

# The Use of True Potato Seed as Pro-poor Technology: The Efforts of an International Agricultural Research Institute to Innovating Potato Production

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Received: 7 December 2009 / Accepted: 8 December 2009 /  
Published online: 13 February 2010  
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**Abstract** The International Potato Center (CIP) and collaborating institutions implemented an intensive research programme over a period of 25–30 years on the use of botanical seed of potato as an alternative way of growing a potato crop. The use of botanical or ‘true’ potato seed (TPS) had many advantages over the use of seed tubers. Potentially, the use of TPS was especially attractive for small-scale farmers in developing countries. The difference of using TPS as compared to using seed tubers meant in many respects the development of a new crop–commodity chain, requiring research on breeding, seed production, agronomy and marketing aspects. This research made it possible to produce potatoes from TPS at commercial scale: it removed a number of important constraints in the uniformity and earliness of the TPS varieties and in seed physiology. Experimentation and adoption by farmers in a wide range of countries showed that the technological advantages of using TPS were only translating in economical benefits as compared to tuber seed when the last one was costly or not available. Since the economic performance of seed tubers is likely to continue to fluctuate, TPS remains an interesting alternative. Study of the use of TPS in various countries could contribute to better understanding of factors that promote or inhibit crop technology innovation. The article gives an overview of the various areas of TPS research in CIP and presents information on the application of TPS technology in several developing countries.

**Keywords** Botanical seed · Multiplication · Seed system · *Solanum tuberosum* · True potato seed

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## Introduction

True potato seed (TPS) was launched as an alternative to growing potatoes from seed tubers by the International Potato Center (known under the abbreviation of CIP, for Centro Internacional de la Papa) in the second half of the 1970s. Until that time, evidence of occasional use of botanical seed in Peru and Bolivia was reported, and one case of utilisation of this technology by Inca descendents in the surroundings of Cuzco was described (Johns and Keens 1986; Malagamba and Monares 1988). Also, in developed countries, various researchers looked into the use of TPS (e.g., Umaerus 1987), but a reference to a feasible large-scale use of the botanical seed for ware potato production did not exist.

Developing the TPS technology was first of all a change from the conventional vegetative propagation of potato to a modality of sexual propagation (Table 1). This meant that efforts were needed to modify essentially all aspects of the potato production: breeding, seed management, sowing and agronomy. A successful TPS technology also asked thinking about the organisation of the different players in the potato production chain, including the market and the service supply in terms of the development of new varieties and production and commercialisation of seeds. Also, the consumers were relevant players as variation in tuber skin colour, size and culinary quality of ware crops from TPS varieties differed from ware crops from clonal varieties. Practically speaking, developing TPS technology meant the development of an entire crop–commodity chain.

Whilst many other research organisations in developing and developed countries experimented with aspects of the TPS technology, CIP played a leading role in research and experimentation with all aspects of the technology (Umaerus 1987). In 1974, a breeding approach for the utilisation of TPS of potato cultivation was discussed by Rowe (1974). The first TPS research at CIP started in 1977 with breeding and agronomic experiments. The first presentations on the topic were published in 1983–1984 in the Proceedings of ‘Research for the Potato in the Year 2000’ (Hooker 1983) and in the 28th Planning Conference at CIP on ‘Innovative Methods for Propagating Potatoes’ (CIP 1984). In 1984, more than 34 countries experimented with TPS, and TPS was used by farmers in five countries. In particular, the reports of extensive use of TPS in China increased the enthusiasm in CIP circles for the innovative technology. In 1989, Burton had integrated a chapter on propagation by true seed to the third edition of his book ‘The Potato’. Since then, the technology has been experimented with,

**Table 1** Main characteristics of TPS

100 seed weight (mg)	75
No. of seeds per berry (number per berry)	200
Flower production (number per stem)	50–100
TPS production (kg/ha)	200
TPS weight sown per 1 m <sup>2</sup> nursery bed in mg (50–100 stems/m <sup>2</sup> )	50–75
TPS weight sown per ha in mg (20 stems/m <sup>2</sup> )	150–200
Seedling tuber weight (kg/ha; 14 stems/m <sup>2</sup> , 5–10 g tubers)	700
Seed tuber weight (kg/ha; 14 stems/m <sup>2</sup> , 40–60 g tubers)	2000

Sources: Wiersema (1985, 1986), Almekinders (1995), Upadhyia (2001)

introduced and adapted in a wide range of countries, and in various moments, also commercially interested players were involved. Approximately 30 years after the start of the TPS programme at CIP, this article reflects on its experiences in research and with the introduction of the technology in farmers' fields. Much of the information is based on personal communication, and the authors emphasise that assessments, where made, are their own interpretation of the information available to them.

### **Origin of CIP's Engagement**

Prior to the 1970s, sexual propagation of potato was principally used by breeders to generate new diversity through crossing in order to select clonal varieties and occasionally as a way to eliminate virus from the stock material. TPS came into focus soon after CIP was founded in 1972. The interest in TPS was particularly triggered and enhanced by Dr. Richard Sawyer and Dr. Orville Page, the first director and director of research of CIP, respectively. In their view, using true potato seed would have the advantage that small-scale farmers could eat or commercialise the tubers that he or she would otherwise had to store or buy for next planting (Peter Schmiediche, personal communication). This created the slogan 'a handful of seed replaces 2 tonnes of tubers'. In addition, and importantly, TPS was not bulky; one could take it in his or her pocket into the hills of Nepal or the Philippines. TPS also did not require cold storage and did not transmit virus diseases from one generation to another or soil-borne diseases from one field to another. These advantages were measured against the alternative of setting up national potato seed programmes in the various developing countries where potato was or could become a more important crop for small-scale farmers. Potato was an attractive income-generating crop in most of these countries, but high costs of quality planting material was a barrier for poor small-scale farmers in most of these countries to move into potato production. As compared to seed tubers, TPS could serve a potato production that was labour-using, but less capital-intensive, and thereby in particular suitable for small-scale farmers. Since the small-scale farmers were the target group for the Consultative Group on International Agricultural Research (CGIAR)-related centres in the first place and it was unlikely that any other organisation would put efforts in developing the technology, it was a logical decision to give high priority for CIP to develop this alternative technology (see also CIP 1980).

An extensive research programme was carried out by CIP and partners over the following two decades. The activities reached a height around the middle of the 1990 decade. In 1996, CIP projected a spending on TPS research of about \$1.1 million compared to \$1.0 million on conventional seed systems and \$2.6 million on late blight resistance—which was CIP's largest research project (Walker and Collion 1999). Since then, spending on TPS-related activities has progressively declined, and currently, CIP faces a decision on the closing down of all TPS-focused work.

### **Agronomic Research and Breeding**

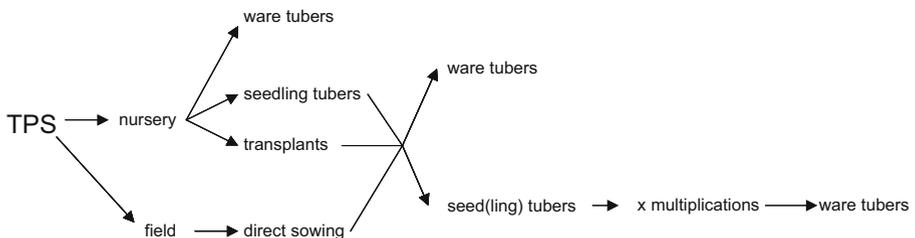
Initially, an intensive programme of agronomic research was carried out by the Physiology Department of CIP at its headquarter and its experimental stations in

Peru during the 1980s. The agronomic starting point was the experience with growing seedlings from TPS produced from crosses by the breeders. Two ways of using the TPS were explored in parallel and compared: (1) producing ware potatoes from the botanical seed either through direct sowing of the seed or by transplanting seedlings to the field and (2) producing seedling tubers in nursery beds to be used as seed tubers in the next planting, with direct seeding into the nursery beds or from sowing in trays and transplanting to the nurseries (Fig. 1). From the experimentation on these two ways of growing potatoes, a range of challenges in the technology emerged and that set the agenda for the TPS researchers. These challenges related to the agronomy, seed production and physiology and breeding.

### Agronomy

*Direct Sowing* Growing a potato plant from botanical seed and producing a commercially and economically attractive crop was the first challenge that was tackled by the researcher from the CIP physiology department. A first and obvious constraint was the longer growing period of a crop grown from TPS. The slow germination and poor growth of the less vigorous seedling could make the crop tuberise too early whilst prolonging the duration of the growing season (at least) 1 month as compared to a crop grown from seed tubers. In addition, it was clear that the small potato seeds were demanding in their germination conditions, and emergence in field conditions was usually poor. Seed germination was unreliable and little was known on seed physiology, seed germination and the factors affecting it. Seedling growth at early stages was slow, and physiological stress resulted in early tuberization, poor harvest indices and low yields. These characteristics made a TPS-grown field crop sensitive and vulnerable and explained why most of the times realised yields remained below the potential yield. Many therefore soon considered direct sowing an unfeasible alternative.

*Transplanting* To shorten the growth period, early maturing parental clones were to be used in crosses, but also raising seedlings in a nursery bed could shorten the field period of the crop. Raising seedlings in a nursery bed and transplanting them to the production field also made it possible to optimise germination conditions and growing conditions for the seedlings. An intensive experimentation with different types of substrate and transplanting regimes under controlled conditions of irrigation and shading followed. However, successfully improving the early growing phase in



**Fig. 1** Schematic presentation of possible TPS utilisation systems (adapted from Almekinders 1995)

the nursery showed the importance of the bottleneck in the next phase, i.e. when seedlings were transplanted to the field: the transplanting shock. Potato seedlings showed more sensitivity to transplanting and to the conditions of the soil into which they were planted than seedlings of other vegetable crops. ‘Damping off’ of the seedlings frequently occurred. Soil preparation, timely irrigation and weeding were crucial as drought stress did express itself in early tuberisation, leading to an extremely early maturing and poor yielding crop.

*Seedling Tuber Production* The sensitivity of potato seeds to the conditions of germination, the transplant shock and the slow seedling growth increased the interest in the alternative strategy: production of seedling tubers in nursery beds. Nursery beds in confined areas facilitated the use of specially prepared substrates, intensive watering schemes and shading in order to avoid stress and to allow undisturbed seedling growth. It could be done off-season and in screen houses to keep aphids out and ensure the seedling tubers would be virus-free and therefore more apt for seed multiplication. The experiences with the seedling crops allowed learning that leaves from seedlings were very attractive to aphids and more prone to virus infection than potatoes grown from tubers. With intensive management, spectacular yields were obtained. A density of 100 seedlings per square metre and intensive management could yield 7–10 kg of  $\pm 1$  g tubers (Table 2), and one trial is reported with 1,365 tubers, totalling 13.1 kg/m<sup>2</sup> (Wiersema 1985). The harvested so-called seedling tubers were then stored until planting to produce either a seed potato crop or a ware potato crop. The small size of the seedling tubers gave a high sprout-to-tuber weight ratio, which made them especially economic for use and storage as seed tubers. Also, with lower plant density in the nursery beds, quite attractive ware potato yields could be obtained: the tubers were small but could be well used in curries and soups.

### Breeding and Seed Production

Initially, the crop physiologists in CIP used true seed from crosses of clonal male and female parents which were selected based on seemingly logical criteria related to flowering and other crop and tuber characteristics (Atzimba  $\times$  DTO 33, Serrana  $\times$  LT 7) to evaluate the various ways in which TPS could be used. However, from the start of

**Table 2** Effect of seedling density on number of seedling tubers per size grade and total yield in direct-sown nursery beds. Means of two families (DTO-33 OP and Atzimba  $\times$  DTO-33). Source: Wiersema (1985, 1986)

	No. of seedlings/m <sup>2</sup>	No. of tubers/m <sup>2</sup> bed				Total yield of usable (>1 g) tubers	
		<1 g	1–10 g	10–40 g	>40 g	No./m <sup>2</sup>	kg/m <sup>2</sup>
6		75	194	99	23	316	4.25
12		119	248	142	19	409	4.99
24		183	384	184	21	589	6.58
48		283	535	234	22	791	7.92
96		434	710	249	18	977	8.76
LSD (5%)		71	84	42	ns	88	1.04

experimentation with TPS, the researchers realised that in order to make the TPS technology successful, it needed the development of well-adapted varieties and production of large quantities of botanical seed. Thus, the breeders revised assumptions and options for TPS varieties of the tetraploid potato. Obviously, the primary challenge was to arrive at maximum tuber uniformity. Different strategies were pursued, with considerable input from the co-researchers Peloquin and Hermesen in Wisconsin and the Netherlands, respectively (CIP 1984, 1985; Umaerus 1987).

### Prospects of Apomixis

Apomixis was proposed as early as 1980 as the ideal scheme for growing potatoes from botanical seed, combining the advantages of both vegetative and generative reproduction. Although components of apomixis are found in potatoes, i.e. gametes with unreduced chromosome number, parthenogenesis and synaptic mutants, no apomictic potato has been found. The use of apomixis for breeding TPS varieties is, however, still an option. New enhancer detection and transposon-based gene trapping strategies have now been proposed to identify apomixis in potato.

### O.P. vs. Hybrid Varieties

The Chinese had initially used seed from open pollination (O.P.) varieties that flowered well and spontaneously produced berries with seeds. However, these  $4x \times 4x$  O.P. varieties showed in most cases strong segregation, giving rise to very heterogenous seedling populations. Options for hybrid varieties were a way to explore increased uniformity. Rowe (1974) proposed a hybrid seed scheme of  $4x \times 2x$  crosses which produced extremely uniform, vigorous and high-yielding offspring. This scheme also promised to maximise heterozygosity and possibilities of obtaining hybrid seed without having to hand-pollinate. However, initially, O.P. varieties and hybrid seed from  $4x \times 4x$  crosses were further explored as the  $4x \times 2x$  crosses scheme resulted in relatively low seed set. A high seed set would be required for commercial seed production.

Because soon the O.P. seed was generally found inferior to hybrid seed in both tuber yield and uniformity of plant and tuber traits of agronomic importance, the research concentrated on the different options for hybrid varieties. Developing inbred lines was considered, but rendered impossible in potato (Umaerus 1987). It was reasoned that the costs for emasculation could be avoided by the development of male sterile  $4x$  parents in  $4x \times 4x$  crosses. It was reasoned that emasculation of the female flower would make the seed production too expensive for the technology to become economically feasible.

Parallel to the efforts of the breeders in Lima to identify suitable TPS varieties, Mahesh Upadhyya, breeder of the National Potato Programme in India and CIP collaborator, developed his own TPS breeding programme. He paid attention to culinary quality of the TPS-grown tubers, embryo type of the TPS, tetrad sterility and stability of flower and berry production (Upadhyya 2001). Tetrad male sterility was found stable and readily used. Highly uniform  $4x \times 4x$  progenies were selected that incorporated a male sterile  $4x$  female parent. Using Tuberosum (TBR)  $\times$

Andigena (ADG) hybrids also yielded heterosis, and this 4x TBR × 4x ADG scheme using a male sterile female parent became a standard at CIP. Later, Upadhyya transferred and continued his work in the Physiology Department of CIP Headquarters in Lima. From his programme stem the crosses that have relatively early male sterile *Solanum tuberosum* female parents and more profusely flowering *Solanum andigena* male parents, like Serrana × TPS 13 and MFII × TPS-67. These crosses are still being used.

Selection of TPS progenies for direct sowing has not been the primary breeding objective of the CIP breeders, partly because it soon was considered that the main way of utilising TPS would be by raising seedling tubers in protected nurseries. There was also a lack of response to selection for improved seedling resistance to transplanting. This was due to the high variability in seedling stand—probably as a result of the transplanting shock. Primary attention was given to selection with seedling tubers instead, i.e. in the first generation of tubers produced from seedling tubers. Selection at the seedling stage was further complicated by the extreme day length and temperature sensitivity of the seedlings. This implied that performance for tuberisation, maturity and yield of TPS varieties were very location-specific and screening for target areas with other temperature and day length regimes were difficult to centralise at CIP Peru.

Also, other aspects of the TPS technology influenced the breeding programme. Depending on how the seed would be used, there would be various opportunities for selection of superior genotypes in the population (Atlin and Wiersema 1988). Best performing seedlings could be transplanted to the field, tuberlets from the highest producing first generation could be kept for further multiplication, plants with unattractive performance could be culled out, etc. All these techniques could counteract the heterogeneity in the performance and genetically improve the progeny. These would make uniformity a less conditional factor in the breeding scheme and even led to speculations how these mechanisms could be used by farmers to select disease (read late blight)-resistant seedlings, thus giving rise to farmer varieties. Also, this placed the question for the need to emasculate on the table since this would logically be an important cost factor in commercial TPS production.

Breeders also tackled earliness of TPS varieties. As information on the performance of TPS in the field became available, the length of the growing period showed up as a major constraint. A period of 120 days or more was too long to fit into most of the Asian rice-based cropping systems. Responding to this constraint was believed crucial for the success of the TPS technology. Concentration on earlier male parents, like the LT family (clones initially selected for the lowland tropics), shortened the growing period but did not give the TPS technology the push that was envisioned. Earlier maturity has remained an important TPS breeding objective.

Currently, CIP has a list of 30 superior TPS progenies of which it produces and distributes seed. This list still includes female parents Atzimba, Serrana and LT8, clonal materials that were identified in the early phase of the TPS work. Other crosses involve MF I, MF II, TPS 13, TPS 25 and TPS 67. New crosses are FLS-20 × TPS-67 and C96H-01.6 × C99HT2-32.43. Significant progress has been made in terms of male sterility (for seed production), earliness, uniformity and incorporation of disease resistance. Emasculation is no longer necessary as the clones currently used as female

parent all have tetrad sterility. However, there are aspects in the genetic improvement for TPS that can still be further exploited (Simmonds 1997; Upadhya 2001).

### Seed Production Technology

Botanical seed production obviously needs a well-flowering mother plant to obtain high seed yields. Successful potato varieties in developed countries were recognised as poorly flowering crops, presumably because they were the result of two centuries of selection for below-ground tuber production and not for above-ground shoot development. In addition, because a crop grown from TPS has a longer growing season than a crop from seed tubers, the use of early clones dominated and early-maturing clones produce fewer flowers (Almekinders 1995). The combinations of varieties that produced high-yielding TPS progenies thus initially included the DTO and later the LT, materials selected for adaptation to lowland tropics and for giving a mature crop in 90–100 days. But under the natural day length conditions in Peru, these clones produced at best a couple of flowers per plant (Table 1) and were therefore only useful as male parent: the pollen from one flower could be used for many female flowers.

*Flower Production* Lack of flowering in potato is a constraint that breeders had learnt to deal with. To make potato plants develop flowers, various tricks were used. They all relied on restrictions or delays of tuber formation. The most commonly used methods were: planting the plant on top of a brick to facilitate the ‘milking’ of tubers, grafting on tomato, cutting the inflorescences and keeping them on a bottle with water, spraying the plant with gibberellic acid and prolonging the photoperiod with additional artificial light (bulbs) at the end of the day or in the middle of the night. The first methods were satisfactory for use by breeders: they were reliable and provided well-controlled conditions for their scheme of crossings for which they typically needed only a relative small number of inflorescences of a range of different varieties. However, TPS production was asking for mass production of botanical seeds and, thus, of mass production of flowers. A logical option was to produce TPS under long-day conditions. This meant that if TPS was to be used in tropical countries where day length varies between 12 and 13 h (see Malagamba 1988), the TPS would have to be produced elsewhere by an institution in a location with long-day conditions. The location would also have to be a place where labour was available at relatively low costs since initially, it was considered that hybrid varieties would be asking hand pollination and emasculation. Rather than thinking of industrialised countries in the north, CIP looked for developing countries in the south as candidates for setting up TPS production that could provide potato programmes in developing countries with seed. The Technical Advisory Committee of the CGIAR had already commented critically on CIP’s actual role as supplier of hybrid TPS to a large number of users all over the world and pressed for handing over the TPS production. Eventually, it was thought that such seed provision would have to be in the hands of the private sector, but for CIP as an international organisation, it was problematic to directly engage with the private sector. Chile came into the picture as a candidate TPS producer. The relations with the national potato programme of Instituto Nacional de Investigacion Agropecuaria (INIA) were

used to set up seed production in Osorno at a latitude of 40° S. Training of personnel in the management of the mother crop (training and pruning, pollination and seed extraction and storage) and technical support paved the way for reliable provision of TPS. Whilst solving that day length problem in relation to flowering, it also meant the CIP had found a politically acceptable solution as to what type of organisation they would support to develop into a reliable true seed supplier.

*Seed Technology* Pollination techniques, seed extraction and processing were largely copied and adapted from tomato practices. Emasculation was initially copied as well, but later, the argument gained ground that the genetic variation in the TPS varieties and the way the TPS was used did not ask for such strict pureness as in tomato. Because research showed that larger potato seeds significantly improved the germination and seedling growth, it became relevant to find out how management of the mother crop could increase seed size. Stem density, pruning of lateral stems, number of inflorescences per plant and pollinated flowers per inflorescence were variants that resulted to have an effect on seed size (Almekinders 1995). An important bottleneck in the use of TPS was the seed dormancy. TPS has a longevity of 8–10 years but is dormant for a period of time that varies, usually from 6 to 12 months. This meant either an appropriate period of storage before selling and using the seed or developing measures to break dormancy. Both options had disadvantages. Storing the TPS for a year requires reliable seed producers who are willing to have their capital tied up in stored seed. Too early selling means that users run the risk of low germination. The other option, treating the TPS with gibberellic acid, was routine for the breeders, but often, such treatment gave elongated and sometimes chlorotic and non-vigorous seedlings. The work at Pallais and his group has shown that storage of TPS with low humidity (3.5–4%) at relatively high temperature (30 °C) breaks dormancy in about 6 months after harvest, resulting in uniform germination (Table 3). Storage thereafter at 18 °C maintains seed vigour at a

**Table 3** Effects of storage temperature, seed moisture content (SMC) and storage time on germination (%) at 27 °C

Temperature (°C)	SMC (%)	Storage (months)					
		1	2	3	4	5	6
15	3.4	1	2	0	1	0	1
	5.1	2	4	4	5	6	20
	7.3	3	3	7	13	17	52
30	3.4	2	3	5	6	12	38
	5.1	4	21	55	63	72	81
	7.3	9	21	50	59	67	87
45	3.4	2	45	74	79	78	92
	5.1	14	69	61	63	34	50
	7.3	22	15	0	0	0	0

Adapted from Pallais and Falcon (1997)

high level for a long period. TPS treated and stored like this showed after 8 years still more than 75% germination (see, e.g. Pallais et al. 1996; Pallais and Falcon 1997). This research is the basis for current protocols of seed management and storage at CIP and allows production of relative large volumes of seed that can be strategically stored and used for example after a disaster when small-scale farmers need to be supported to quickly restart potato production, like in the case of Chacasina in Peru, 1995–1996 (see below). The work of this research group further emphasised the value of seed size. Large seeds show much better performance, up to a level that direct field sowing did come back into the picture as a feasible way of using TPS for producing a ware crop (H. Zandstra and E. Chujoy, personal communication).

Currently, CIP produces 20–50 kg of TPS per year in its experimental station in Huancayo (3,300 m.a.s.l., latitude 12 °S), in Peru, principally for experimentation and distribution to national agricultural research (NAR) partners. INIA still produces TPS, on request, and sells among others to the INTA potato programme in Nicaragua. In addition, national potato programmes of the NARs in India, Bangladesh, Nepal and Vietnam produce TPS and Bejo—India still advertises with TPS, but it is not clear whether this company actually commercialises seed.

### Pests and Diseases

The interest for use of TPS also highlighted the potential advantage in relation with virus infection. Where seed tuber programmes always strive for minimising the build-up of virus infection, TPS had the advantage that viruses did not transmit via botanical seed. The potato spindle tuber viroid proved to be an exception, but it did not really threaten the technology as it could be fairly easily controlled. Resistance to important fungal diseases, in particular *Phytophthora infestans*, could be crossed into the TPS varieties by selection of resistant or partially resistant clonal parents. The potential of the TPS technology to select for disease resistance in the seedling tuber generation or thereafter was also explored. However, natural selection for disease resistance at the farmer level showed little viability. It required all the investment and management of nurseries, with meagre survival rates of seedlings after a serious infection. Nevertheless, in Nicaragua, the resistance of the TPS-derived materials is one of the reasons the technology there still thrives (Noel Pallais, personal communication).

### Experiences in Different Countries and in Various Cropping Systems

In 1994, CIP reported a well-established TPS-based programme in China, vigorous TPS programmes in 13 countries and fledging TPS programmes in another 11 developing countries (CIP 1994). The first places where the TPS technology was brought into the field and tried out with farmers was in those places that CIP researchers had identified as the areas where conventional seed tubers were most constraining for small-scale farmers to grow a profitable potato crop. Because healthy seeds tubers ask for high-technology local seed tuber production or

importation of seed tubers, the costs of investing in a successful potato crop are high and inhibitive for small-scale farmers, whilst labour for seed bed management and transplanting would be available in many situations. Thus, a number of situations and countries became the pilots for the TPS technology so far developed. Later, opportunities in other countries were identified or emerged. Practically speaking, one can assume that in all developing countries with a potato programme, there has been experimentation with TPS. This has yielded a wide range of experiences. Some of those are shortly reported below.

## China

The relative extensive use of TPS in China importantly stimulated the interest of CIP scientists to explore the potential of TPS for potato production in developing countries. In the 1960s, farmers in China were reported to be planting about 15,000 ha of TPS and TPS-derived seed tubers (Bofu et al. 1987). This helped them to overcome lack of quality planting material in terms of virus and physiological age. Later, stimulated by the work of Chinese researchers, this area increased to 22,000 ha in the 1970s and 1980s (Chilver 1997). The TPS scheme consisted in growing TPS transplants and selection of the tubers from the best producing plants for the next planting. In this system, seed tubers produced from TPS were multiplied for on average six generations. The remaining non-selected tubers in each planting were used as seed for table potato production. TPS has been reintroduced in Yunnan Province where an estimated 1,500 ha of TPS and derived clonal progenies are currently grown. Currently, the prospects for TPS appear to be as a temporary seed source until a reliably functioning seed provision system with certification is in place.

## Peru

The use of quality seed tubers in the coastal areas of Peru had been a research area at CIP since its foundation in 1972. The conditions in the coastal area are not favourable to produce quality seed tubers, and most preferred tuber seed source is the higher altitude in the Andes. However, potato seed programmes in Peru have not been proven to be sustainable, and as a consequence, small-scale farmers in the coastal area had limited access to quality potato seed tubers. This provided CIP with an interesting situation for experimenting under farmer conditions with the various options for using TPS. In the early 1980s (1982–1984), CIP researchers experimented extensively with minitubers (Cañete, with potato farmers) and transplants (Callao, with vegetable farmers). In both experiences, tuber yield was acceptable as compared to seed tubers that farmers commonly used. The marketing, however, proved difficult. The perception was that the produce was a mix of potato varieties. In a country like Peru, where production from the Andes gives consumers access to quality at affordable prices, this was a serious constraint. Buyers offered a very low price (about 50% of that of local clonal varieties), which made TPS non-acceptable to farmers. These initial TPS progenies (Atzimba × R-128.6 and DTO-28 × 7XY.1) were not as uniform for tuber characteristics as compared to new progenies developed since then.

In 1995, the phenomenon of El Niño caused flooding in the Peruvian Andes and many Andean communities lost their potato crops. CIP became involved in a project of the Catholic Church in the Callejon de Conchucos, Central Peru. With TPS, farmers could rapidly restore their potato production, their staple food crop, by producing seedling tubers from the cross Yungay  $\times$  104.12 LB. Because the male parent in this cross gives the seedling tubers interesting resistance to *P. infestans*, the material of this progeny is still in use as later generation seed tubers but also by occasional sowing of TPS to produce disease-free seedling tubers. The progeny is called Chacasina after the name of the village where the farmers and CIP focused their collaboration (Rolando Cabello, personal communication).

## India

Mahesh Upadhyia has been leading an active TPS breeding programme in India since the early period of TPS research at CIP. Over time, a strong TPS programme has been established by Tripura State with a remarkable diffusion and availability of TPS in seed stores. Tuber seed price in this part of India is very high, and currently, an estimated 1,500 ha is planted with TPS in Tripura State alone. Over the last 5 years, the Tripura National Programme distributed an increasing amount of TPS: 90 kg in 2000 up to 158 kg in 2004. An additional 8 kg was distributed to farmers in other states, including West Bengal, Bihar and Nagaland (Monjour Hossein and Sarath Illangantileke, personal communication).

## Bangladesh

TPS was an interesting technology for Bangladesh directly from the start. Potato production in Bangladesh is commercially interesting in the fertile lowland during winter, and it fully depended on expensive basic seed tubers imported from the Netherlands which did not have the right physiological age at planting time. The long warm storage season asked for cold storage of locally multiplied seed tubers, and the lack of a highland area restricted the options for the emerging national seed programme to set up a multiplication scheme for quality seed tubers. Important advantages of TPS in this situation were that it was easily storable and seedling tubers had low storage volume. Furthermore, the champion researcher of the Bangladeshi potato programme, Lyle Sikkha, drove an intensive experimental programme. The area planted with seedling tubers in Bangladesh is still varying around 500 ha. Farmers mostly use the seed of the officially registered variety TPS-1, which is the cross MF-II  $\times$  TPS 67. In 2006, farmers' interest in TPS-grown seedling tubers jumped up due to the high prices of seed tubers from clonal varieties. BARI, the Bangladeshi NAR institute, now follows a strategy in which it provides TPS to a number of NGOs, cooperatives and large-scale farmers who produce seedling tubers for commercialisation as seed tubers after grading and bagging.

## The Philippines and Indonesia

Both countries have to cope with a warm potato storage season and soils infested with bacterial wilt and degenerated local varieties. Both countries also have national

potato seed programmes (GTZ and Jica supported, respectively) to provide healthy and physiologically adapted seed tuber material. Both countries were thus faced with conditions that constrained multiplication of seed tubers and sustaining quality of the seed over generations. Producing seedling tubers from TPS and subsequent multiplication was envisioned to solve the problem. However, two major TPS-related constraints emerged. The yield of marketable tubers reduced from generation to generation due to the selection of small tubers after each planting, hence presumably shifting the frequency of genotypes towards small tuber-producing genotypes. This reduction in tuber size affected yield in particular in later generations. The other constraint was the lower prices paid for produce from TPS because of a larger variation in tuber characteristics than present in clonal varieties.

### Nicaragua

In the northern part of Nicaragua, which has mild to cool climatic conditions, potato is a commercially interesting cash crop, but imported quality seed tubers are beyond the financial possibilities of small-scale farmers. In addition, in the years after the civil war, the country did not have foreign currency to import expensive Dutch basic seed tubers. Informally imported seed tubers from Guatemala did not perform well in the field, and the yield turned out to be perishable after harvest because of high levels of *P. infestans* infection in most of the growing seasons. Noel Pallais, researcher from Nicaragua but working at CIP in Lima, importantly contributed to setting up a TPS-based seed programme in the country in the 1980s. After starting to work with TPS in Nicaragua in 1985, 20 years later, TPS is still used by a group of around 500 farmers who produce seedling tubers from the TPS varieties Atzimba × 7XY and MF 2 × TPS 67. These varieties have a level of resistance to *P. infestans* that makes the seedling tubers attractive in comparison to the informally imported tubers from Guatemala. The fact that in particular Atzimba × 7 XY gives a yield of different shades of yellow to white as a consequence of segregation is not important for the Nicaraguan consumer (Noel Pallais, personal communication). For those purposes in which uniformity of the tubers is more important, the MF 2 × TPS 67 yields adequate quality. Actually, the majority of Nicaraguan consumers cannot afford potatoes at all, and it is only a relatively small portion of the population that consumes potatoes. This can explain why the use of TPS remains at the current level. INTA orders TPS every year from INIA Chile, buying a varying amount, and distributing the TPS to farmers who have expertise and conditions to produce quality seedling tubers. INIA's strategy so far has been to avoid misuse of TPS, which could easily lead to an infection of all suitable production land with soil-borne diseases.

### Egypt

Initially, seedling tubers from TPS were a promising replacement for locally produced seed tubers which were of suboptimal quality and were used for the winter planting (CIP 1984). The winter planting is a high-value cash crop because its harvest is partially exported to Europe in February. TPS was also an alternative for expensive imported seed which does not have the right physiological age for this winter planting. This situation spurred an intensive research programme on seedling

tuber production. Later, when also commercial TPS providers came into the picture, opportunities for large-scale production from TPS were explored in Egypt. The desert in the winter with sprinkler irrigation provided a homogeneous and ideal condition for direct sowing and production of ware potatoes for the local market and, potentially, for the early spring market in Europe. Mechanisation could significantly reduce the costs of the crop.

## Vietnam

The 3-month cool winter season of the Red River Delta in the North of Vietnam provides good conditions for potato production. However, there has been a lack of quality tuber seed. The country is not blessed with a seed potato programme or an area where high-quality seed tubers could be produced with the right physiological age at time of planting in the Red River Delta. Production of seed tubers in the Red River Delta itself meant a long storage period during the hot summer. High virus disease incidence also contributed to low yields. TPS provided for high-quality planting material almost doubled the yield of clonal varieties. Yearly seed replenishment with new planting materials from TPS compensated for the high virus incidence. Initially, the TPS varieties were too late-maturing to fit the short winter growing period between two rice crops. Although later TPS varieties were still relatively late-maturing, they much better fitted in the growing season. A study found that farmers were able to reduce their TPS seeding rates to about 120 g of TPS per hectare, rates well below the ones used elsewhere. Farm surveys showed that TPS seedling tubers out-yielded the seed tubers of the dominant variety it replaced by an average of 6.8 Mg/ha. Between 1994 and 1999, TPS-derived materials, mostly first-generation seedling tubers, were used to plant 3,500 ha or about 10% of the total area under potato in Vietnam.

TPS is currently still used on nearly 800 ha, the true seed principally produced by the Vietnamese potato programme or sent from CIP in Peru. The use of TPS is not expected to expand further (Fuglie 2001). Vietnam is opening the market to physiologically fit tubers of new clones from China, and the use of this material as seed tubers will provide farmer yields that are economically competitive with the use of TPS. Finally, the development of a national seed tuber programme in the mountainous region near Dalat with support from GTZ will also challenge the use of TPS.

## Involving the Commercial Sector

Commercial players followed the advances in the TPS technology with more than normal curiosity. They were anxious to know whether this technology was going to make it and wanted to be sure to be ‘in time’ when TPS was becoming competitive with vegetative seed tuber multiplication. Initially, the TPS initiatives of CIP were met with scepticism, not in the last place from the side of the conventional seed tuber companies in the Netherlands. Most breeders of these companies were convinced that the advantages of using high-quality tuber seed were so enormous that TPS would at best create new potato production areas and thereby new markets for seed

tubers. There was also interest from vegetable seed companies. They considered that the move from vegetative propagation to sexual propagation would make the potato crop in many aspects a vegetable crop. The option to grow potatoes from TPS also created space for new players. The most prominent player has been the TPS Products Company—later Potato Products International. TPS Products Company operated as a daughter company of ESCA Genetics. It did set up its own breeding programme, focusing on ‘look-a-likes’ of the most commonly grown potato varieties in Northern America. The seed they sold was produced by a joint venture of another ESCA-Genetics daughter with INIA-Chile in Osorno, Chile. TPS Products was involved in Egypt and explored possibilities of mechanised direct field sowing in the Republic of South Africa. The company does not exist anymore. Bejo Seeds, another player, still offers botanical seeds for potato production, and in northwestern India, several small companies produce and sell TPS.

### **Economic Evaluations and Other Controversies**

The work of Monares was the first socioeconomic evaluation of TPS technology, mostly focusing on the use of TPS in the Peruvian coast. Later on-farm studies and in particular the work of Chilver analysed the economic profitability of the use of TPS and TPS-derived tubers.

An economic analysis of TPS-derived planting materials based on adaptability trials showed that TPS progenies competed favourably with the clonal check in four broad agro-ecologies of India: on average, TPS yielded 3.4 Mg/ha more. This showed a net benefit of USD 415/ha. Based on these results, a conservative projection was made of 78,000 ha under TPS in India by 2015 (Khatana et al. 1996). Further work showed robust profitability in the northeastern hills of India and marginal profitability in the northeastern plains of India.

Subsequently, CIP conducted on-farm research in the mid 1990s to compare TPS with a clonally propagated variety in Egypt, India, Indonesia and Peru. This showed a much less favourable scenario for TPS. The study identified a key trade-off between lower cost of TPS and lower value of the crop harvest compared with the clonal variety. Cost savings from TPS came close to 50% in three of the sites. Ware potatoes grown from TPS seedling tubers received a similar price to the clonal check per kilo per size grade, but in most locations, yield was lower and there was a larger proportion of smaller tubers (Chilver et al. 2005).

Economic analysis showed that TPS seedling tuber technology was very profitable in Chacas, Peru. The variety Chacasina yielded 11.4 Mg/ha more than the late-maturing Yungay variety which had a significantly lower stand establishment in the dry year of 1997. A follow-up survey 1 year later under wetter conditions showed no yield advantage to Chacasina.

All these data show that TPS use implied high labour costs for farmers and that the economic attractiveness depends largely on the comparison with seed tubers. Costs and quality of the seed tubers, the last one principally determined by degeneration and the associated yield reduction, therefore define the opportunities for the TPS technology. The results of the on-farm research led to the development of an empirical rule-of-thumb to identify a good predictor of TPS profitability based

on the performance of the existing clonal system. This rule-of-thumb was that TPS is likely to be profitable in situations where seed costs comprise 22% or more of the value of the tuber production. The implication is that TPS is not appropriate for all production environments but is an economically interesting option in some local areas where clonal seed is hard to get hold of and expensive. This was most clearly the case in the northeastern hills of India (Chilver et al. 2005). Given the dynamic nature of cropping systems with globalisation, urbanisation and climate change as important drivers for change, the economic comparison of TPS vs. seed tubers is likely to remain variable. Consequently, interest will fluctuate as well, flaring up when seed tubers are not readily available or expensive.

## Current Situation, Constraints and Opportunities

### Research

In the 1990s, CIP reduced its research on physiology of seedlings related to TPS agronomy and practically finished the same on pathogen transmission. Research on basic aspects of seed physiology continued until it was gradually phased out in the 2000s when there was enough knowledge to formulate protocols for breaking dormancy and testing seed quality. CIP devolved TPS production and dissemination to the NAR potato programmes and the private sector in the same period. CIP continues to explore various lines of breeding research that can contribute to better performance of TPS, such as apomixis, R-gene deployment (for resistance to *P. infestans*), development of inbreeding lines and the multi-line approach.

### Current Use

TPS is currently used by farmers in at least a dozen locations, including China, India, Nepal, Bangladesh, Vietnam, Peru, Nicaragua and Venezuela (Fernando Ezeta, Jose Santos Rojas, Monjour Hossein, Carlo Carli and others, personal communication). Estimates of acreages cropped with TPS and TPS-derived materials are difficult to acquire, among others because the estimates depend on the extent to which later generations of TPS materials can be traced and are included in the estimates. CIP uses the estimate of 10,000–5,000 ha in total with planting material derived from TPS. In most situations, this is presumably production of seedling tubers in nursery beds after direct sowing or transplanting from sowing trays. An estimated 100,000 families have benefitted in one form or another from the technology. Recently, positive experiences from experimentation with TPS in Central Asia have made it clear that TPS technology continues to attract new attention. This is underlined by current orders for TPS as received by INIA Chile by researchers in other countries in Central and Latin America, following up on the advantages of TPS over the use of seed tubers like demonstrated in Nicaragua. In addition, the observation that commercial Indian-Nepalese companies yearly sell an estimated 60–70 kg TPS to farmers who produce seedling tubers which are used as alternative to expensive seed tubers and which cover an estimated 7,000 ha of TPS-derived material grown by resource

poor farmers (Guy Hareau, personal communication) in Nepal suggests that the TPS technology has found its niches.

### Reflection on the Experience

When measured by the area currently planted under TPS or TPS-derived materials, the success of the TPS technology is relatively modest (see also Almekinders et al. 1996). However, when looking at the efforts as a programme to develop a new crop chain, the results are impressive. Research had to cope with a broad spectrum of interrelated issues. One of the attractive characters of the TPS technology was the potentially different use options (e.g. direct seeding or nursery beds). This flexibility of the technology represented at the same time a constraint in the sense that a broad research programme was needed to explore the different options. Different breeding strategies were to be explored (development of inbreeding lines, apomixis,  $4x \times 2x$  or  $4x \times 4x$  crosses) in a time span that was relatively short for breeding. In addition, TPS technology resulted highly location-specific in its performance (sensitivity to soil medium stress, day length and temperature sensitivity), requiring a high degree of decentralisation of the research and breeding efforts. These factors made it difficult to concentrate and focus the research efforts.

The technology asked for an integration of requirements of characteristics of sexually and vegetatively multiplied crops. This made it not only crop-technologically complex but also meant a complex organisation of actors. Companies that cater for vegetatively propagated potato are different from those that principally deal with seed and seed grown crops. The breeding and commercialisation of seed would need combined expertise and marketing channels. Other services like that for substrate components and mechanisation would require attraction of commercial sector players.

Despite these complexities, major obstacles in the use of the TPS technology have been removed, i.e. late maturity, unreliable germination and uniformity of the produce. Although the yield potential of a TPS-grown crop equals that of a seed tuber-grown crop, the technology is still at a disadvantage on these points as compared with the use of seed tubers. This explains that at the moment quality seed tubers are not available or show sudden increases in price, TPS immediately comes into the picture and can be readily implemented. Since seed tuber availability and costs strongly fluctuate in time, niches for TPS are also likely to appear and disappear. This is currently shown by the renewed interest in the technology in Bangladesh and the emerging one in Central Asian countries like Tajikistan and Uzbekistan (Carlo Carli, personal communication).

Given the flexibility of the technology and the possibility to store seeds over longer periods, the TPS technology is a ready-on-the shelf one and can be implemented when quality seed tubers are not available or in complementary ways. In remaining alive as a ready-to-use technology, TPS faces strong competition of various rapid multiplication techniques. These maintain the clonal character of the crop, and these techniques can thus be used for already adopted successful clones; no special breeding activities need to be deployed and no extensive research on the agronomy is needed. As compared to earlier versions of rapid multiplication techniques, the currently promoted ones have been refined and suitable equipment is

available for scales of production and prices that make it affordable for national programmes or small enterprises in development countries.

## Concluding Remarks

Exploring the potential of TPS in a large range of countries yielded interesting experiences. Research reports on the first experimental results in the various countries showed interesting opportunities and promising extrapolations. However, it has been proven difficult to find the information on the current status of TPS use and, more importantly, information that can explain why the TPS did not take off and spread further. The easy assumption is that economic profitability did not stand up to tuber seed technology. This does, however, forego on important insights that could emerge from more systematic analysis in the various countries on other factors that may have influenced, like the effect of farmer experimentation with a still-not-ready technology, importance of a champion-like research leader taking the technology forward, openness of the market and private sector to engage, perceptions of consumers, etc. In a broader sense, such insights would respond to the current interests in understanding what stimulates and obstructs pro-poor technology innovation.

Whilst one could conclude that using TPS as a common way of producing potatoes in the developing countries has been too revolutionary to become mainstream, it does continue to have important niche uses, such as to restore genetic diversity or food security, like after disasters like in Chacasina Peru. Also, the research has contributed to the knowledge on the various aspects of the potato crop physiology, agronomy and breeding, as is reflected by the hundreds of journal publications that have been produced on TPS in potato. Finally, whether this is all there is to say about TPS remains to be seen. Not all options for further technology improvement are fully explored. The technology may be further improved, notably through breeding and seed quality, making it a more robust technology. In any case, the 30 years of work of CIP and collaborating researchers have shown that with relatively modest budget and intensive research efforts, a totally new crop technology can be put in place. It has not resulted in the ideal pro-poor production technology as researchers were dreaming of, but the repeatedly flaring up of the interests of researchers and farmers in different parts of the world in the use of TPS suggest that TPS will probably continue to be a ready-to-use technology. It remains a competitive potato technology for places and moments when seed tubers are hard and expensive to get.

**Acknowledgements** The authors acknowledge the important input from Rolando Cabello, Carlo Carli, Fernando Ezeta, Monjur Hossain, Sarath Illangantilek, Wouter Gerritsma, Noel Pallais, Peter Schmiediche, José Santos Rojas and others. Without their contribution, it would have been impossible to give any reasonable account of historical and current TPS affairs since only a fraction of the TPS experiences is reflected in published documents.

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