1587.25	-14.971	0.306	0.132
66	640.10	-49.976	0.363	0.112
67	1498.33	-12.771	0.304	0.139
68	734.09	-58.059	0.366	0.093
69	2148.90	-9.751	0.322	0.139
70	1811.66	-13.060	0.290	0.110
71	2462.78	-12.854	0.351	0.159
72	2564.73	-14.308	0.355	0.128
73	1858.19	-100.606	0.357	0.130
75	1224.77	-12.083	0.287	0.111
76	2481.38	-6.685	0.366	0.146
77	1307.09	-55.198	0.365	0.129
78	2078.86	-6.522	0.354	0.149
79	1480.56	-75.549	0.370	0.091
80	2315.32	-14.059	0.323	0.134
81	1519.06	-105.499	0.399	0.116
82	3144.47	-9.311	0.374	0.168
83	1881.91	-53.757	0.337	0.116
84	2602.19	-9.573	0.348	0.162
85	3065.42	-9.143	0.383	0.161
86	2286.67	-165.085	0.458	0.110
87	1369.53	-87.855	0.321	0.118
88	1416.29	-12.731	0.301	0.107
89	1975.30	-36.602	0.351	0.115
90	1806.81	-16.423	0.334	0.129
91	2005.88	-18.865	0.331	0.142
92	1834.50	-26.808	0.369	0.144
93	1807.40	-26.095	0.361	0.106
95	1927.19	-21.196	0.315	0.117
96	2114.64	-11.380	0.351	0.117
97	1202.24	-14.454	0.257	0.141
98	1852.46	-14.415	0.281	0.139
99	2141.59	-11.326	0.326	0.128
100	1647.04	-12.615	0.304	0.125
101	1609.11	-20.517	0.283	0.125

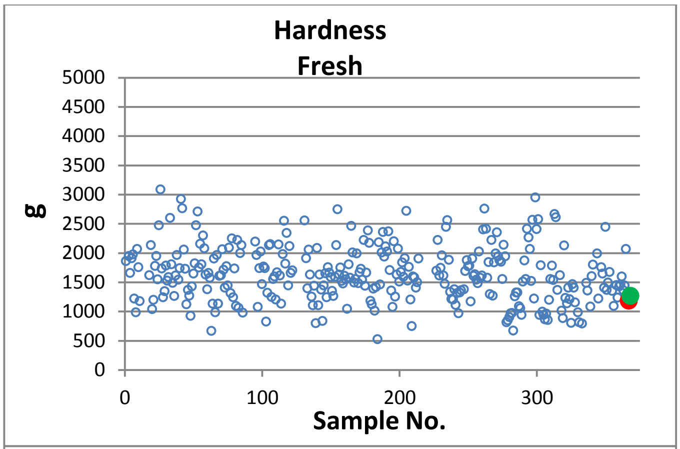
102	1865.60	-8.536	0.330	0.111
103	751.52	-90.884	0.396	0.125
104	1019.07	-119.374	0.376	0.097
105	2074.26	-19.189	0.313	0.124
106	2444.10	-10.755	0.357	0.163
107	1179.19	-106.793	0.372	0.088
108	1600.77	-14.393	0.282	0.136
109	1483.75	-106.258	0.348	0.107
110	1490.25	-60.076	0.350	0.089
111	1578.46	-13.039	0.269	0.117
112	2113.26	-14.219	0.325	0.104
113	1791.40	-12.492	0.293	0.145
114	1086.19	-83.057	0.359	0.107
115	1742.16	-16.247	0.297	0.127
116	2404.85	-14.117	0.342	0.143
117	2157.54	-9.679	0.319	0.143
118	2931.11	-9.551	0.373	0.139
119	1525.18	-127.688	0.355	0.105
120	2682.05	-20.898	0.336	0.154
121	1746.78	-18.425	0.280	0.095
122	1477.92	-11.844	0.269	0.104
123	1712.06	-14.847	0.308	0.130
124	1960.54	-11.136	0.302	0.132
125	1865.93	-87.671	0.333	0.115
126	1668.21	-20.036	0.288	0.122
127	1801.38	-110.465	0.354	0.115
128	2053.41	-32.435	0.320	0.127
129	1728.04	-16.650	0.293	0.120
130	1696.10	-15.697	0.285	0.127
131	2263.06	-30.204	0.305	0.132
132	2049.69	-36.586	0.318	0.142
133	1164.36	-56.167	0.288	0.094
134	2331.17	-19.676	0.349	0.161
135	1985.85	-13.504	0.324	0.156
136	1490.08	-15.233	0.294	0.123
137	953.63	-63.123	0.365	0.147
138	1447.63	-11.064	0.278	0.105
139	652.76	-85.564	0.386	0.113
140	1752.10	-46.242	0.326	0.098
141	968.07	-113.711	0.423	0.158
142	1515.90	-31.280	0.298	0.092
143	1158.92	-83.437	0.359	0.128
144	851.97	-95.122	0.425	0.102
145	1812.17	-13.147	0.293	0.155
146	1804.04	-16.706	0.297	0.125
147	1456.81	-11.800	0.264	0.126
148	2318.39	-33.728	0.379	0.116
149	1987.93	-24.697	0.334	0.102
150	2035.04	-11.830	0.344	0.161
151	1457.45	-23.682	0.318	0.108
152	1531.00	-9.149	0.308	0.125
153	1845.98	-16.603	0.296	0.139
154	2214.39	-15.215	0.312	0.136

155	2178.89	-10.687	0.333	0.154
156	1022.01	-97.908	0.421	0.092
157	1945.24	-28.496	0.323	0.125
158	1843.11	-16.822	0.305	0.139
159	1783.90	-25.292	0.333	0.114
160	1947.18	-11.598	0.329	0.147
161	2051.97	-19.275	0.306	0.114
162	1235.22	-109.680	0.387	0.093
163	2524.34	-23.005	0.364	0.127
164	1907.43	-26.244	0.350	0.133
173	1187.63	-52.853	0.343	0.082
174	1496.82	-8.536	0.301	0.115
175	1342.20	-8.568	0.300	0.134
176	1604.81	-5.894	0.310	0.130
177	1756.23	-9.270	0.346	0.125
178	1578.55	-7.445	0.298	0.125
179	1241.21	-30.858	0.319	0.113
180	993.67	-16.094	0.342	0.098
181	2321.31	-8.160	0.354	0.142
182	2155.79	-11.088	0.335	0.143
183	2445.09	-7.436	0.333	0.153
184	1316.95	-43.875	0.310	0.093
185	2198.32	-13.605	0.297	0.139
186	1782.24	-32.167	0.310	0.126
187	1714.64	-21.011	0.269	0.142
188	2531.89	-17.426	0.345	0.149
189	2645.85	-7.015	0.366	0.139
190	2057.23	-9.195	0.328	0.119
191	1854.95	-51.761	0.381	0.134
192	2606.09	-7.796	0.359	0.137
193	1493.94	-110.310	0.362	0.102
194	1117.91	-55.448	0.315	0.111
195	963.97	-96.919	0.394	0.086
196	2854.56	-10.859	0.370	0.168
197	2204.06	-12.205	0.327	0.114
198	2041.39	-13.309	0.313	0.146
199	3844.18	-4.527	0.412	0.161
200	2424.54	-3.399	0.382	0.151
201	2620.52	-4.405	0.384	0.148
202	2950.54	-4.401	0.427	0.196
203	3637.99	-5.279	0.421	0.135
204	2222.98	-8.763	0.335	0.145
205	3260.76	-10.095	0.362	0.147
206	1876.63	-34.715	0.329	0.117
207	1963.31	-12.581	0.295	0.136
208	1458.67	-103.518	0.370	0.145
209	1035.75	-73.175	0.328	0.085
210	1761.53	-13.587	0.274	0.103
211	1628.80	-27.717	0.299	0.091
212	1826.01	-13.961	0.284	0.108
213	1991.67	-9.204	0.317	0.124
214	2052.46	-10.885	0.334	0.130
215	1204.70	-8.591	0.312	0.142

216	918.55	-5.549	0.304	0.125
217	504.82	-18.127	0.295	0.086
218	1361.80	-5.102	0.335	0.122
219	1263.93	-4.889	0.311	0.130
220	350.20	-10.908	0.318	0.078
221	1070.03	-5.888	0.333	0.114
222	428.24	-27.033	0.341	0.095
223	478.32	-18.472	0.338	0.096
224	878.76	-5.261	0.312	0.102
225	403.00	-12.655	0.306	0.068
226	1371.16	-7.421	0.365	0.109
227	1911.11	-25.461	0.289	0.119
228	2184.68	-13.355	0.280	0.128
229	1699.44	-17.192	0.264	0.131
230	1263.63	-55.476	0.343	0.104
231	1897.60	-17.031	0.295	0.123
232	1973.29	-12.090	0.299	0.144
233	1756.47	-13.482	0.281	0.118
234	2591.04	-16.671	0.324	0.130
235	3417.35	-13.704	0.366	0.139
236	2011.20	-20.811	0.319	0.149
237	1736.90	-6.678	0.292	0.119
238	1502.68	-8.799	0.260	0.113
239	1618.06	-8.732	0.292	0.133
240	2428.53	-22.088	0.345	0.127
241	1685.92	-160.424	0.443	0.126
242	1446.65	-27.013	0.290	0.094
243	1269.76	-65.393	0.345	0.091
244	1970.30	-14.118	0.309	0.165
245	1319.29	-17.206	0.251	0.111
247	1198.05	-6.907	0.277	0.127
248	1434.99	-23.340	0.305	0.119
249	1556.37	-9.935	0.265	0.120
250	1683.47	-8.135	0.299	0.114
251	1392.05	-7.884	0.293	0.107
252	1353.51	-38.534	0.357	0.092
253	1342.15	-6.196	0.297	0.119
258	2116.94	-14.470	0.287	0.128
259	1882.61	-15.816	0.276	0.119
260	1783.12	-14.307	0.286	0.125
261	3135.35	-8.724	0.346	0.155
262	2799.20	-9.838	0.362	0.152
263	2558.45	-18.117	0.344	0.110
264	2326.10	-36.618	0.340	0.105
265	2820.95	-11.312	0.389	0.142
266	1472.92	-37.282	0.291	0.065
267	2083.83	-7.362	0.316	0.125
268	1429.30	-13.348	0.261	0.113
269	1851.34	-11.751	0.317	0.102
270	1745.03	-16.485	0.317	0.094
271	2198.65	-15.547	0.359	0.129
272	2064.93	-5.064	0.325	0.132
273	2253.43	-6.752	0.354	0.135

274	1827.84	-12.486	0.293	0.103
275	1505.81	-11.178	0.295	0.103
276	2120.63	-6.944	0.319	0.124
277	2285.79	-11.861	0.320	0.133
278	1345.30	-61.992	0.401	0.079
279	1430.18	-14.689	0.281	0.107
280	1257.35	-11.109	0.267	0.106
281	2450.69	-28.146	0.375	0.105
282	1461.52	-8.321	0.273	0.103
283	1026.76	-45.276	0.303	0.083
284	2300.73	-7.317	0.341	0.138
285	2187.66	-7.375	0.331	0.142
286	2340.34	-7.890	0.340	0.123
287	1678.61	-11.619	0.276	0.121
288	1740.90	-8.195	0.312	0.111
289	1414.25	-12.166	0.284	0.133
290	1932.98	-11.440	0.348	0.120
291	1984.40	-12.434	0.302	0.132
292	1770.62	-9.734	0.296	0.142
293	2642.90	-14.791	0.345	0.133
294	2258.71	-12.911	0.320	0.104
295	2152.37	-11.445	0.360	0.114
296	1681.50	-5.423	0.292	0.119
297	3275.46	-4.411	0.421	0.145
298	1226.55	-96.489	0.365	0.081
299	3483.30	-6.616	0.420	0.151
300	3000.52	-7.028	0.370	0.151
301	2891.09	-3.650	0.421	0.123
302	1233.86	-50.066	0.322	0.071
303	2832.33	-3.757	0.356	0.162
304	1297.51	-48.670	0.334	0.081
305	1203.21	-76.203	0.348	0.065
306	1245.70	-69.262	0.339	0.067
307	1854.93	-23.689	0.318	0.080
308	1612.41	-31.957	0.327	0.103
309	1714.45	-20.730	0.325	0.110
310	1955.35	-11.504	0.298	0.143
311	1678.86	-54.793	0.328	0.083
312	1813.11	-12.102	0.277	0.117
313	2194.66	-10.547	0.316	0.119
314	2455.51	-12.836	0.345	0.106
315	1180.23	-45.835	0.345	0.073
317	1811.47	-8.930	0.287	0.134
318	975.16	-67.874	0.341	0.068
319	791.52	-42.256	0.342	0.079
320	2158.16	-8.664	0.336	0.093
321	1244.26	-56.463	0.318	0.078
322	1070.09	-29.656	0.293	0.078
323	1741.11	-36.522	0.317	0.072
324	1101.21	-50.308	0.342	0.068
325	729.42	-68.248	0.409	0.115
326	1649.14	-21.467	0.306	0.106
327	1975.12	-28.359	0.298	0.126

328	1743.08	-5.856	0.282	0.098
330	1326.87	-49.897	0.325	0.092
331	1379.37	-8.854	0.280	0.121
333	998.80	-69.694	0.352	0.073
336	2054.00	-4.650	0.360	0.114
337	1800.57	-6.358	0.312	0.119
339	1572.57	-29.522	0.318	0.106
340	2927.86	-3.312	0.425	0.130
341	1559.70	-101.010	0.404	0.112
344	2099.70	-12.101	0.355	0.116
345	1543.59	-47.954	0.332	0.106
347	1902.87	-12.865	0.307	0.189
348	1971.59	-13.761	0.305	0.141
349	1532.54	-69.989	0.324	0.101
350	3224.05	-12.437	0.364	0.146
351	1315.55	-120.674	0.332	0.117
352	1616.45	-45.238	0.276	0.083
353	1736.17	-10.374	0.284	0.120
355	1427.01	-15.188	0.302	0.095
356	1050.95	-70.484	0.349	0.090
358	1331.10	-73.291	0.302	0.101
359	1126.58	-56.541	0.315	0.113
360	1609.98	-5.943	0.294	0.115
361	1022.97	-88.068	0.316	0.088
362	1703.43	-37.573	0.291	0.093
363	1356.80	-25.438	0.271	0.099
364	1589.85	-12.317	0.280	0.107
365	1891.63	-9.361	0.303	0.129
366	1098.02	-73.237	0.298	0.095
PRD - 367	1526.85	-113.560	0.445	0.102
TK - 368	1699.13	-11.874	0.296	0.125


Hardness
Fresh
g
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4500
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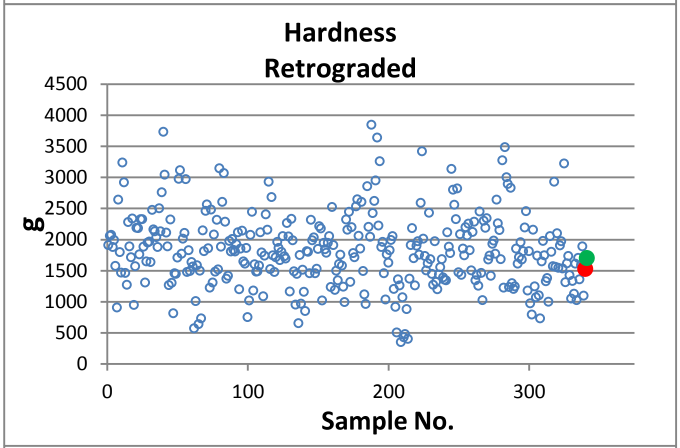
Sample No.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Retrograded
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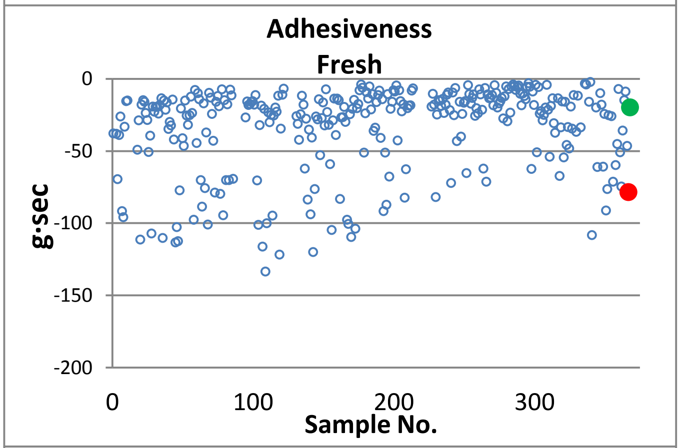
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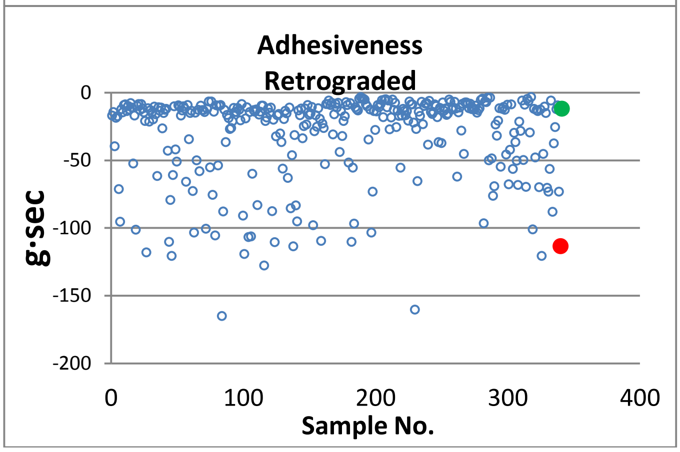
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Retrograded
g·sec
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Sample No.

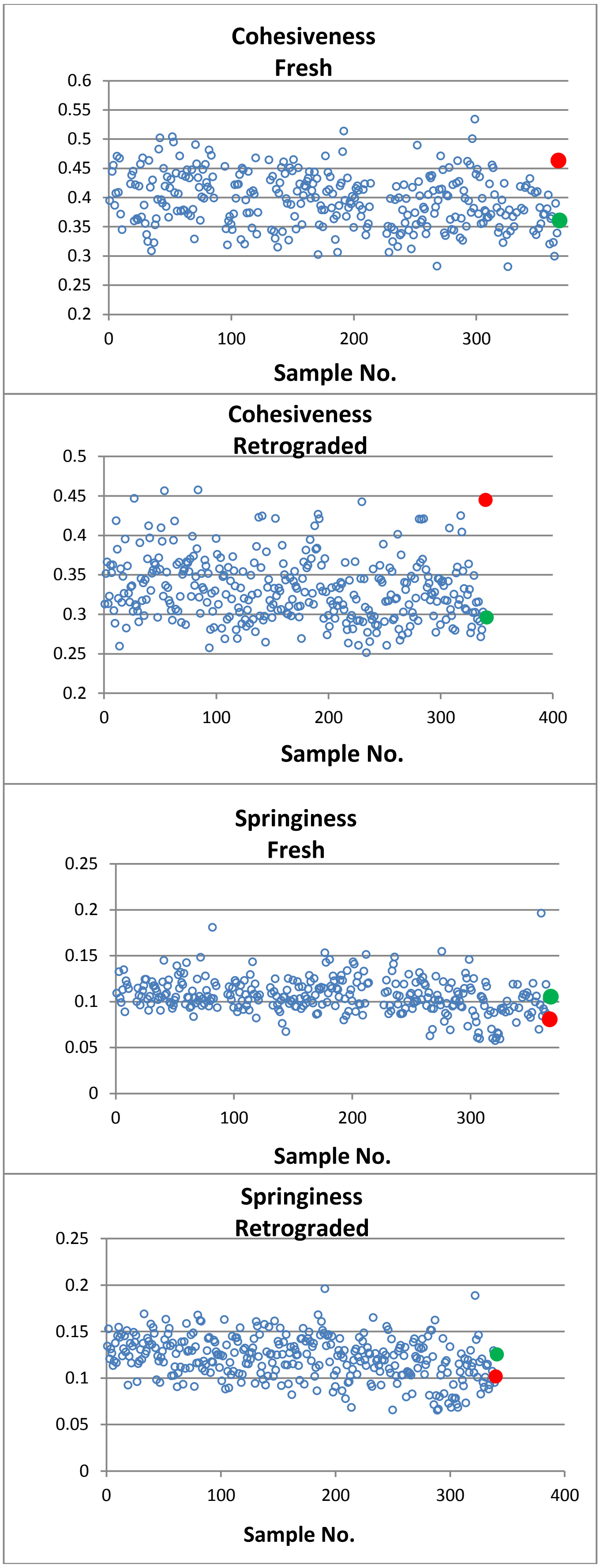

Figure 6. Scatterplots of textural attributes of the PRD x TK population as measured in the TA.XT plus Texture Analyser

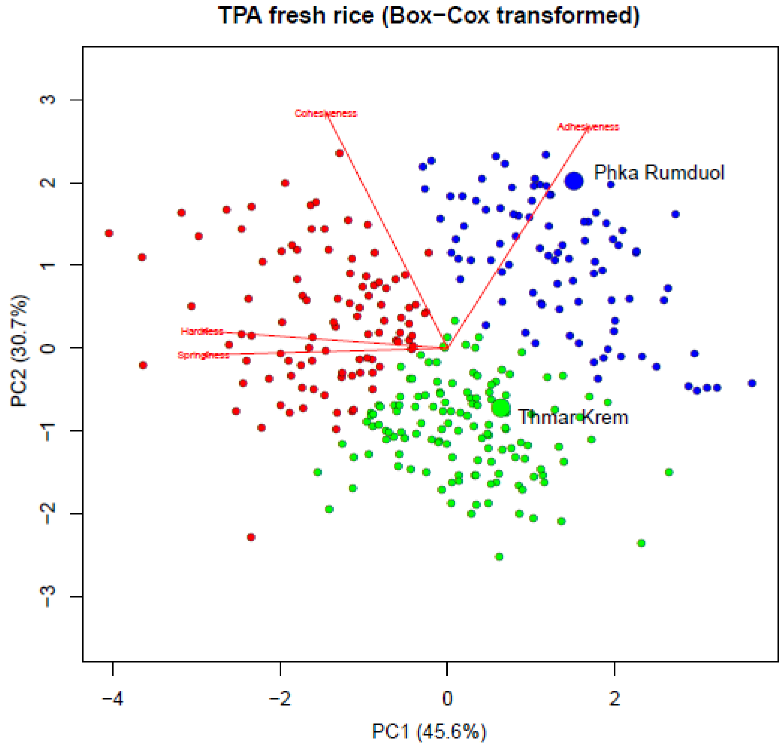

Figure 7. PCA based on textural attributes: hardness, adhesiveness, cohesiveness and springiness, of freshly cooked PRD x TK lines. Three clusters formed using k-means clustering: blue, PRD-like; green, TK-like and red are the intermediates. The order of decreasing contribution to PC1 which showed the higher variation is as follows: 1-hardness, 2-springiness, 3-adhesiveness and 4-cohesiveness. The order of decreasing contribution to PC2 is the following: 1-cohesiveness, 2-adhesiveness, 3-hardness and 4-springiness

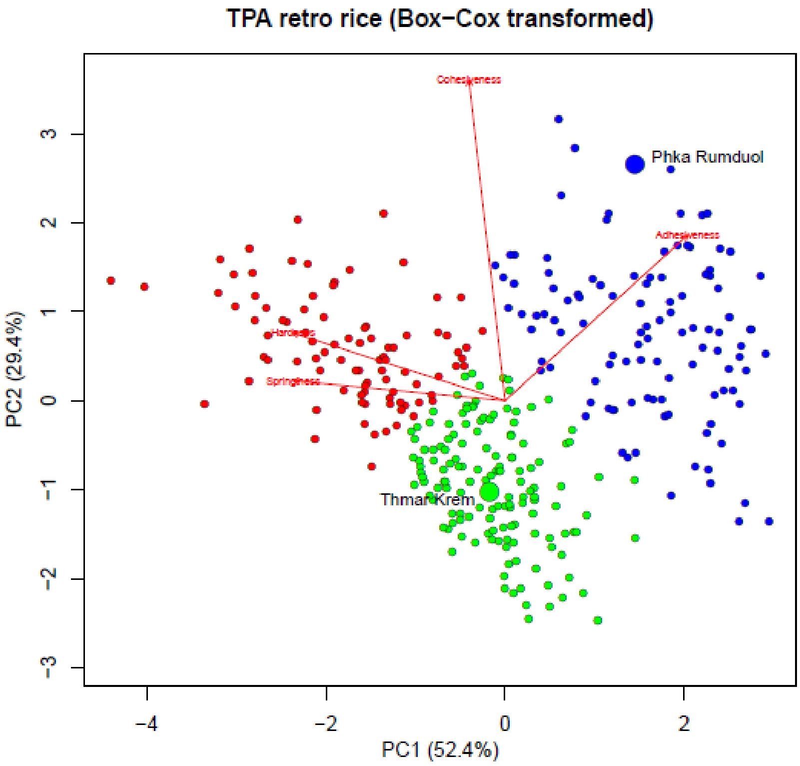

Figure 8. PCA based on textural attributes: hardness, adhesiveness, cohesiveness and springiness, of retrograded PRD x TK lines. The three clusters shown are blue, PRD-like; green, TK-like and red are the intermediates between the parents. The same order of contribution of the four attributes to PC1 and PC2 in the fresh samples was also shown in the retrograded samples.

11.6 Appendix 6: UQ report

Objective 1: ***Identify the current and future germplasm needs of Cambodian farmers and traders to determine the priorities and strategies for new germplasm development and dissemination***

For Activities 1 and 2, a survey was conducted across the rice market chain in three provinces in order to focus the research towards understanding and selected for the traits that stakeholders valued most highly. The valued traits of quality were aroma, grain shape and translucency, and softness of the cooked rice. This information led to the IRRI project team undertaking quality evaluation of material from IRRI's breeding program focussing on aroma, grain appearance and softness, in order for CARDI to combine quality with the agronomic trait of short duration. The second outcome was for the IRRI team to evaluate quality traits of the breeding material from CARDI, developed in Objective 2, to enable selection based on agronomic traits and quality. The data from the survey is currently in the final stages of readiness for publication.

Objective 3: ***Understand scientific basis of sensory quality of Cambodian rice and develop capacity in Cambodia for rice quality assessment and MAS.***

The activities of this objective focussed on quality of Cambodian rice, quality evaluation and capacity building. In 2011, a CARDI staff member visited IRRI's quality evaluation program (QEP) to learn how to measure quality; extract DNA and assay genes for aroma; prioritise analyses through the QEP workflow; analyse data; and trouble shoot for the QEP instruments, the genotyping equipment and for irregularities in the data. After returning to Cambodia, the IRRI project team purchased quality evaluation equipment, chemicals and consumables for polishing rice, measuring the physical traits of grains, measuring amylose content, and for genotyping for the fragrance gene. This equipment was selected because of the traits prioritised in the survey. Amylose content is a key indicator of softness of the cooked rice, the marker for aroma is well validated, and collecting data for physical appearance insures that grain shape and translucence are selected for. The instruments were shipped to Cambodia in 2011 to be commissioned at CARDI to enable CARDI to measure quality and aroma for their breeding program and for testing of new material from other breeding programs. This was commissioned by a team from IRRI's Grain Quality Centre, and training was undertaken at CARDI. The quality evaluation program is now operational at CARDI and a direct outcome of this project.

In order to understand quality of Phka Rumduol (PRD), CARDI developed a biparental population between a high quality parent and a low quality variety, Thmar Krem (TK). This population was ready for grain quality analysis in the final year of the project when it reached F_6. In December 2011, the IRRI project leader (Fitzgerald) relocated to UQ, where additional knowledge could be leveraged for the project, in particular for the population between PRD and TK, and the grain quality components were then to be carried out under the supervision of the new head of Grain Quality at IRRI.

The population of 384 progeny was harvested at the end of 2013, and split into three parts. Seeds (25-30g/ line) were shipped to IRRI for sensory evaluation, starch molecular weight distribution by size exclusion chromatography and genome-wide SNP genotyping. Samples of milled rice (~10g/line) were shipped to the University of Queensland in March 2014 for metabolomic profiling on several platforms, which is to be completed by a John Allwright Scholar (Crystal Concepcion). At IRRI, Crystal extracted DNA and coordinated the genotyping, using a SNP chip of 5000 loci. The data became available in May.

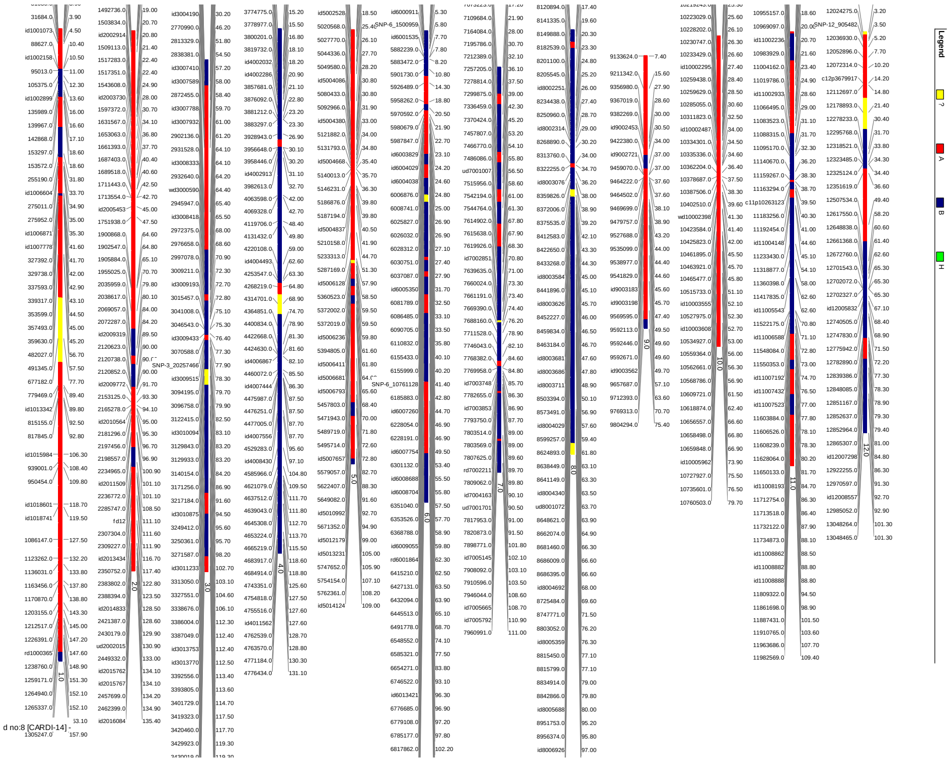

Figure 1. Location of 692 polymorphic SNPs between PRD and TK.

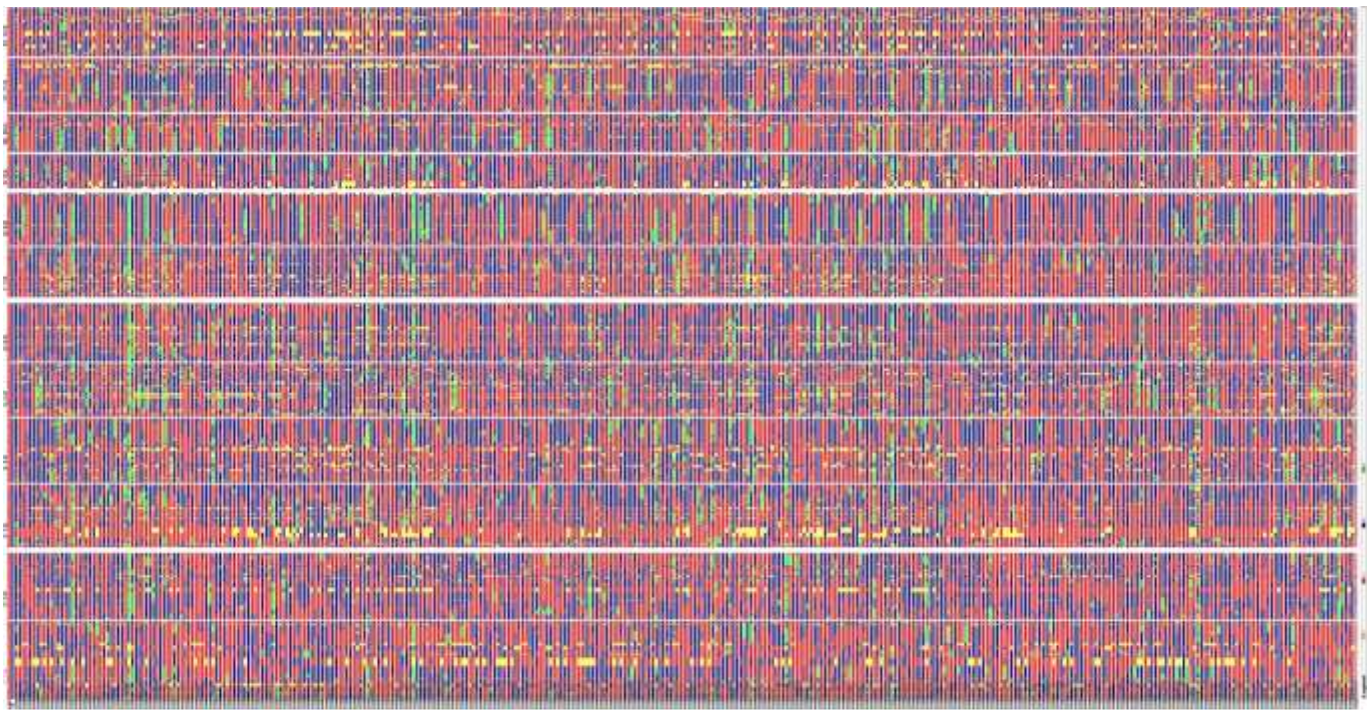

Figure 2. Introgression patterns of PRD (red) and TK (blue) genotypes in 384 progeny (x-axis) across the 12 chromosomes (y-axis).

Only 692 loci were polymorphic between the parents, which suggests that a different genotyping platform, without SNPs preselected could have been more useful. However, 692 loci should still be sufficient for QTL mapping, especially since the polymorphic loci are distributed quite evenly across all of the 12 chromosomes (Figure 1).

Figure 2 shows a map of the genotype of each line in the population. The map shows significant differences in the percentage of each parent present in each line, and looking across each chromosome (left to right), it appears that hybridisation occurred widely.

Metabolomic phenotyping will be carried out in depth in the next three years, as the core of the John Allwright scholarship associated with this project. However, volatile compounds emitted from PRD and TK grains were measured earlier, as grain was available and because of the importance of showing difference between the two parents of the population. Figure 3 shows a plot of the discriminating compounds that reproducibly define the volatile metabolome of PRD and TK, and the relative contribution of each compound to the metabolome. The fragrance compound, 2AP, is the fourth most discriminating compound, with coordinates of 10, 0.04 (Figure 3), and the first three compounds are mentioned in patents which describe their extraction from jasmine flowers and gardenia flowers, however more work is needed in chemical databases to confirm this. Table 1 shows a list of compounds that most discriminate between the two, and the abundance of each compound based on the average peak area of three replicates.

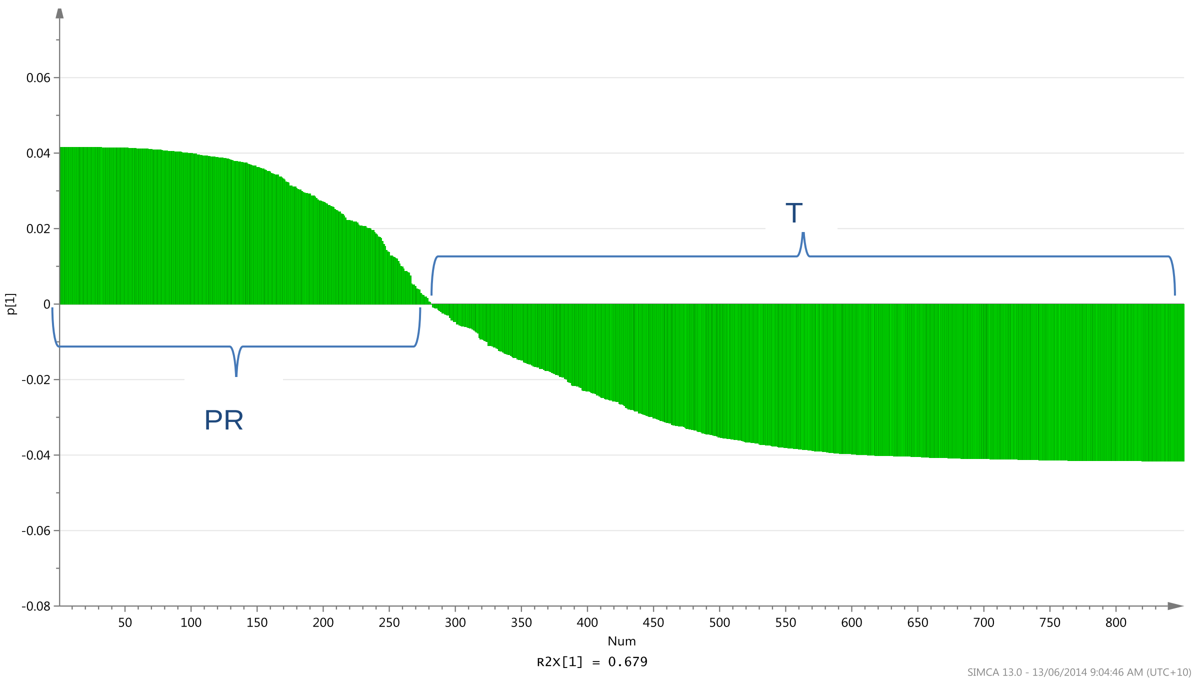

Figure 3. Relative contribution of compounds to the volatile metabolome of PRD (positive) and TK (negative).

The compounds shown in Table 1 have been selected for their degree of discrimination, known odour threshold, and published aromatic description. The nature of aroma of each compound, provides a lens into why TK may not be favoured by consumers, while the floral and sweet aromas of PRD provide an explanation for its wide acceptance. The first discriminating compound between the two is 2 acetyl 1 pyrroline. PRD is aromatic and TK is not. There are a number of aldehydes that also differ in amount between the varieties, all with fragrances that are of sufficiently low odour threshold to be detectable by humans (Table 1). PRD has a higher concentration than TK of many of the pleasant smelling aldehydes, whereas those with unpleasant aromas are found only in TK. The compounds indicate the aroma of PRD is a mixture of sweet (vanillin and dairy) and floral compounds, whereas that of TK consists of grassy, rancid and sewer animal notes. In TK, one of the most discriminating compound classes were the furanones. There were seven furanones detected in TK and PRD, and these are all found in the aroma profile of bitter beer and wine made from noble rotten grapes, suggesting unpleasantness in the aromatic profile. The peak abundance of these in TK is six-seven fold higher than in PRD, and several of them have a very low odour threshold, meaning that they contribute significantly to the aroma of TK.

Table 1: Discriminating compounds of taste and flavour between PRD and TK.

Compound	Aroma	PRD	TK
2AP	Popcorn	63228	328
Pentanal	Almond	109,558	285,155
Hexanal	Grassy	1,159,487	6,890,128
Heptanal	Floral	58553	37800
Octanal	Fruit/Floral	31709	32893
Nonanal	Floral	58249	31634
Decanal	Citrus	16463	37045
2-heptenal	Dairy	52241	6809
2-octenal	Fatty/Green	nd	964096
2-nonenal	Fatty/Rancid	nd	4004321
2-decenal	Fried citrus	nd	908818
Vanillin	Vanilla	67756	64036
Indole	Faecal	nd	153115
2(3H)-Furanone, dihydro-5-methyl-	Rotten grape	1123363	7742357

Since the genotyping data and grains for metabolomics phenotyping only became available in the last two months, sufficient data has not been collected to report upon. A John Allwright scholar, Crystal Concepcion, will conduct the metabolomic phenotyping of the population using two dimensional gas chromatography with time of flight mass spectrometry (GCGCTOFMS) for volatile compounds, GCMS for primary polar compounds and ultrahigh pressure liquid chromatography for secondary compounds. We will then use that phenotyping date to search for quantitative trait loci (QTLs) for important compounds of aroma, taste and flavour. Once we have found QTLs for those compounds, we will test them in other populations between PRD and other non-fragrant varieties. These populations have been developed in this project by the Australian collaborators. We will also test the QTLs in a diverse set of 400 genotypes, which are currently undergoing genotyping by sequencing at Cornell University. This dataset will provide a much richer pattern of genetic diversity than we currently have, due simply to the nature of the genotyping platform. Therefore, this project has launched and equipped us to pursue the identification of new traits of cooking and eating quality, using new generation phenotyping tools, and also enabled us to take advantage of the rapidly developing genotyping capability to convert the newly identified traits into tools suitable for use in many rice improvement programs.