Research Article

Neeraj Sharma*, Wichard Sanders, Robert Graveland, John Schoper, Hugo Campos

A public–private partnership to speed up potato breeding

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Abstract: The process to develop potato cultivars is complex and lengthy due to numerous reasons, viz., tetrasomic inheritance with heterozygous nature, large number of phenotypic recurrent selections, low efficiency of selections in early generations, slow multiplication rate of selected clones, and others. In Southeast Asia, varieties are primarily developed by public sector having poor seed multiplication facilities, and the complexity is further aggravated by the presence of few commercial seed multipliers. To speed up the breeding and selection processes and ensure the adoption of developed varieties by strengthening the seed value chain, a public–private partnership has been established between International Potato Center and HZPC, a leading private potato seed company. The adopted integrated breeding approach is a blend of modern and traditional breeding techniques involving shuttle breeding and stringent selection of disease-resistant cultivars through marker-assisted selection at early stage, followed by parallel evaluation in several environments and rapid disease-free multiplication of the elite material. This study simultaneously addresses the issues related to the extensive and complex variety registration process in the region by initiating discussion with the local authorities. The collaboration is likely to set norms for licensing and benefit-sharing between public and private partners in future alliances.

Keywords: rapid breeding, smallholder farmers, shuttle breeding, Southeast Asia, potato variety development

* **Corresponding author: Neeraj Sharma**, Potato Breeder, Genetics, Genomics and Crop Improvement, International Potato Center (CIP), Hanoi, Vietnam, e-mail: n.sharma@cgiar.org

Wichard Sanders: Potato Breeder, HZPC Research B.V., Metslawier, Netherlands

Robert Graveland: Research and Development Director, HZPC Research B.V., Metslawier, Netherlands

John Schoper: Former Head, Genetics, Genomics and Crop Improvement, International Potato Center (CIP), Lima, Peru

Hugo Campos: Director of Research, International Potato Center (CIP), Lima, Peru

1 Introduction

Southeast Asia is a home to a large number of small-holder farmers with average agricultural landholding ranging from 0.12 ha (Vietnam) to 0.36 ha per capita in Cambodia (OECD-FAO Agricultural Outlook 2017; World Bank 2017). With the increasing population and outspreading area under urbanization, the trend of further decrease (Figure 1) has been reported in Indonesia, the Philippines, and Thailand (Lowder et al. 2014). Resource-poor farmers with small pieces of agricultural land are not able to achieve sustainable livelihood and assured food security in spite of having improved access to the better production technologies in term of varieties, infrastructure, and expertise (Rigg et al. 2016). To combat food insecurity in the region, green revolution in late 1960s transformed rice in a staple food (Pingali et al. 1997; Vos 2018). Development of high-yielding varieties suitable for the irrigated and rainfed areas resulted in rapid adoption of the rice as the main crop (Dufumier 2006; Thi and Kajisa 2006). A strong support from the local governments in the form of subsidies to boost crop yields led to the monoculture rice-based system. Developed short-duration varieties provided opportunities for cultivation of two or more rice crops in the same cropping calendar. Over the period, the persistent support from governments, developed infrastructure, and improved technologies transformed the region into self-sufficient and subsequently as a major rice exporting hub (Dufumier 2006; Alavi et al. 2011; Dawe et al. 2014; OECD-FAO Agricultural Outlook 2017). Importance of rice in the region in terms of its GDP increased intensely (FAOSTAT 2017) and concurrently, and a significant reduction was noticed in the crop area along with the related poor infrastructure, frail seed system, lower production, and consumption of other cereals and noncereals. To improve the balance in farm production, it is a critical time to bring in diversification in the cropping pattern (Pingali et al. 1997; Vos 2018). Broadening the genetic basis of the cropping system will contribute to nutritional security, enhanced farm income, better disease management, improved soil health, and

Figure 1: Distribution of farm size in Southeast Asia during the 2000s (Lowder et al. 2014).

climate change adaptation. Chavas and Di Falco (2011) informed that contrary to the popular belief, small-scale farms are adopting diversification to stabilize the farm income and minimize the risk. A drift has already been noticed in the region, and agricultural production of rice has reduced its contribution to the total gross agricultural production from around 40% in early 1990s to 30% in 2013 (FAOSTAT 2017). Pingali (2007) reported transition in diets in cities and smaller towns, where a decline in rice consumption was substituted by the increased consumption of vegetables, fruits, meat, and dairy products. Policy-makers in the region are recognizing the importance of crop and diet diversification and have started developing policies for promoting other crops.

Interestingly, potato (*Solanum tuberosum*), third important food crop globally (Dreyer 2017), has not received the attention it deserves in the region. Total potato area in Southeast Asia is approximately 1,50,000 ha, with the average yield of 16.6 t/ha, which is significantly lower than the global (19.6 t/ha) (FAOSTAT 2017). Per capita consumption per year of potato is extremely low in the region at 4.7 kg compared with neighboring South Asia (27.0 kg), East Asia (38.6 kg), and global (34.2 kg). Being short duration and better climate resilient, potato can complement already existing rice-based cropping system by bringing in the fallow areas under cultivation between two rice crops in the region (Shopan et al. 2012; Prasad et al. 2013; Gatto et al. 2018). Early maturing disease-resistant varieties can intensify the cropping pattern and improve the livelihood security of the smallholding farmers. Potato can diversify and complement the dominant rice-based food habits. The total caloric intake through potato is less than 1% in the region and needs to be improved (Fuglie et al. 2002).

Potato is a rich source of calcium, iron, potassium, fiber, vitamins, and minerals and its supplement to local diets will contribute to nutritional security (Kolasa 1993; Camire et al. 2009; Navarre et al. 2009; Vreugdenhil et al. 2011; Kempenaar et al. 2017). Regional governments realize the importance of potato in improving food security and have occasionally promoted its cultivation. A temporary increase in potato production was noticed in Vietnam during late 1970s and early 1980s to meet the food demand but could not sustain in the following years (Fuglie et al. 2001). The poor productivity and production of potato across the region is a consequence of many factors including weak formal and informal seed system supplying the limited quantity of healthy genetically pure seed, cultivation of varieties that are prone to biotic and abiotic stresses, poor knowledge of management practices, and bio-physical properties. Among all these, supply of seed with doubtful genetic integrity of not so preferred or unfamiliar varieties seems to have discouraged potato cultivation the most (Fuglie 2007). The public sector with the limited budget and technical expertise is not able to produce required quantity of quality seed. The seed value chain is further weakened by the negligible presence of private companies engaged in variety development and seed system. On top of these, the seed registration processes are more intricate, which do not consider complexity of the vegetatively propagated crops. The intertwined factors where poor production leads to less consumption and *vice versa* discourage potato production in the region.

Irrespective of these problems related to production, the region is not unaffected by the growing global demands of the processed products of potato. Vos (2018)

and Fuglie *et al.* (2002) reported the increased consumption of processed products with an increase in income and expansion of urbanization. Like other parts of the world, urbanization is happening at fast pace in Southeast Asia, and by 2025, 53% population in Southeast Asia is projected to be urban (de Fraiture *et al.* 2009). Global chains of quick service restaurants are already popular among youth in urban areas of the region, fostering demand of frozen potatoes. Import of frozen potatoes is on rise due to the lack of locally grown suitable varieties (Fuglie *et al.* 2002; FAOSTAT 2017). The region is importing potato in the form of both fresh and frozen with the value of approximately \$450 million (FAOSTAT 2017). Different countries including the United States are source of this import in the region. National Potato Council of United States indicated the importance of the region in its recently shared online report (National Potato Council 2019). Import in Vietnam increased from \$3.5 million to \$11.6 million in last three years, clearly signifying the growth of the processing sector. The Philippines is the fifth largest export market for US fries, importing approximately 58,000 metric tons in 2017–2018.

1.1 Significance of TAP-5 project in Southeast Asia

To improve the potato production and strengthen the national potato research system, International Potato Center (CIP) is operating in the region since 1980. Until 2015, 16 varieties in Indonesia and nine varieties in Vietnam have been released by using germplasm received from CIP (Gatto *et al.* 2018). However, due to the absence of the robust seed system, the efforts have translated into poor adoption of these varieties. Realizing the existing gap coupled with strong opportunity, CIP in collaboration with HZPC, B.V. and Syngenta Foundation for Sustainable Agriculture (SFSA) has developed a market-driven research program ensuring timely access to the quality seed. The developed TAP-5 project entitled “the collaborative breeding of five tropically adapted potato varieties” aims to increase potato productivity and stability and competitiveness, enhancing food security and family income of the resource-poor farmers of Southeast Asia. Beyond commercial interests, HZPC, B.V., a leading potato seed company, is working globally with a mission to feed the growing world population through responsible food. SFSA, a funding partner of the project, also provide technical inputs in the implementation of the

project. The project aims to build on and combine the strengths of each partner to speed up and optimize the development of new potato varieties. This will serve the needs of smallholder farmers in the context of productivity gains, quality assurance, diversification, climate change, and nutritional security.

1.2 Public–private partnerships in agriculture sector

The concept of public–private partnership is relatively new in agriculture and hold promises for those areas, where public sector is not strong enough to support the growing demand of farmers due to inadequate resources and expertise. Private sector is turning challenges into opportunities through such collaborations by converting the resource-poor farmers into market-linked producers for harmonious future growth. The International Service for National Agricultural Research, International Food Policy Research Institute, Food and Agriculture Organization, and CIP have conducted different studies on public–private partnership in the agriculture sector (Spielman and von Grebmer 2006; Hartwich and Tola 2007; Spielman *et al.* 2007; Horton *et al.* 2009; Rankin *et al.* 2016). There is a strong support for such initiatives in the findings with some suggested precautions to achieve successful outcomes (Kozin *et al.* 2020; Sedykh *et al.* 2020). Rosenau (2000) considered public–private partnerships as the second generation of efforts to bring competitive market discipline to bear on government operations. Hall (2005) argues that public–private partnerships are critical for capacity strengthening, providing the research organization of the beneficiary countries with access to the advanced material and techniques and to expose the local research organizations to the modern way of working. Hall (2006) cautioned that promotion of such partnerships has more challenges than we may assume, but the potential for their growth is very high. Spielman and von Gerbmer (2006) cited some successful collaborations in agricultural research for improving food security, reducing poverty and development in the agriculture sector. The Netherlands Ministries of Economic and Foreign Affairs is operating identical alliances targeting potato value chains since 2013 in Asian and African countries like China, India, Indonesia, Vietnam, Bangladesh and Myanmar, and Ethiopia and Kenya (Kempenaar *et al.* 2017). Some of the themes like yield gap analysis, cropping systems, and value chains

are common across the locations, whereas some are country specific like for Indonesia to reduce pesticides and nutrient inputs, Vietnam to broaden the genetic base, and Myanmar to develop cultural practices for the increased yield. Hartwich et al. (2008) cautioned that before initiating the partnership, the stakeholders should consider about enough common interests and positive cost-benefit relationship for each partner. Thijssen et al. (2020), Adjei-Nsiah et al. (2019), and Ministry of Agriculture, Livestock and Fisheries, Republic of Kenya (2019) have advocated the need of strong partnership between public and private sectors for improving food security through root crops in Africa. The TAP-5 project has taken in considerations all the suggested safeguards, and a considerable time was devoted in formulating the terms and conditions for a meaningful, successful, and a model collaboration.

2 Methods

The project partners selected Vietnam as the most suitable country to start operations with the prospects of expanding this or related joint breeding efforts to additional tropical and subtropical potato production environments in the coming years. The crossing plan involved combining the material sourced from HZPC and CIP from their elite stock. CIP has developed the exclusive group of germplasm resistance to major potato diseases like late blight and viruses suitable for lowland tropics and subtropics, and tolerant to abiotic stress (Gastelo et al. 2014, 2015). HZPC germplasm specializes of potential high yield, efficacy assays, state-of-the-art analytical methods, and quality components. New germplasm was developed by conducting the crossing program in the screenhouse of International Potato Center at La Molina, Peru. Line $\times$ tester crossing pattern was followed to develop new population, where frozen pollen imported from HZPC was used on CIP female progenitors. Crossing was carried out in three seasons spreading over 2015, 2016, and 2018. A set of common parents involving 41 from CIP and nine from HZPC was used during 2015 and 2016, whereas another set involving different 30 CIP parents was used in 2018. Till July 2019, four lots consisting of approximately 200 true seed families have been received in Vietnam. The targeted product profiles for table and processing sectors were developed, and the partners pre-identified a list of the progenitors meeting the project's requirements. Dalat (11°56'25.5084"N, 108°27'29.9268"E, 1500MASL), central highlands in Lam

Dong province of South Vietnam, provides favorable conditions for potato cultivation throughout year and has been identified as the leading center for evaluation of the material. The site allows a greater number of phenotypic recurrent selection cycles, which otherwise is a substantial barrier in any potato breeding program (Lindhout et al. 2011; Jansky and Spooner 2018). A screenhouse of 1,000 m² has been erected at the field station of local partner institute Potato, Vegetable and Flower Research Center (PVFC), Dalat, to evaluate F₁ seedlings and parallel multiplication of selected clones across all the stages under disease-free conditions. The selections from F₁ populations are subsequently being evaluated at farmers' field in the surrounding area. For evaluation in lowlands, Hai Phong (20°51'53"N, 106°41'00"E, 8 MASL) in Red River Delta was selected, where the main potato season is during only winter. The selections from highlands and lowlands are being transferred between them by adapting shuttle breeding for faster selection and to test their suitability at different altitudes. At the early stage of evaluation (F₁C₁), augmented block design was laid out to evaluate large number of populations, whereas, in subsequent stages, RCB layout was followed to evaluate the selections. For the statistical analysis, CropStat and HIDAP software were used. Data in the advanced stages have been collected on growth parameters during cropping season like plant vigour, uniformity, growth habit, flowering and fruiting pattern, and senescence. Observations on important biotic stresses including fungi, viruses, bacteria, and nematodes are being recorded on regular interval for selections. During harvesting, clones having tuber defects like hollow heart, internal black spot, and greening etc are discarded. All the selected clones after the F₁C₂ stage have been evaluated for traits related to processing like dry matter, reducing sugar, chipping, French frying, and boiling.

3 Results

Shipment of first two TPS lots arrived at 1 month's interval in 2016, third lot in April 2017, and fourth in August 2018. DNA of the progenitors was exchanged between the participating organizations. Molecular analysis of CIP parents was done in HZPC laboratories, and the results are used for the progeny selections. All the received true potato seed lots are being evaluated under different schemes and are at different stages. Criteria of the selections are tuber traits, disease resistance ability in field conditions and through DNA analysis, processing

traits, performance under high temperature, and earliness. A defined protocol and selection criteria developed by the team have been followed for raising and screening the clones. Seedlings of the received TPS families are being raised in screenhouse followed by farmer field evaluations. Lot 1 and Lot 2 received at 1 month's interval in 2016 have been merged subsequently in one set in highlands and are at the most advanced stage (F_1C_5) with five selections. Nine clones from same families have been selected under lowlands in the F_1C_3 stage. Lot 3 of the same families received in 2017 are at the F_1C_3 stage in highlands as well as lowland with eight and ten selected clones, respectively. Total 177 selections have been made from Lot 4 of 83 families at F_1C_2 , which were received in August 2018.

As the project aims to develop desirable clones in short span with a target to establish them in the market successfully, an integrated approach of preselection and postselection processes is being followed simultaneously. For preselection processes, selected clones were subjected to the laboratory analysis at early stages for disease resistance. DNA analysis of the 73 selected clones from different schemes has been done at HZPC laboratory to determine their resistance against late blight, cyst nematode PVY, and TRV. During 2019, field trials in Central Highlands of Vietnam when exposed to severe late blight infestation confirmed the most advanced clones possessing resistance to late blight. The elite five clones during DNA analysis were found carrying resistant genes and also survived well in the field and produced significantly higher yield (up to 35.9 t/ha) than the check variety Igorota (14.3 t/ha). Potato tubers in targeted tropical areas tend to add in the glycoalkaloid concentration due to high temperature. These toxic substances cause bitterness and have harmful effects on human health (Friedman 2006; Gastelo *et al.* 2017). A glycoalkaloid level less than 7 mg/100 g is considered safe in warmer area than the acceptable level of 20 mg/100 g in traditional areas (van Dam 2002; Gastelo *et al.* 2017). Transported freeze-dried samples of five selected clones with sufficient tubers were found within the safe level when tested for glycoalkaloid contents in CIP laboratories at Lima. *In vitro* multiplication of selected advanced clones is being carried out at local partner institute PVFC to keep disease-free planting material readily available for faster multiplication to conduct varietal release trials. The clones that are being discarded during selections are removed simultaneously from the *in vitro* stock. Before proceeding for the seed multiplication, the *in vitro* stock of most advanced clones is being tested by ELISA kits imported from Lima for prominent viruses, i.e.,

Table 1: Five most advanced clones shortlisted from the Lot 1 and Lot 2

Stage	Harvesting time	Location	Selections
F_1	February 2017	Dalat and Hai Phong	588
F_1C_1	October 2017	Dalat	23
F_1C_2	June 2018	Dalat	15
F_1C_3	February 2019	Dalat	12
F_1C_4	December 2019	Dalat	5
F_1C_5	September 2020	Dalat	5

Potato Virus Y, Potato Virus X, Potato Virus S, Potato Leaf-roll virus, Potato Virus A, and Potato Virus M. The selected disease-free plants will be the source of germplasm export also. While following the shuttle breeding, from 2016 to 2020, most advanced clones selected from Lot 1 and Lot 2 have been evaluated up to the F_1C_5 stage under central highlands in Vietnam where two phenotypic recurrent selection cycles are possible in a year (Table 1). The clones possessing resistant genes for cyst nematode, late blight, PVY, and TRV have been part of the selections.

As a part of postselection strategies, efforts have been initiated to get familiar with the challenging national variety release procedures of the region. The exertions include organizing meetings with the national authorities playing vital role in the variety release process and having discussion with the national partners to understand the varietal trials protocol. Besides that, the stakeholders from CIP, HZPC, and SFSA are organizing workshops and brainstorming sessions to develop pathway for variety release process. To facilitate the export of selected clones, information is being collected on the corresponding protocols of the targeted countries.

To strengthen the capacity of the local partners, the project is also providing trainings to the national scientists. The trainings target on improving the quality of data collection by generating genotype lists and field books, database management, statistical analysis, bar coding, and the use of CIPCROSS software. Until now, 34 national scientists have been trained on data management.

4 Conclusion

Although bordered with leading potato producing countries, its production and consumption in Southeast Asia is lowest among all the regions across the globe. Most of the varieties in the region have been developed by public sectors, whose mandate is limited to varietal development or genetic improvement. The dominating informal

seed system in the region keeps on multiplying the seed of leading varieties, while neglecting newly developed varieties due to different reasons such as poor networking between public sector and seed multipliers, inaccessible and not enough seed available for multiplication, demand of existing varieties by farmers, and many more. In addition, being vegetatively propagated primarily, potato accumulates more viruses than seed propagated crops and seed degeneration is inevitable after certain multiplication cycles especially under tropical conditions. The long-term breeding efforts coupled with the absence of the capable seed system translate all the investments in poor or no acceptance of the varieties by farmers. For a successful breeding program, efforts of the public sector need to be well supported by the strong seed value chain. The interesting situation in the region, where despite having low production and consumption, potato need to be imported, provides an excellent opportunity to establish potato in the list of the commercially important crops. The scope lies not only in meeting the existing domestic demand but also simultaneously increasing it with the increased per capita consumption through awareness. The concept of public-private partnership in agriculture hold promises to bridge gaps between the targeted deliverables and actual requirements of the farming community in the deprived areas (WEF 2013; Kuruppu et al. 2020; Marbaniang et al. 2020). TAP-5 project brings these diverse but complementary strengths at one platform with the aim to develop a robust potato producing system in the region. This study aims to develop demand-driven fresh and processing varieties in short span and ensuring that seeds are available to the producers. Crossing program of the project started in 2016, and within a short span of 4 years, already five clones have been identified for variety released proposal in Vietnam. Success of the breeding program has encouraged the partners to test the material to similar agro-ecologies in other regions like in Africa. Also, a new breeding program within the project has been formulated for new phase aiming to develop processing varieties with major biotic stresses' resistance. Bacterial wilt caused by *Ralstonia solanacearum* species is also a serious threat for potato production in Asia and Africa, and its tolerant in commercial varieties is completely absent. A new bacterial wilt population has been developed in 2020 by combining bacterial wilt tolerant lines maintained at CIP with HZPC's commercial germplasm. The partnership aims to develop germplasm that would act as a source genepool of developing bacterial wilt tolerant commercial varieties. This study establishes itself as a reference model as so far not many examples of

successful public private partnership are available for vegetatively propagated crops. The success of the collaboration is likely to encourage more PPPs and motivate the private sector to invest more in smallholder farming.

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