

Resilience and Growth

***Realizing the potential of vegetables
to benefit smallholder farmers and
consumers in Asia and Africa***

2020 Annual Report

ACIAR - World Vegetable Center Partnership Agreement



ACIAR's 2020 annual support to the World Vegetable Center enabled more understanding and findings for better vegetable production for increased resilience of the vegetable venture among resource-poor, vulnerable smallholder producers. The disruptions caused by the COVID-19 pandemic propel for a greater and pressing thrust to increase the roles of vegetables for healthier lives and more resilient livelihoods.

WorldVeg's work on sustainable safe vegetables production and consumption aimed to create new jobs and sources of income for smallholder households and increase the availability of nutritious vegetables for consumers, contributing to SDG 1 (No poverty), SDG 2 (Zero hunger) and SDG-3 (Good health and well-being).



WorldVeg implements its research for development agenda through three outcome-oriented flagship programs:

- **Safe and Sustainable Value Chains**
- **Vegetable Diversity and Improvement**
- **Healthy Diets**

and one cross-cutting flagship program:

- **Enabling Impact**

Safe and Sustainable Value Chains

Different vegetable production systems have their own challenges that are addressed through a combination of technological, organizational and institutional innovation. WorldVeg focuses on developing safer options for farmers to improve soil health, to better control vegetable pests and diseases with minimal use of chemical pesticides, through the introduction of improved varieties with good agricultural practices before and after harvest, and collective action in both production and marketing, and traceability systems.

Complexity of sweet pepper anthracnose disease

Anthracnose is a formidable disease in sweet pepper production. Although the disease can affect all parts of the plant during any stage of its growth, lesions on pepper fruit are causing the most damage economically. The disease is caused by *Colletotrichum gloeosporioides* species complex with at least 22 species and one subspecies. In summer 2016, a new anthracnose disease was found infecting sweet pepper in the highlands of Taiwan. The causal agent was subsequently identified as *C. coccodes*. To understand the



Anthracnose-causing *Colletotrichum* species vary in the aggressiveness of attacks on sweet pepper fruit.

current diversity of the species complex in Taiwan, 19 anthracnose isolates were collected from sweet pepper and characterized during 2020. The predominant species was identified as *C. fructicola*, closely followed by *C. siamense*. About 10% of the samples were infected by *C. tropicale* and *C. tainanense*. The isolates showed significant variation in their aggressiveness in causing lesions on sweet pepper cultivar 'Andalus'. The most aggressive isolates have been selected and will be used to screen sweet pepper lines for resistance against the disease.



Grafting can address root-knot nematode infection.

Eggplant rootstocks to produce more resilient tomato

Grafting is the union of two plant parts, a rootstock and a scion. The rootstock provides the root system to the scion for producing the harvestable yield. Eggplant rootstocks that are resistant to soil-borne diseases are used to graft tomato scions to manage the diseases. Among eggplant family members, pea eggplant (*Solanum torvum*) is also found to possess resistance and/or tolerance to biotic and abiotic stresses.

Four lines of *S. torvum* showed high level of tolerance to root-knot nematode (RKN) infection and producing significantly fewer root galls. The lines also showed a high level of tolerance for short-term waterlogging. These lines are thus excellent rootstock candidates for grafting tomato against RKN and waterlogging. Other four eggplant lines previously shown to have good grafting compatibility and resistance to bacterial wilt disease demonstrated good resistance to phylotype I of the disease causal agent *Ralstonia pseudosolanacearum* under controlled conditions. These lines have broad-spectrum bacterial wilt resistance and can be used as rootstocks to graft tomatoes.

Can Fall armyworm attack vegetable crops?

Fall armyworm (*Spodoptera frugiperda*) is a notorious pest that feed on 353 host plants belonging to 76 plant families. It has spread rapidly to Asia after its initial report in Africa during 2016. Although the pest predominantly feeds on grass family Poaceae, the flowering plant family Asteraceae and legume family Fabaceae, it is important to know whether it can adapt to feed on vegetable crops.

WorldVeg did a laboratory study in 2020 to determine the pest potential damage to vegetables in the absence of suitable host plant in new regions. The study used three vegetable crops (cabbage, soybean, and tomato) in comparison with corn, the insect's usual host plant and an artificial diet.



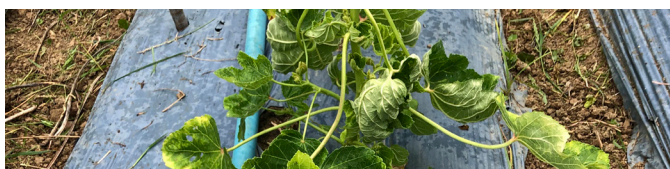
Fall armworm caterpillars feed, grow and reproduce on vegetable crops, including tomato and cabbage.

Soybean-reared insects had the highest survival (85%), followed by tomato and cabbage. The vegetable crops significantly influenced the Fall armyworm fecundity, development, and reproduction. Female adults lived 30-40% longer in cabbage and soybean, compared to control (in corn). Fecundity in soybean, cabbage, and tomato was 5-fold higher compared to control, although adult females were reluctant to lay more eggs in vegetable crops compared to corn.

The study revealed that the Fall armyworm female moths do not lay more eggs on vegetable crops, even under a forced situation. However, the surviving caterpillars can feed, grow and reproduce better on these vegetable crops than on its usual host plant, corn. Hence, more attention and care should be given if the Fall armyworm larvae are spotted on vegetable crops since it could lead to significant yield losses.

Vegetable Diversity and Improvement

Plant phenotyping measures the plant's physical appearance and performance that results from the interaction between its genetic make up and the environment. Phenotyping vegetable biodiversity has been the main focus of WorldVeg work on vegetable diversity and improvement in 2020. A high throughput phenotyping system equipped with laser scanners and color sensors was applied to measure growth and health status of vegetable amaranth, heat stress responses of pepper, and tolerance to water logging in okra. Growth and health status of the plants were measured continuously over the experimental period in a non-invasive manner.



Phenotyping heat stress responses in a biodiverse pepper collection

Heat stress affects crop yields in many parts of the world. Crops that grow and yield reliably under elevated temperatures help farmers adapt production to climate change and allow for more profitable off-season production in tropical regions.

A core collection of 300 genebank accessions representing the global diversity of cultivated pepper (*Capsicum annuum*) was phenotyped for vegetative and generative traits under heat and control conditions. In total 72 parameters including morphological data and physiological indices were measured. Fruit set in pepper under heat stress was measured by determining pollen number and viability using impedance flow cytometry. This has enabled high throughput phenotyping of generative traits important for pepper fruit set. Vegetative growth, pollen viability and fruit set varied strongly among the accessions. Interestingly, heat tolerance of vegetative functions such as high biomass accumulation or maintained vegetation index was not correlated with pollen viability or fruit set traits, suggesting that combining best performers for these traits may result in more heat tolerant lines.

Phenotyping salt stress tolerance in eggplant seedlings

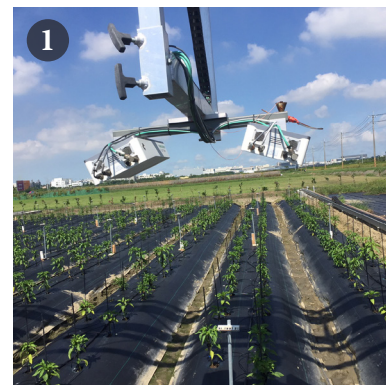
Saline soils or saline irrigation water is a widespread problem in arid zones. Salt tolerant eggplant, together with agricultural practices that reduce the salt contamination in soils, could support the crop production in these regions. WorldVeg measured salt tolerance of eggplant at the seedling stage with a simple image-based phenotyping application using cell phones¹. An eggplant core collection representing the global diversity of cultivated *Solanum melongena* was exposed to salt stress and their stress tolerance was estimated by comparing height, leaf area and biomass increment between stress and control conditions. Significant variation in growth traits was observed among the accessions in salt and control treatments. The trial will be repeated in 2021 to collect data that are appropriate for a genome-wide association genetics analysis to identify genetic loci associated with salt stress tolerance at the seedling stage of this crop.

Phenotyping Begomovirus resistance in okra

Begomovirus infection, specifically Bhendi yellow vein mosaic virus (BYVMV; previously known as Okra yellow vein mosaic virus) and Okra enation leaf curl virus (OELCuV), are seriously affecting okra production in Asia and Africa. Resistant varieties would enable farmers to continue cultivating this nutritious and profitable crop, which is well adapted to hot environments. Resistance to these viruses seems to be absent among okra (*Abelmoschus esculentus*) germplasm and needs to be sourced from other *Abelmoschus* species, mainly *A. manihot* and *A. caillei*. WorldVeg has assembled a germplasm set of 559 accessions, mostly *A. caillei*, *A. manihot* and *A. moschata*, plus selected *A. esculentus* accessions and promising lines collected at putatively virus infected regions that may contain some tolerance to these viruses. Seed of this germplasm set has been multiplied and has been shipped to the WorldVeg field station at Kamphaeng Saen, Thailand for resistance screening during the summer season 2021. Both BYVMV and OELCuV have been verified over two years to be endemic at the field station.

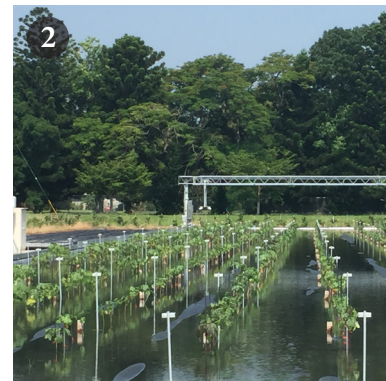
Phenotyping responses of okra to flooding stress

Okra (*Abelmoschus esculentus*) is a nutritious and heat tolerant crop with good production potential in hot climates. In tropical monsoon regions, heavy rainfall during the hot season leads to flooding and waterlogging. Crops adapted to such conditions need to be tolerant to both heat and waterlogging. WorldVeg measured growth and vigor of 93 biodiverse okra accessions before, during and after flooding using our high throughput phenotyping system. Based on biomass increment per day and vegetation and senescence indices during flooding and recovery, putatively tolerant and susceptible accessions were identified for a more detailed physiological study².

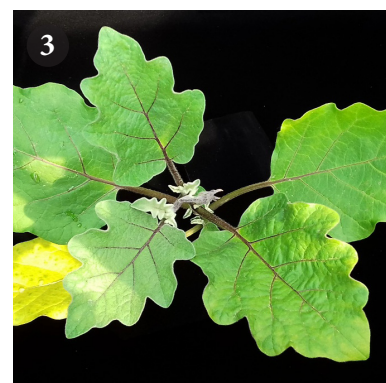


Phenotyping Begomovirus resistance in pepper

Whitefly-transmitted Begomovirus causes devastating viral diseases affecting chili pepper production in South and Southeast Asia. Management of the disease with insecticide sprays directed against the whitefly vector is costly, only partially effective and causes hazards to farmers, consumers, and the environment. Resistant chili pepper varieties would be a more effective management strategy.



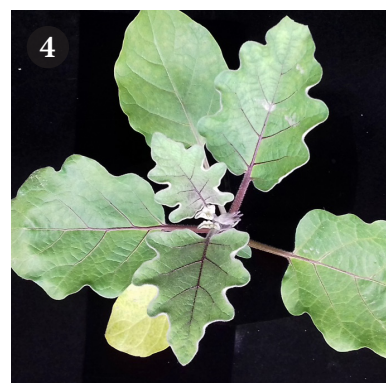
Around 100 *Capsicum* accessions were screened for resistance to PepYLCThV (Begomovirus) at disease hot spots in Khon Kaen and Kamphaeng Saen, Thailand. Except for one, no other accession was identified as being immune to the disease, while all previously reported Begomovirus resistant lines appeared to be susceptible in this study. The one new accession identified to be resistant across the environments is now investigated for gene action and used to move resistance genes into elite germplasm. Multi-location trials with promising materials are about to be implemented in India.



¹ Müller-Linow et al., 2019. Plant Screen Mobile: An open-source mobile device app for plant trait analysis. *Plant Methods* 15:1

² Schafleitner R, Lin CY, Lin YP, Wu TH, Hung CH, Phooi CL, Chu SH, Jhong YC, Hsiao YY. 2021. The World Vegetable Center okra (*Abelmoschus esculentus*) core collection as a source for flooding stress tolerance traits for breeding. *Agriculture*, 11:165

Phenotyping in action: 1) Heat stress response, pepper; 2) flooding response, okra; 3 & 4) salt stress tolerance, eggplant; 5) Begomovirus resistance, okra; 6) Begomovirus resistance, pepper.



Healthy Diets

Vegetables are an essential and irreplaceable part of a healthy diet. Yet, around the world, most people's diets are low in vegetables, despite their importance to human health. WorldVeg analyzes the constraints to increased vegetable consumption using a food systems approach and promotes increased intake through a range of interventions such as home and school gardens, social behavior marketing and policy interventions.

In 2020, people's ability to eat a healthy diet was severely affected by the COVID-19 pandemic. The effects of the pandemic were well-illustrated by a study of vegetable farmers in four states of India, which conducted phone interviews with 448 farmers from May-June 2020. About 80% of the vegetable farmers reported declining sales with 20% saying that they sold almost nothing.

Furthermore, 90% of the vegetable farmers reported a drop in their farm income, and 62% reported disruptions to their diets, particularly of fruit, legumes and fish, meat and eggs (Figure 1)³. The COVID-19 pandemic showed that vegetable supply chains are prone to disruption and people deprioritized vegetable buying when faced with income uncertainty.

One way to address these factors is to encourage people to grow their own vegetables in home gardens (see page 10). WorldVeg distributed 15,770 seed packs to people in need through local partners in Mali, Benin, Arusha and Thailand.

The supply of small packages of easy to grow, nutritious, short-duration vegetables can be an effective strategy to promote vegetable gardening and assist people in building their tolerance to disease as well as long-term resilience to cope with disaster.

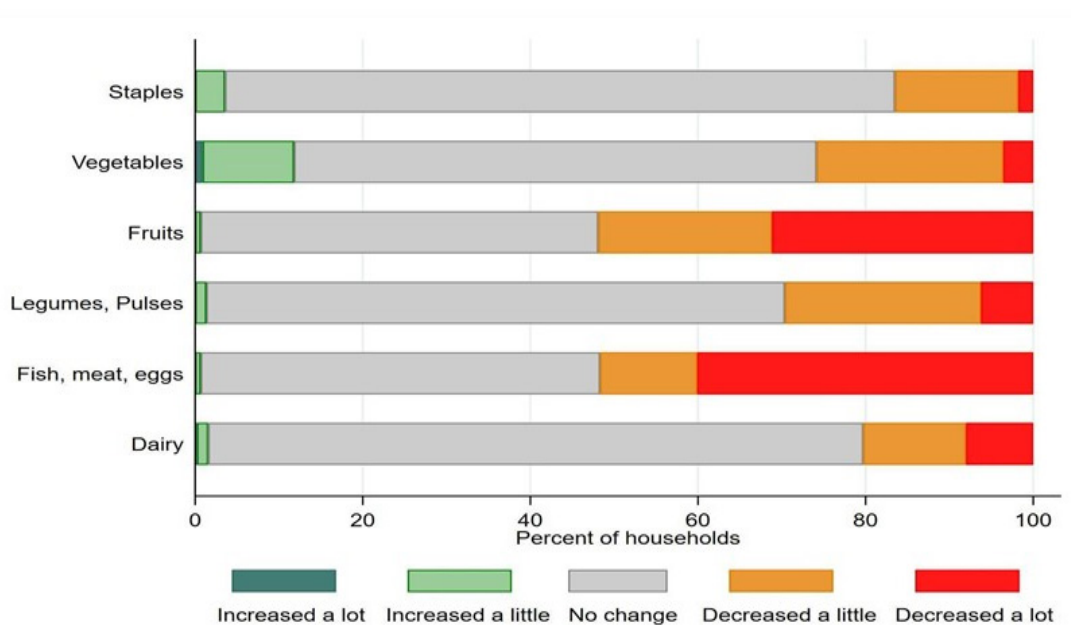


Figure 1. Self-reported change in diets among vegetable producing households in India affected by the COVID-19 pandemic, May-June 2020.

³ Harris, J., Dejenbusch, L., Pal, A.A. et al. Food system disruption: initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Sec.* 12, 841–851 (2020). <https://doi.org/10.1007/s12571-020-01064-5>

Enabling Impact

There is a clear need to increase vegetable consumption and production while reducing losses along the value chain and increasing the use of more environmentally benign production methods. A key challenge to achieving this is a lack of knowledge of which interventions work, which don't, and why? WorldVeg builds the evidence basis for interventions in the vegetable sector, identifies key challenges to impact, and strengthens the intervention designs used by the Center.

A study together with the Asia & Pacific Seed Association (APSA) looked at how the seed trade in Asia and the Pacific region has been affected by the COVID-19 pandemic (Figure 2). Three surveys among seed companies were conducted in April, May and August. It showed dramatic effects of the pandemic on the seed trade during April, somewhat of a recovery during May, but continued challenges in August.

A study of 13 mungbean producing countries in Asia and Africa showed that mungbean is planted on 6.4 million hectares in these countries and that 32% of this is planted to varieties developed by WorldVeg⁴. This is estimated to benefit 1.7 million smallholder farm households annually.

Another study published in 2020 quantified the economic impact of WorldVeg mungbean varieties in Myanmar. It found that four mungbean varieties coming out of international agricultural research and released by the national agricultural system of Myanmar created aggregate economic gains of USD 1.4 billion from 1980 to 2016 and this is projected to increase to USD 3.7 billion by 2030^{5, 6}.

One of the key constraints to mungbean production in Asia is the labor needed to harvest the crop. Most of that labor is provided by women and many of them are hired for the time of the harvest. The use of combine harvesters could help farmers in their production, but is likely to displace hired workers.

An ACIAR-funded study therefore analyzed how women in Myanmar and Bangladesh are likely to be affected if combine harvesters are introduced to collect mungbean⁷. It found that the manual

harvesting of mungbean provides an important source of income for women, particularly landless women and particularly women with children who cannot easily move around to take other jobs. Social norms regarding women's mobility furthermore restrict their opportunity to take other jobs while there are only few alternative job opportunities nearby.

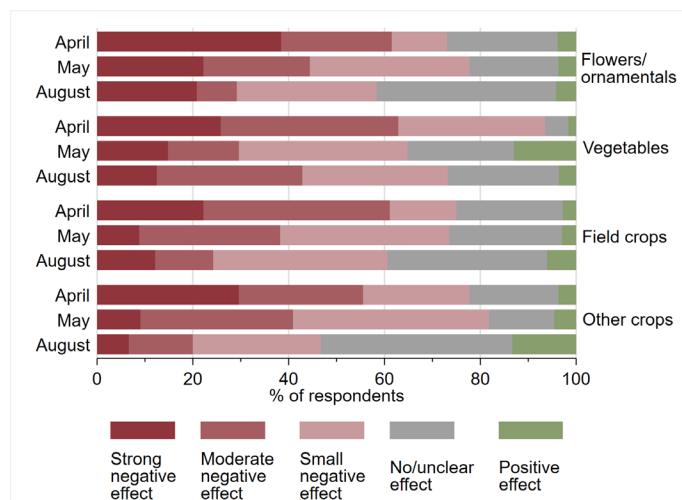


Figure 2. Perceived impact of the COVID-19 pandemic on the shipment of seeds in the Asia and Pacific region during 2020.

Source: <https://web.apsaseed.org/news/asiapacific-seed-trade-on-long-road-to-recovery?s=03>

⁴ Schreinemachers, P., Sequeros, T., Rani, S., Rashid, M.A., Gowdru, N.V., Rahman, M.S. et al. 2019 Counting the beans: quantifying the adoption of improved mungbean varieties in South Asia and Myanmar. *Food Security*, 11 (3), 623-634. <https://doi.org/10.1007/s12571-019-00926-x>

⁵ Sequeros, T., Ochieng, J., Schreinemachers, P., Binagwa, P.H., Huelgas, Z.M., Hapsari, R.T. et al. 2021 Mungbean in Southeast Asia and East Africa: varieties, practices and constraints. *Agriculture & Food Security*, 10 (1), 2. <https://doi.org/10.1186/s40066-020-00273-7>

⁶ Sequeros, T., Schreinemachers, P., Depenbusch, L., Shwe, T. and Nair, R.M. 2020 Impact and returns on investment of mungbean research and development in Myanmar. *Agriculture & Food Security*, 9 (1), 5. <https://doi.org/10.1186/s40066-020-00260-y>

⁷ Farnworth, C.R., San, A.M., Kundu, N.D., Islam, M.M., Jahan, R., Depenbusch, L. et al. 2020 How Will Mechanizing Mung Bean Harvesting Affect Women Hired Laborers in Myanmar and Bangladesh? *Sustainability*, 12 (19), 7870. <https://doi.org/10.3390/su12197870>

Looking ahead

Future research opportunities

Broader availability of **phenotyping data** through investment in high throughput phenotyping and access to multi-location trial data through breeding networks is a great step forward in identifying new traits for breeding improved stress tolerant and nutritious vegetable varieties. In parallel, large amounts of DNA genotyping and re-sequence data for Worldveg germplasm is becoming available from a Horizon2020 EU-funded project, from the “Agricultural Greater Good Initiative Award” funded by Illumina and from a Worldveg initiative to produce better reference sequences for *Capsicum* using long read sequencing. These phenomic and genomic data are used for genome-wide association mapping and pangenomics analyses to investigate the genetic basis of breeder-desired traits. ACIAR support will strengthen the bioinformatics and biostatistics team to speed up the accomplishment of these analyses.

WorldVeg has recently transferred genes conferring **resistance to whitefly** from wild tomatoes into cultivated lines. These materials have the potential to act as a second line of defense against whitefly transmitted Begomovirus by making *Ty*-gene-dependent resistance to Begomovirus more durable. Resistance to whitefly also may protect against other insect pests, such as the tomato leaf miner *Tuta absoluta*, which is causing huge damage in tomato production. In 2021, testing putatively insect resistant tomato lines and backcrossing the resistant materials to improve fruit size is planned and expected to result in materials for multi-location testing.

Food safety is a significant concern in vegetables as many kinds are eaten with minimal processing. Contaminants in vegetables include foodborne pathogens (harmful microbes) and chemicals such as residues of pesticides, nitrate from fertilizers, and heavy metals. Consumers are increasingly concerned about food safety in vegetables. When consumers hold the perception that vegetables are associated with health risks because of food safety, they are likely to reduce consumption. Research is needed to identify food safety risks in vegetables and test interventions at various levels, from farm to policy, to address it.

Low vegetable (and fruit) consumption is a key contributing factor to early mortality in both high- and low-income countries. Increasing vegetable supplies will only address part of the problem. Many consumers have a low **acceptance of vegetables** and will not consume more even if vegetables were more widely available. School education programs are important to create awareness and interest in vegetables at a young age. WorldVeg has shown the effectiveness of school and home garden interventions in Nepal, but there is a need to expand this area of work, especially in the COVID-19 situation, and ensure that vegetables are a standard part of every meal.

