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Review article

Alleviating potato seed tuber shortage in developing countries: Potential of true potato seeds

Jane Muthoni[1, 2*], Hussein Shimelis[1] and Rob Melis[1]

[1]African Centre for Crop Improvement, University of KwaZulu-Natal, College of Agriculture, Engineering and Science, School of Agricultural, Earth and Environmental Sciences, Private Bag X01, Scottsxille 3209, Pietermaritzburg, South Africa
[2]Kenya Agricultural Research Institute (KARI). National Potato Research Centre, Tigoni. Kenya

***Corresponding author: jayney480@yahoo.com**

Abstract

Although potato is an important food and cash crop globally, its production in developing countries is hampered by constraints such as low soil fertility, pest and diseases and inadequate supply of good quality seed tubers. Lack of good quality seed is mostly a consequent of the prevailing seeds system; in most developing countries, majority of farmers recycle their own seeds or get them from informal sources. This leads to seed degeneration and buildup of tuber-borne diseases and hence low yields. In mitigating the problem of shortage of good quality seeds, strategies to rapidly multiply the seed tubers such as tissue culture in conjunction with hydroponics and aeroponics have been tried. However, these are expensive for most developing countries and thus unsustainable. Use of true potato seeds (TPS) is a technology that might solve the problem once and for all. The seeds are cheap, easy to carry and store, can be stored for long and do not transmit most diseases. The technology needs to be given serious thought and should be promoted in most developing countries so as to increase potato yields.

Keywords: Developing countries, Potato seed tubers, True Potato Seeds.
Abbreviations: TPS_true potato seeds.

Introduction

Potato (*Solanum tuberosum* L.) is a crop of major economic importance worldwide (Tsegaw, 2005; FAO, 2008). On a global scale, potato is the fourth most cultivated food crop after wheat, rice, and maize (FAO, 2008). Potato is also the most important tuber crop, ranking first in volume produced among root and tuber crops, with an annual production of approximately 320 million tonnes grown on about 20 million hectares; it is followed by cassava, sweet potato, and yam (FAO, 2010). Potato is grown in more than 150 countries worldwide from latitudes 65^0N to 50^0S, and from sea level to 4000 metres above sea level (Acquaah, 2007). The world average potato production is 17 t ha^{-1}, while direct consumption as human food is 31.3 kg per capita (kg yr^{-1}) (FAO, 1995; FAO, 2004). Of the world potato production, 50-60% is used for direct human food, 25% as animal feed, and 10% for seed; the balance is used in the manufacture of industrial products or is discarded as waste (FAO, 2008). Despite the global importance of potato, there are wide regional and subregional disparities in its production. Asia and Europe are the world's major potato producing regions, accounting for more than 80% of world production, while Africa produces the least, accounting for about 5% (FAO, 2008). North America is the clear leader in productivity at more than 40 t ha^{-1}, followed by Europe at 17.4 t ha^{-1}, while Africa lags at about 10 t ha^{-1}(FAO, 2004; FAO, 2008). Potato production in developing countries is hampered by constraints such as low soil fertility, pest and diseases and inadequate supply of good quality seed tubers (FAO, 2009). Among the constraints, lack of good quality seed is a very important factor. The average yield increase from the use of good quality seed is 30 to 50 percent compared to farmers' seeds (Wang, 2008). If availability of good quality seeds can be increased to some extent, it would be possible to increase potato yields in the developing countries significantly. This review paper looks at the persistent problem of lack of quality potato seeds in developing countries and how the problem can be alleviated. In addition, it looks at the potential role of True Potato Seeds in tackling this problem.

Seed potato problem

In potato production the quality of seed potatoes planted is an important determinant of the final yield and quality (Struik and Wiersema, 1999). Quality indicators of potato seed have two dimensions: the biological attributes (biological quality) and the appearance attributes (commercial quality). Biological quality is crucial for productivity, whereas commercial quality mainly affects seed price. The biological quality includes two aspects: a) the level of disease infection and, b) the physiological age of seed tubers. Seed tubers planted continuously for several years will show degeneration. The degeneration is aroused by several kinds of viruses and virus-like organisms. Because of vegetative propagation, viruses and viroids can be accumulated in tubers leading to degeneration of the potato. Major viruses affecting the potato are potato virus Y (PVY), potato virus X (PVX), potato virus M (PVM), potato virus A (PVA), potato leaf roll virus (PLRV) and potato spindle tuber viroid (PSTV). Infection by any one alone or some of them jointly would retard plant growth and reduce tuber yield. Apart from viruses, fungal and bacterial pathogens borne by tubers lead to late blight, ring rot, black-leg and others, and are also limiting factors for seed quality. Commercial quality is defined by uniformity and size of tubers, as well as external appearance. For normal production, a reasonable size of seed tuber or tuber pieces should be about 40 to 50 grams. Big size seed tubers will increase cost and very small ones lead to low yields (Wang, 2008). In terms of biological quality, poor quality seed potato is believed to be one of the major factors contributing to low potato yield in sub-Sahara Africa (Fuglie, 2007). The sub-Saharan region produces an average 8 tons/ha compared to a world average of 17 Tons/ha (FAO, 2008). When farmers use their farm-saved seed potatoes for several cropping cycles without renewing the seedlot from a reliable source, seed-borne diseases accumulate and cause severe yield and quality losses. This process of yield loss over seasons of seed recycling is generally called degeneration, and can be attributed to the accumulation of seed- borne diseases (Gildemacher et al., 2007). Bacterial wilt, (caused by *Ralstonia solanacearum*) and virus diseases (caused by PVY and PLRV) have been identified as the major seed-borne potato diseases in Africa (Turkensteen, 1987). He also mentioned soft rot (caused by *Erwinia chrysanthemi*), Fusarium wilt and dry rot (caused by *Fusarium solani*) and Verticilium wilt (caused by *Verticilium alboatrum*) as economically important seed-borne diseases. Other researchers considered virus diseases and potato bacterial wilt as the most important seed borne potato diseases in Eastern Africa (Gildemacher et al., 2009). Serious yield losses can be expected as a result of high infection rates with potato viruses (Reestman, 1970). The quality of seed farmers' use depends on the prevailing seed system. In the developed potato producing countries, the formal seed system is predominant (Table 1). The potato seed systems are well organized; regulations exist to control the seed business and seed health and the private sector has strong participation (Gildemacher et al., 2009). There are specialized seed potato producers (seed growers) who multiply seed potatoes from pathogen-free starter basic seed. In addition, producers of ware potatoes maintain maximum production potential over the seasons by replacing their seed potato stock each season, or at least frequently, with high quality seed potatoes from a seed grower. This "flush out" system keeps the virus pressure in the entire cropping system low is and seed degeneration is minimal (Struik and Wiersema, 1999). On the contrary, most developing countries have limited success in building such dominant formal seed systems; informal systems are predominant (Jaffee and Strivastava, 1992; Tripp, 1995; Thiele, 1999). The informal seed system prevailing in most developing countries is responsible for the distribution of more than 90% of the seed tuber used by smallholder farmers (Thiele, 1999; Hidalgo et al., 2009; Lung'aho et al., 2010). The formal seed systems are not well organized and those that include certification contribute only less than 5% of the total planting material required in countries such as Bolivia, Ecuador, Kenya and Peru (Thiele, 1999; Gildemacher, 2012). In Kenya, for example, the annual national certified seed requirement is estimated to be 300,000 tonnes; only 1% of this is met through the formal system in the country (Riungu, 2011). As a result, farmers depend on seed from informal sources which include farm-saved (self-supply), local markets, and neighbours (Muthoni et al., 2010). This leads to accumulation of seed-borne diseases, seed degeneration and consequently, low yields. In Pakistan, the most important factor limiting potato production is the non-availability of certified seed tubers of high yielding varieties at reasonable prices (Farook, 2005). More than 95% of seed requirement is met from locally produced seed tubers from informal system that suffers from more than 20 soil- and tuber-borne fungal, bacterial, viral, phytoplasmic and non-parasitic diseases (Bhutta and Bhatti, 2002). Potato viruses are the main causes of degeneration. It has been reported that degeneration ranges from 1-17% in the first year and 37-65% in the subsequent year (Jagirdar et al., 1982). In Indonesia, majority of farmers (94%) use seed from informal sources (Fuglie et al., 2005). Potatoes are mainly propagated vegetatively through tubers (often called "seed" tubers) (Malagamba et al., 1983). Use of seed tubers for potato production has many advantages, including ease of planting, vigorous plant growth, uniform tubers, and high tuber yields. However, the seed tubers represent food that could be eaten instead of being buried in the field (Malagamba et al., 1983). Potato also has a low multiplication rate (1:10); hence it is expensive and time-consuming to produce enough seed tubers. Consequently, the seed tubers are expensive; it is estimated that the cost of seed tubers may account for 20-70% of the total production costs of commercial potatoes (Accatino and Malagamba, 1982). In addition, the seed tubers are heavy, bulky and expensive to transport over long distances. Because they are fresh, the seed tubers may get destroyed easily, sprout too early thereby leading to losses or they may sprout poorly leading to low yields. In sub-tropical and tropical regions of the world, seed stocks degenerate quickly due to systemic as well as tuber-borne diseases (Malagamba and Monares, 1988); as a result, quality seed tubers are not available or the price is too high.

Mitigation strategies

Rapid multiplication of seed tubers

Most farmers in developing countries use conventional method of seed potato multiplication; this involves replanting of potatoes in the field from the previous season's harvest. The continuous recycling of these uncertified seed tubers mostly leads to rapid buildup of tuber-borne diseases. In addition, the conventional method has a low multiplication rate; about 8 daughter tubers per plant (Otazu, 2008). This means that a farmer has to replant the seed tubers many cycles before getting enough seed tubers; this is especially the case where the farmer has a large piece of land where he intends to grow potatoes or he has a specific potato cultivar that he needs to grow and cannot get seed from other sources. To mitigate the bottlenecks caused by this conventional multiplication method, rapid seed potato multiplication methods that have been adopted which include micropropagation (tissue culture), hydroponics and aeroponics. Plant tissue culture is the science of growing plant cells, tissues or organs isolated from the mother plant, on artificial media. This is facilitated through the use of a liquid, semi-solid or solid growth media in sterilized tubes or containers. Tissue culture is characterized by a flexible and a high multiplication rate (Beukema and Zaag, 1990). Meristem culture is the most commonly used (Naik and Karihaloo, 2007; Badoni and Chauhan, 2010). In meristem culture, the apical/axillary growing tips (0.1 to 0.3 mm) are dissected and allowed to grow into plantlets on artificial nutrient media under controlled conditions. This technique is also used for elimination of viruses in the planting material. This is based on the principle that many viruses are unable to infect the apical/axillary meristems of a growing plant and that a virus-free plant can be produced if a small piece of meristematic tissue is propagated (Wang and Hu, 1980; Kassanis, 2008). Elimination of viruses from the apical meristem is possible because the vascular system through which viruses are spread is not developed in the meristematic region, the high chromosome multiplication (due to high cell

Table 1. Availability of certified seed (from formal system) as a percentage of the need.

Country	Available (%)
Kenya	1
Uganda	4
Ethiopia	1.3
Peru	2
Indonesia	6
Pakistan	5
China	20
Argentina	60
United Kingdom	66
Netherlands	99

Sources: (Bhutta and Bhatti, 2002; Fuglie et al., 2005; Barker, 2008; Huarte, 2008; Kang, 2008; Gildemacher et al., 2009; Riungu, 2011).

Table 1. Estimated utilisation of materials derived from TPS-varieties in selected countries.

Country	Total estimated potato area (x 1000ha)	% Under TPS-derived materials		
		In 1990	In 1995	In 2000
China	2500	0.8	0.8	<1
India	1000	0.1	1	18
Bangladesh	125	<0.1	0.1	20
Peru	180	0.1	0.3	5
Egypt	80	0.1	0.1	10
Indonesia	42	1.5	0.5	<1
Vietnam	30	<0.1	0.1	10
Philippines	6	0.3	0.2	<1
Nicaragua	2	2.5	15	50

Adapted from Almekinders et al., 1996

division) and high auxin content in the meristematic tissue may inhibit virus multiplication through interference with viral nucleic acid metabolism and, there exists virus inactivating system with greater activity in the apical region than elsewhere (Naik and Karihaloo, 2007). Tissue culture is not limited by the time of the year or weather; healthy plants can be grown in a laboratory at any time of the year. However, most developing countries fail to maximize on tissue culture technology due to high operational costs involved as it requires specialized equipment which is very expensive. In addition, different nutrients, energy sources, vitamins and growth regulators used for media formulation are also very expensive (Badoni and Chauhan, 2010). The techniques of tissue culture require specialized skills and knowledge which can only be acquired after going through formal training. A lot of care and high level hygiene are required in tissue culture; inadequate sterilisation of equipment can result in 100% contamination and complete loss of planting materials. Plantlets produced from meristematic tissue culture can be transferred into hydroponic system for rapid production of high quality disease-free seed minitubers for commercial use. In its basic principle, hydroponic system entails culturing plants in a nutrient solution containing balanced amount of the essential components that are necessary for plant growth and development. The main hydroponics systems available for the cultivation of leafy vegetables and potatoes are nutrient film techniques (NFT), the deep flow techniques (DFT) and aeroponics (Ricardo et al., 2009). The NFT system consists of series of PVC or asbestos-cement growing troughs with a 1- 4% slope, through which a thin film of nutrient solution (1 cm deep) flows over the roots of the plants. The solution is collected in a tank at the end of the slope and pumped back to the top of the channels by a submersible pump, thus allowing the constant circulation of the nutrient solution. The DFT hydroponics system involves a tank containing the nutrient solution (5-20cm deep), and the plants are placed on a platform with roots completely submerged in the solution. In this system, nutrient solution recirculation occurs through a typical entry-exit mechanism with the aid of a pump. The hydroponic method facilitates adequate supply of nutrients to the plant as well as permitting multiple harvesting of mini-tubers over a period of time thus increasing the yield of tubers compared to conventional method. Aeroponic is seen as a more costly and complex hydroponic system that involves growing plants in an air or mist environment. Aeroponics is the process of growing plants in an air or mist environment without the use of soil or an aggregate media. Aeroponics system refers to the method of growing crop with their roots suspended in a misted nutrient medium. Reports show that the system is ten times more successful than conventional techniques, tissue culture and hydroponics, which take longer and are also more labour intensive (CIP, 2008). Aeroponic system has the ability to conserve water and energy. Aeroponics system uses nutrient solution recirculation hence, a limited amount of water is used. It offers comparatively lower water and energy inputs per unit growing area (Ritter et al., 2001; Farran and Mingo Castel, 2006). Aeroponics method of propagation is one of the most rapid methods of seed multiplication; an individual potato plant can produce over 100 minitubers in a single season (Otazu, 2008), as opposed to conventional method that produce approximately 8 daughter tubers only (Hussey and Stacey, 1981; CIP, 2008). Another advantage of aeroponics system is that of easy monitoring of nutrients and pH. Aeroponics system provides precise plant nutrient requirements for the crop, thereby reducing fertilizer requirement and minimizing risk of excessive fertilizer residues moving into the subterranean water table (Nichols, 2005). Aeroponics system also allows the measurement of nutrient uptake over time under varying conditions. The aeroponic system was used for non-destructive measurement of water and ion uptake rates for cranberries (Barak et al., 1996). Aeroponic system is also space efficient, with plants taking up minimal room. In contrast with other techniques such as hydroponics and conventional system, aeroponics exploits better vertical space for root and tuber development (Stoner, 1983). As a result, many plants can grow at higher density (plants per unit area) than in the traditional forms of cultivation such as hydroponic and soil (Stoner, 1983). However, the system also requires constant power supply throughout the growing season and any prolonged interruption of power to water-pumps may lead to irreversible damages of plants. The system has high installation and operational costs which may be uneconomical in most developing countries. It also requires skilled labour. Both the hydroponics and aeroponics systems produce more tubers than the conventional method. In addition, they can be used to produce disease-free (virus- and bacterial wilt-free) potato seed tubers. Although use of seed tubers maintains genotype integrity of the potato (Grout, 1990), there are dangers of somaclonal variations that are induced during tissue culture (Lizarraga et al., 1989; Kaeppler et al., 2000).

Use of botanical seeds (TPS)

Due to the problems and constraints associated with production and use of seed tubers in developing countries, researchers have often sought for alternatives in production of planting material with focus being on utilization of true potato seed (TPS) (Schmiediche, 1997). Use of TPS for potato seed-tuber production probably originated in the Andes (Umaerus, 1987; Malagamba and Monares, 1988). True potato seeds were used thousands of years by Incas of South America to renew their seed stock and to improve production (Umaerus, 1987; Malagamba and Monares, 1988). During the 18th, 19th and 20th century, farmers in Europe, North America and Asia used TPS to replace degenerated material or to produce planting material when tubers were not available (Umaerus, 1987; Burton, 1989). In the mountainous part of southern China, where transportation of volumes of seed tubers was impossible, TPS was used extensive in the 1960s and 1970s by farmers to produce their own planting materials (Bofu, et al. 1987). Renewed interest and research efforts to exploit the TPS potential in developing countries was initiated by International Potato Center (CIP) in 1977 (CIP, 1987; Umaerus, 1987). At present, there are few potato growing countries in developing world where TPS has not been tried on a large scale or suggested as a means to alleviate the seed problem. The experimentation in developing countries often together with farmers' experiences showed that yields from TPS varieties are often comparable or higher than the yields of locally produced clonal materials (CIP, 1985). Previous work has shown good potential of TPS for commercial production of potato in tropical Africa (Kidanemariam et al., 1985). In previous studies, TPS hybrids gave high tuber yields in addition to some selected quality characteristics (diseases, pests, and environmental stresses which compared well with standard clonal propagated cultivars (Love et al., 1997).

Advantages and disadvantages of using TPS

The merits for using TPS include the small mass of seed required to sow (only about 150 grams of TPS are required to plant one hectare as opposed to 2 tonnes of seed tubers normally needed for the same area), transportation and storage of TPS are generally safe, easy and inexpensive, there is a possibility of long-term TPS seed storage, low seed costs and the fact that most seed-borne diseases are not transmitted through the true seed (Rowell et al., 1986). Use of TPS reduces production cost by eliminating the cost of expensive seed tubers which can represent 40-70% of the total production costs (Accatino and Malagamba, 1982). In the warmer climates, costs of healthy seed tubers can account for 50-70% of the total production costs (Upadhya, 1994). The cost of production of hybrid TPS has been calculated to be < 10% of the price of the imported seed tubers needed for planting a similar area (CIP, 1985). In addition, use of TPS saves food as seed tubers are food. The major disadvantages of TPS include lack of crop uniformity, low yields, and limited capacity of seedlings to tolerate environmental stresses (Malagamba, 1988). The genetic heterogeneity of a TPS crop is not very serious disadvantage: segregation in plant and tuber performance in the field and in storage is low (Almekinders et al., 1996). The TPS seed is already a potential clone because it is an F1 and there is no further segregation. In addition, the genetic heterogeneity of TPS varieties has been shown to enhance late blight resistance (Almekinders et al., 1996). Although there are variations between progenies, typically, a stem grown from TPS produces a larger number of tubers with a lower average tuber weight than a stem from a normal sized tuber (Wiersema, 1984; Benz et al., 1995). The small sized tubers of TPS crop as opposed to the conventional seed tuber may not be a major disadvantage where the main aim of using TPS is to produce seed and not ware potatoes. In fact it could an advantage as it will reduced the seeding rate. Another disadvantage of TPS grown potato crop is the slow initial development of the seedlings. As a result, TPS crop needs longer duration in the field (Gaur et al., 2000). To shorten the growth period, early maturing parents were identified by CIP breeders and physiologists (CIP, 1994; Golmirzaie et al., 1994; CIP, 1995) which could be crossed to yield early maturing progenies. Although early maturing clones produce few flowers (Almekinders, 1995), they can be used as male parents because pollen from one flower can be used on many female flowers. In addition, research on seed processing, storage and dormancy (CIP, 1992; Pallais, 1992; Pallais and Espinola, 1992; CIP, 1993, 1995) has considerably improved the performance of TPS in the field. Furthermore, raising seedlings in a nursery bed and transplanting then later could shorten the field duration of the crop (Almekinders et al., 2009).

TPS use in some developing countries

The technical flexibility and adaptability of the TPS technology to various agro-ecological and socio-economic conditions is evidenced in developing country agriculture: TPS is used by farmers in at least a dozen locations including China, India, Nepal, Bangladesh, Vietnam, Peru, Nicaragua and Venezuela (Almekinders et al., 2009). The TPS is direct-seeded in Egypt, hand-transplanted to the field on small farms in India, Vietnam, Indonesia, the Philippines and Nicaragua, and sown in and harvested from seedbeds in India, Bangladesh, Sri Lanka, Peru, Nicaragua and other countries (Almekinders et al., 1996). 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 of 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. The TPS technology has been reintroduced in Yunnan

Province where an estimated 1,500 ha of TPS and derived clonal progenies are grown (Almekinders et al., 2009). Of the countries where TPS has reached a level of importance (Table 2), India represents perhaps the country with the greatest realizable potential (Upadhya, 1994; Khatana et al., 1995). In India, the locally bred TPS progenies have good yield potential and show late blight resistance than the commercial cultivars. From transplants in the fields, yields of 29-32 tons per ha are obtained (CIP, 1993). The estimated yield averages from transplants (20 tons/ha) and seedling tubers harvested from the nursery beds (25 tons/ha) appear very competitive with yields from farmers' seed tubers (16 tons/ha) (Khatana et al., 1995). An estimated 1,500 hectares are planted with TPS in Tripura State; the Tripura National Programme distributed an increasing amount of TPS over the years i.e. 90kg in 2000 and 158kg in 2004 (Almekinders et al., 2009). Direct seeding of TPS shows potential in India and Bangladesh where small scale farmers grow potatoes with irrigation and intensively in small plots during the winter season, fetching good prices for small sized potatoes in the local markets (Almekinders et al., 1996).The Bangladeshi national agricultural research institute (BARI) follows a strategy in which it provides TPS to a number of non-governmental organizations (NGOs), cooperatives and large scale farmers who produce seedling tubers for commercialization as seed tubers after grading and bagging (Almekinders et al., 2009). Seedling tuber production from TPS during the spring season has been shown to alleviate seed-tuber problems for the autumn planting in Egypt (Almekinders et al., 1996): the involvement of 3 to 4 private companies in the large scale production of seedling tubers on commercial farms (El-Bedewy et al., 1994) means that some of the potential could be realized. The TPS technology has never reached a significant number of farmers in countries like Rwanda, Tunisia and Pakistan (Almekinders et al., 2009).

Production of TPS

Genotype, day length, temperature and mineral nutrients are the main factors that determine flowering and fruiting in potato. The primary requirement for production of TPS on large scale is that the identified parental clones of TPS families should have good flowering. It has been reported that late maturing genotypes flower profusely and for longer duration than vary early maturing clones (Gopal, 2003). For the subspecies *tuberosum*, flowering and berry setting are best when long days (around 16 hours), abundant moisture, and cool temperatures prevail (Almekinders and Struik, 1996; Sleper and Poehlman, 2006). Thus TPS production is reduced in warm tropical conditions but altitude can have a compensating effect. Sparse flowering and reduced pollen fertility resulting from high temperatures restrict berry and seed setting in potatoes. However, when clones selected for use as parents under high temperature conditions are used, TPS improves considerably (Malagamba, 1988). In a previous study, it was found that blooming of clones under short days was enhanced by a gibberellic acid (GA) and N-(phenylmethyl)-*H*-purin-6-amine (BA) solution applied to the developing trusses as soon as they appeared (Pallais et al., 1984). Pollen yield and fertility were also increased considerably. In plants treated with three applications of GA at weekly intervals beginning 1 week after plant emergence, a larger proportion of stems formed inflorescences and more flowers developed per inflorescence (CIP, 1984). Other techniques to improve TPS production have involved the manipulation of the soil-plant environment. Studies have shown that periodic supplemental nitrogen applications to the soil during seed development at rates higher than recommended for tuber production enhance flowering and delayed plant maturity thereby prolonging the berry development period (CIP, 1985). Flower production was increased by more than three times when supplemental N rates up to a total of 240kgha^{-1} were applied at weekly intervals. In addition, significant increases in 100-seed weight were obtained with supplemental application of N (Pallais, 1986). In a subsequent experiment, the highest 100-tps weight was found in plants receiving N at 600 kg ha^{-1}. Therefore N rates greater than those required for tuber production enhance quality TPS production. Environmental factors affecting TPS performance include soil characteristics, nutrition of the parent plants, temperature during fruit and seed development, fruit maturation period, seed extraction methods, seed moisture content at harvest, seed storage conditions and duration (Sadik, 1983). True potato seed produced under cool conditions has stronger dormancy and greater sensitivity to high temperature during germination than seed produced in warmer environments; it also has a greater seed weight (CIP, 1981).

Open pollinated Vs Hybrids?

In spite of suggested potential, sustained research and promotion efforts, TPS has never reached a significant number of farmers (Almekinders et al., 1996). Even China, which once had gained recognition for its pioneer work on TPS (Li and Shen, 1979; Bofu, 1984), has little area under potato crop grown from TPS (Bofu et al., 1987; Gaur et al., 2000). This was mainly due to use of open pollinated TPS. The open-pollinated population was highly heterogeneous for most of the economic characters and also had low yields due to inbreeding depression (Ramanujam, 1950, 1954; Golmirzaie et al., 1994; Golmirzaie et al., 1998). Cross-pollinated (hybrid) families have been reported to be better than open-pollinated families for seedling performance for various characters including tuber yield (Kidanemariam et al., 1984; Mendoza, 1984; Golmirzaie et al., 1994; Golmirzaie et al., 1998). Kidanemariam et al. (1984) found higher TPS weight in hybrids than in open-pollinated seed. Within a seed lot, heavier seeds are known to result in vigorous and high yielding seedlings (Sharma and Choudhary, 1985). Hybrid seed also germinate faster, are more uniform and grow more vigorously than open pollinated seed (Macaso-Kwaja and Peloquin, 1983). A positive correlation between TPS weight and tuber number and yield was reported (Dayal et al., 1984). Low yields in the open pollinated families are attributed to inbreeding depression (Golmirzaie et al., 1994). The increase in homozygosity and decrease in intra- and interallelic interactions due to reduction in number of alleles per locus as a result of selfing are the basis of low yields (Macaso-Kwaja and Peloquin, 1983). Though hybrid families are in general more productive, selected open-pollinated families can be advantageously used for raising commercial TPS crop, particularly if poor vigour seedlings are discarded prior to transplanting. It has been found that some open-pollinated families can be as productive as the best hybrid families (Golmirzaie et al., 1994; Gopal, 2003). It was also found that TPS of open-pollinated families, though they were slightly lighter than those of the cross-pollinated ones, the two did not differ in terms of seed germination and pre-transplanting seedling vigour. Open-pollinated families yielding even higher than hybrids have also been reported (Golmirzaie et al., 1994). This suggests that some lines might be able to "resist" the inbreeding depression. Further, open-pollinated families are products of not only self-pollination (inbreeding), but also have hybrid seeds depending upon the activity of wind and natural pollinators such as bees of the genus *Bombus* (Atlin, 1985; Golmirzaie et al., 1998). Production of open-pollinated true seeds is inexpensive and costs only a fraction of that of hybrid seeds (Golmirzaie et al.,, 1994; Golmirzaie et al., 1998). Farmers can therefore produce their own TPS by collecting the seed resulting from natural pollination in the field. Thus, open-pollinated families can be advantageously used for commercial TPS crop, as performance of the open-pollinated families would improve for tuber yield and its components if poor vigour seedlings/families were discarded before transplanting (Gopal, 2003). Production of hybrid seed by emasculation and hand pollination is cumbersome, expensive and involves the risk of damage to female reproductive part thereby affecting seed setting (Gopal et al., 2004). In a previous study it was shown that hand pollination of freshly opened non-emasculated flowers (before anther dehiscence) resulted in much higher number of seeds per pollinated flower than those from emasculated flowers (Gopal et al., 2004). Therefore, for large scale hybrid seed production, it would be desirable to hand-pollinate the non-emasculated flowers. However, such seed lots may have some self-pollinated seeds depending upon stage of flowers pollinated, the male fertility and self-compatibility status of the females. Self-seed, if any, in such seed lots can be eliminated by discarding the poor vigour seedlings prior to transplanting (Golmirzaie and Mendoza, 1986). In addition, tetrad male sterility was found to be stable and is readily used; emasculation is no longer necessary as clones currently used as female parents are sterile (Almekinders et al., 2009).

Processing and storage of TPS

A few days after pollination, berries start to develop and in 40 days, they are ready for harvesting. An advantage with potato berries is, unlike tomatoes to which they are closely related, potato seeds carry on developing even after the berry is detached from the plant. In addition, the berries stay firm for months. Therefore there is no hurry in extracting the seeds. Secondly, it means that all is not lost if the berry is dropped too early or the plant dies prematurely. This is very significant in the light of the late blight problems we are all familiar with; the plants can be struck down by blight, wither and rot and the berries will still survive. In such cases, save the berries and let them mature, and as long as you clean them thoroughly, they will yield perfectly healthy seed. After harvest, they are kept at room temperature until they are soft enough to easily extract the seed (Simmonds, 1997). To extract the seed, berries are shredded in a mechanical blender and the mash is fermented for 24 hours in water to separate the seeds. Seeds are then washed in running water to remove the mucilage that envelops them. They are then dried at room temperature (27^0C) in low relative humidity. In the laboratory, seeds can be dried over silica gel and stored for years at low temperatures while remaining viable (Simmonds, 1963). When kept at room temperature, seed can remain viable for several months upto two years. If hermetically sealed and stored at 4^0C, they can be stored for several years without losing viability. In general, low relative humidity during storage is essential to maintain viability. Seed and tubers exhibit dormancy, which is polygenetically controlled and correlated. Seeds have a longer dormancy period than tubers and it can last for four to nine months. To break dormancy, seeds are soaked in 1500 ppm GA_3 solution for 24 hours. After dormancy breaking, seeds are sown on filter paper in petri dishes at room temperature (23-27^0C) to calculate percentage of germinated seeds after 21 days (Wiersema, 1982; El-Gizawy et al., 2006).

Field establishment of true potato seed

While using TPS, potato crops can be grown by 1) direct sowing of TPS in the field for production of seed or ware tubers (Martin, 1983; Almekinders et al., 1996), 2) raising seedlings from TPS in a greenhouse or seedbed and transplanting them later into the field for production of seed or ware tubers in the same season (Rowell et al., 1986), and 3) Direct sowing of seeds in the seedbeds at close spacing for production of seedling tubers which are then used for producing a commercial crop in the next season (Farook, 2005). Of the three methods, use of seedling tubers is the most common (Almekinders et al., 1996; Simmonds, 1997). Seedling tubers can be produced off-season in a screenhouse thereby allowing another crop to be grown in the field at that time. In addition, use of seedling tubers avoids the problems associated with direct sowing (i.e. slow seedling growth, physiological stress resulting in early tuberization and hence low yields), and transplanting seedlings (i.e. transplanting shock) (Almekinders et al., 2009). The use of seedling tubers or later- generation tubers from TPS varieties is agronomically similar to the use of tubers from conventional cultivars in terms of seed rate, initial crop development, number of tubers per stem etc (Almekinders et al., 1996). Also, the yield potential of seedling tubers and later generations of selected TPS varieties competes well with that of clonal cultivars (Wiersema, 1984; CIP, 1987; Love et al., 1994; Benz et al., 1995; CIP, 1995). Direct seeding or transplanting for ware tuber production only seems to have potential in areas where the market accepts small tubers or consumption (Almekinders et al., 1996; Almekinders et al., 2009).

In situations where field conditions for direct seeding are not favourable or where the growing season is too short, raising seedlings in nursery beds and transplanting them into the field is an alternative (Almekinders et al., 1996). This shortens the growing period of the crop in the field. The common observation is that transplants often have a longer growth duration, higher tuber set and smaller tuber size compared to plants derived from conventional tuber seed or tuber generations of TPS (Thomson, 1980; Simmonds, 1997; Chujoy and Cabello, 2007). However, seedling transplants often have a lower yield (tuber number per plant x average tuber weight) than the conventional tuber seed crop, and seedling tubers from TPS usually outyield seedling transplants (Gisela and Peloquin, 1991; Patel et al., 1998; Chujoy and Cabello, 2007). It can be generalized that nearly all seedling families, however propagated are inferior in yields to standard clones, often very inferior (Bedi et al., 1980); occasionally, the best families approximate the best standards. On the contrary, it has also been observed that direct sowing of TPS, transplanting seedlings and use of seedling tubers from TPS give higher tuber yields than the locally available clonal seed tuber (Kidanemariam et al., 1985).

Conclusion

Use of TPS appears to be the technology to solve the problem of shortage of good quality potato seed tubers in the developing countries. The obstacles that have prevented the adoption and widespread use of TPS such as late maturity of a TPS crop, unreliable germination and non-uniformity of the produce have been removed. Other advances in TPS technology are the use of male sterility to increase hybrid TPS production and incorporation of disease resistance.

References

Accatino P, Malagamba P (1982) Potato production from true seed., Centro Internacional de la Papa, Lima, Peru

Acquaah, G (2007) Principles of plant genetics and breeding., Blackwell Publishing Ltd., 350 Main Street, Malden, MA, USA

Almekinders CJM (1995) On flowering and botanical seed production in potato (*Solanum tuberosum* L.). PhD Thesis, Wageningen University, The Netherlands

Almekinders CJM, Struik PC (1996) Shoot development and flowering in potato (*Solanum tuberosum* L). Pot Res. 39*:* 581-607

Almekinders CJM, Chilver AS, Renia HM (1996) Current status of the TPS technology in the world. Pot Res. 39*:* 289-303

Almekinders CJM, Chujoy E, Thiele G (2009) The use of True Potato Seed as a pro-poor technology: The efforts of an International Agricultural Research Institute to innovating potato production. Pot Res. 52*:* 275-293

Atlin G (1985) Inbreeding in TPS progenies: Implications for seed production strategy. p. 71-85. In: Page OT (ed) Present and future Strategies for potato breeding and improvement. CIP, Lima, Peru

Badoni A, Chauhan JS (2010) Conventional vis -a- vis biotechnological methods of propagation in potato: A review. Stem Cell 1*:* 1-6

Barak P, Smith JD, Krueger AR, Peterson LA (1996) Measurement of short- term nutrient uptake rates in cranberry by aeroponics. J Plant Cell Environ. 19*:* 237-242

Barker I (2008) Challenges and opportunities for improving availability of quality potato seed in Eastern and Central Africa. Paper presented at Global Potato Conference, New Delhi, India, 9-12 December 2008.

Bedi AS, Smale P, Burrows D (1980) Experimental potato production from true pottao seed in New Zealand. p. 100-116. In: Report of the planning conference on the production of potatoes from true seeds, Manila, Philippines, 12-25 June 1979

Benz JS, Keller ER, Midmore DJ (1995) Planting materials for warm tropic potato production: Growth and yield of transplanted seedlings or rooted cuttings and tuber materials in the field. Field Crops Res. 40*:* 179-192

Beukema HP, Zaag VD (1990) Introduction to Potato Production. Wegeningen. Netherlands.

Bhutta, A. R. and F. J. Bhatti.2002. Seed certification in Pakistan. p. 1-12. Federal Seed Certification and Registration Department, MINFAL, Islamabad

Bofu S (1984) Use of true potato seed in China. CIP Circular 12: 6-7

Bofu S, Yu QD, Zaag PV(1987) True potato seed in China: Past, present and future. Ame. J Pot. Res. 64*:* 321-327

Burton WG (1989) Propagation by true seed.p. 68-83. *In* The Potato. Longman Scientific and Technical. Longman Group UK Ltd

Chilver AS (1997) Innovation paths in developing country agriculture: True potato seed in India, Egypt and Indonesia. PhD thesis, University of East Anglia, Norwich, UK

Chujoy E, Cabello R (2007) The canon of potato science: The true potato seed (TPS). Pot Res. 50*:* 323-325

CIP (1981) Annual Report 1980. Centro Internacional de la Papa, Lima, Peru.

CIP (1984) Potato for the developing world. A collaborative experience. Centro Internacional de la Papa, Lima, Peru

CIP (1985) Annual Report 1984. Centro Internacional de la Papa, Lima, Peru

CIP (1987) Annual Report 1986-1987. Centro Internacional de la Papa, Lima, Peru

CIP (1992) Annual Report 1992. Centro Internacional de la Papa, Lima, Peru

CIP (1993) CIP in 1992. Program Report. Centro Internacional de la Papa, Lima, Peru

CIP (1994) CIP Circular 20 (1). Centro Internacional de la Papa, Lima, Peru

CIP (1995) Program Report 1993-1994. Centro Internacional de la Papa, Lima, Peru

CIP (2008) Quality Seed Potato Production Using Aeroponics. Centro Internacional de la Papa. Lima, Peru

Dayal TR, Upadhya MD, Chaturvedi SN (1984) Correlation studies on 1000 true seed weight, tuber yield, and other morphological traits in potato (*Solanum tuberosum* L.). Pot Res. 27*:* 185-188

El-Bedewy RC, Crissman C, Courtbaoui R (1994) Progress Report. Egypt's seed system based on true potato seed. CIP Circular 20 (1)*:* 5-8

El-Gizawy AM, El-Yazied AA, Tawfik AA, El-Kaddour AA (2006) Effect of Gibberellic acid (GA_3) on enhancing flowering and fruit setting in selected potato cultivars. Annals of Agricultural Science, Ain Shams University, Cairo 51*:* 173-189

FAO (1995) Potato in the 1990s. Situation and prospects of the world potato economy. A joint study by the Basic Foodstuffs Service, FAO Commodities and Trade Division, and Post Harvest Management Marketing Program. Food and Agriculture Organisation of the United Nations, Rome

FAO (2004) Production statistics [Online]. Available at http://www.apps.fao.org (Accessed 10 March 2010). Food and Agriculture Organisation of the United Nations, Rome

FAO (2008) International year of the potato [Online]. Available at http://www.potato2008.org (Accessed 10 March 2010). Food and Agriculture Organisation of the United Nations, Rome

FAO (2009) Sustainable potato production:Guidelines for developing countries. Food and Agriculture Organisation of the United Nations. Rome. ISBN 978-92-5-106409-2

FAO (2010) Strengthening potato value chains:Technical and policy options for developing coutries. Food and Agriculture Organisation of the United Nations, Rome

Farook K (2005) Use of true potato seeds for beteer yields. Ph. D Thesis. University of Arid Agriculture, Pakistan

Farran I, Mingo-Castel AM (2006) Potato minituber production using aeroponics: Effect of plant density and harvesting intervals. Ame J Pot Res. 83*:* 47-53

Fuglie KO (2007) Priorities for potato research in developing countries: results of a survey. Pot Res. 84*:* 353-365

Fuglie KO, Adiyoga W, Asmunati R, Mahalaya S, Suherman R (2005) Supply and demand for quality potato seed in Indonesia: Farmers' perspectives and policy options. UPWARD Working Paper Series No. 8 CIP-UPWARD, Los Baños, Laguna, Philippines

Gaur PC, Ilangantileke SG, Thakur KC (2000) True potato seed: Asian scenario. In: Khurana SMP et al (ed) Potato: Global research and development

Gildemacher P (2012) Innovation in Seed Potato Systems in Eastern Africa. Ph. D Thesis.Wageningen University, The Netherlands

Gildemacher P, Demo P, Kinyae P, Nyongesa M, Mundia P (2007) Selecting the best plants to improve seed potato. LEISA 23*:* 10-11

Gildemacher P, Kaguongo W, Ortiz O, Tesfaye A, Woldegiorgis G, Wagoire W, Kakuhenzire R, Kinyae P, Nyongesa M, Struik P, Leeuwis C (2009) Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Pot Res. 52*:* 173-205

Gisela CS, Peloquin JS (1991) Performance of true potato seed families. II. Comparison of transplants versus seedling tubers. Pot Res. 34*:* 409-418

Golmirzaie AM, Mendoza HA (1986) Effect of early selection for seedling vigour on open-pollinated true potato seed. Ame J Pot Res. 63*:* 426 (Abstr)

Golmirzaie AM, Malagamba P, Pallais N (1994) Breeding potatoes based on true seed propagation. In: Bradshaw JE, Mackay GR (ed) Potato Genetics, CAB International, Wallingford, UK

Golmirzaie AM, Ortiz R, Atlin GN, Iwanaga M (1998) Inbreeding and true seed in tetrasomic potato. I. Selfing and open pollination in Andean landraces (*Solanum tuberosum* Gp. *Andigena*). Theor Appl Gen. 97*:* 1125-1128

Gopal J (2003) True Potato Seed: Breeding for Hardiness. J New Seeds 5*:* 57-73

Gopal J, Kumar V, Thakur SS (2004) Hybrid and open pollinated true potato seed production: Some considerations. Ame J Pot Res. 31*:* 13-20

Grout BWW (1990) Meristem tip culture .p. 597. In: Pollard JW Walker JM (ed) Methods in molecular biology: Plant cell and tissue Culture. Humana Press, New Jersey

Hidalgo O, Manrique K, Velasco C, Devaux A, Andrade-Piedra JL (2009) Diagnostic of seed potato systems in Bolivia, Ecuador and Peru focusing on native varieties. In: 15th International Symposium of the International Society for Tropical Root Crops (ISTRC), Lima, Peru, 2-7 November 2009

Huarte, M (2008) Trends in seed potato production in Latin America. Paper read at Global Potato Conference, New Delhi, India , 9-12 December 2008

Hussey G, Stacey NJ (1981) In vitro propagation of potato (*Solanum tuberosum* L.). Ann Bot. 48*:* 787-796

Jaffee S, Strivastava J (1992) Seed system development: The appropriate roles of private and the public sectors. In: World Bank Discussion Papers 167. The World Bank. Washington

Jagirdar AP, Jandan MD, Solangi AB (1982) Studies on the rate of degeneration of some potato varieties in Pakistan. Pakis J Agric Res. 2*:* 115-118

Kaeppler SM, Kaeppler HF, Rhee Y (2000) Epigenetic aspects of somaclonal variation in plants. Plant Mol Biol. 43*:* 179-188

Kang GS (2008) Seed production in India. Paper read at Global Potato Conference, New Delhi, India, 9-12 December, 2008.

Kassanis B (2008) The use of tissue cultures to produce virus-free clones from infected potato varieties. Int J Ann Appl Biol. 45*:* 422-427

Khatana VS, Upadhya MD, Chilver AS, Crissman C (1995) Economic impact of true potato seed on potato production in India. Monograph for CIP Exernal Program Review. Centro Internacional de la Papa, Lima, Peru

Kidanemariam HM, Arndt GC, Macaso-Kwaja AC, Peloquin SJ (1984) Hybrid vs Open pollinated TPS families .p. 25-37. In: Report of the 28th planning conference on innovative methods for propagating potatoes, Centro Internacional de la Papa, Lima, Peru, 10-14 December 1984

Kidanemariam HM, Arndt GC, Macaso-Kwaja AC, Peloquin SJ (1985) Comparisons between 4x X 2x hybrid and open pollinated true potato seed families. Pot Res. 28*:* 35-42

Li CH, Shen CP (1979) Production of marketable and seed potatoes from botanical seed in the People's Republic of China. p. 21-28. In: Production of Potatoes from True Potato Seed. Report. Planning Conference, Manila, Philippines

Lizarraga R, Huaman Z, Dodds JH (1989) Invitro conservation of potato germplasmat the International Potato Center. Ame J Pot Res. 66*:* 253-276

Love SL, Thomson-John A, Werner BK (1994) Evaluation of TPS lines for 1992 and 1993. Research Report. University of Idaho, College of Agriculture, Aberdeen, Idaho

Love SL, Werner BK, Groza HI, Thomson JA (1997) Performance of commercially available true potato seed hybrids grown from tubers. HortSci. 32*:* 728-732

Lung'aho C, Nyongesa M, Mbiyu MW, Ng'ang'a NM, Kipkoech DN, Pwaipwai P, Karinga J (2010) Potato (*Solanum tuberosum*) minituber production using aeroponics: Another arrow in the quiver?Paper presented at the 12th KARI Scientific Conference, KARI Headquarters, Kenya, 8-12 November 2010

Macaso-Kwaja AC, Peloquin SJ (1983) Tuber yields of families from open pollinated and hybrid true potato seed. Ame J Pot Res. 60*:* 645-651

Malagamba P (1988) Potato production from true seed. HortSci. 23*:* 495-499

Malagamba P, Monares A (1988) True potato seed: Past and present uses, Centro Internacional de la Papa, Lima, Peru

Malagamba P, White J, Wiersema S, Accatino P, Sadik S, Monares A (1983) True potato seed. An alternative method for potato production. Centro Internacional de la Papa, Lima, Peru

Martin MW (1983) Field production of potato from true seed and its use in breeding programme. Pot Res. 26*:* 219-227

Mendoza HA (1984) Selection of uniform progenies to use TPS in commercial potato production.p. 5-16. In: Innovative Methods for Propagating Potatoes. Report 28th Planning Conference, Centro Internacional de la Papa, Lima, Peru

Muthoni J, Mbiyu MW, Nyamongo DO (2010) A review of potato seed systems and germplasm conservation in Kenya. J Agric Food Infor. 11*:* 157-167

Naik PS, Karihaloo JL (2007) Micropropagation for the production of quality potato seed in Asia-Pacific. Asia-Pacific Consortium on agricultural biotechnology, New Delhi, India

Nichols MA (2005) Aeroponics and potatoes. p. 201-206. In: Proceedings of the First International Symposium on Root and Tuber Crops 'Food Down Under' Leiden, Netherlands

Otazu V (2008) Quality seed potato production using aeoponics. A potato production manual, Centro Internacional de la Papa, Lima, Peru

Pallais N (1986) Techniques to improve the sowing value of true potato seed. HortSci. 21*:* 826 (Abstr)

Pallais N (1992) Effects of temperature and seed moisture content during storage of true potato seed. Ame J Pot Res. 68*:* 627

Pallais N, Espinola N (1992) Seed quality as affected by nitrogen during true potato seed production and moisture conditioning during storage. Ame J Pot Res. 69*:* 85-93

Pallais N, Fong N, Berrios D (1984) Research on the physiology of potato sexual seed production. p. 149-168. *In*

Innovative methods for propagating potatoes. Report of XXVIII Planning Conference on International Potato Culture, Centro Internacional de la Papa, Lima, Peru

Patel PK, Pande PC, Sarkar BB, Kadian M (1998) Multilocation evaluation of seedling and seedling tubers derived from true potato seed (TPS). J Indian Pot Assoc. 25*:* 30-32

Ramanujam S (1950) Problems and prospects of potato improvement in India. Indian J Genet Plant Breed. 10: 1-6

Ramanujam S (1954) The potato in Indian agriculture. J Soil Water Conserv India 3*:* 4-14

Reestman AJ (1970) Importance of the degree of virus infection for the production of ware potatoes. Pot Res. 13*:* 248-268

Ricardo MC, Jose EDPP, Valdemar F, Ce'sar ABPP, Erika SR (2009) The production of seed potato by hydroponic methods in Brazil: Fruits, vegetables and biotechnology. Global Science Books 1*:* 133-139

Ritter E, Angulo B, Riga P, Herrán C, Relloso J (2001) Comparison of hydroponic and aeroponics cultivation Systems for the production of potato minituber. Ame J Pot Res. 44*:* 127-135

Riungu C (2011) No easy walk for potatoes. Horticultural News. The East African Fresh Produce J. 19*:* 16-17

Rowell AB, Ewing EE, Plaisted RL (1986) General combining ability of neo-tuberosum for potato production from true potato seed. Ame J Pot Res. 63*:* 143-153

Sadik S (1983) Potato production from true seed; present and future.p.18-25. In: Hooker WL (ed) Research of the potato in the year 2000. Centro Internacional de la Papa, Lima, Peru

Schmiediche P (1997) Overview of CIP work in East and South East Asia and the Pacific.p. 15-18. *In* Centro Internacional de la Papa Program Report 1995-1996

Sharma SK, Choudhary SK (1985) Factor analysis of berry and its characteristics in potato. Genet Iber. 37*:* 77-82

Simmonds NW (1963) Experiments on the germination of potato seeeds. I. Pot Res. 6*:* 45-60

Simmonds NW (1997) A review of potato propagation by means of seed, as distinct from clonal propagation by tubers. Pot Res. 40*:* 191-214

Sleper DA, Poehlman JM (2006) Breeding field crops, 5th ed., Blackwell Publishing Professional. 2121 State Avenue, Ames, Iowa

Stoner RJ (1983) Aeroponics versus bed and hydroponic propagation. Florists' Review. 173*:* 44-77

Struik PC, Wiersema SG (1999) Seed potato technology. Wageningen: Wageningen University Press.

Thiele G (1999) Informal potato seed systems in the Andes: why are they important and what should we do with them? World Dev. 27*:* 83-99

Thomson PG (1980) Breeding for adaptation to TPS propagation. p.149-157. In: utilization of the genetic reosurces of the potato III, Centro Internacional de la Papa,, Lima, Peru

Tripp R (1995) Seed regulatory framework, resource- poor farmers: a literature review. *In* Agricultural Administration Network Paper 51. London: ODI

Tsegaw T (2005) Response of potato to paclobutrazol and manipulation of reproductive growth under tropical conditions. Ph.D. Thesis., University of Pretoria, South Africa

Turkensteen LJ (1987) Survey of diseases and pests in Africa: fungal and bacterial diseases. Acta Horti. 213*:* 151-159

Umaerus M (1987) True potato seed. p. 72-103. In: Proceeding of the 10th Triennial Conference of the European Association of Potato Research, Aalborg, Denmark

Upadhya MD (1994) True potato seed: Propagule for potato production in the 21 century. p. 5-11. In: Shekawat GS, Khurana SMP, Pandey SK, Chandla VK (ed) Potato: present and future. Indian Potato Association, Shimla, India

Wang F (2008) The importance of quality potato seed in increasing potato production in Asia and the Pacific region. p. 46-53. In: Papademetriou MK (ed) Proceedings of a workshop to commemorate the international year of the potato. Bangkok, Thailand. 6 May 2008. FAO, Regional office for Asia and the Pacific, Bangkok, Thailand

Wang PJ, Hu CY (1980) Regeneration of virus-free plants through in vitro culture.p. 61-99. In: Flechter A (ed) Advances in Biochemical Engineering. Springer-Verlag, Berlin

Wiersema SG (1982) Evaluation of technology for production of seed tubers from true potato seed. Technology Evaluation Series No. 1. Centro Internacional de la Papa, Lima, Peru

Wiersema SG (1984) The production and utilization of seed tubers derived from true potato seed. PhD Thesis. University of Reading