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Seed potato (*Solanum tuberosum*) production systems in India: A chronological outlook

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ABSTRACT

Seed is a major and important input in potato (*Solanum tuberosum* L.) cultivation. On account of vegetative propagation, the requirement of seed potatoes (tubers) is voluminous and accounts for 40–50% to the total cost of production. Potato productivity in India is low in comparison to developed countries due to the non-availability of quality seed in required amounts. Seed potato production through micro-propagation (tissue culture) techniques can overcome the problems associated with the conventional multiplication system. The everlasting shortage of seed potatoes in most of the potato growing countries can be solved through hi-tech seed production system including micro-propagation and aeroponic techniques. Besides, rapid multiplication, production of disease-free mother stocks under controlled conditions followed by reduced number of field exposures as compared to conventional multiplication system, is an added advantage of seed potato production in these techniques. For expanding quality seeds, the entire seed production systems framework needs to be reviewed. The present review will be an endeavour to outline the historical background of seed potato production, issues and challenges, supply frameworks and policy implications in India.

Key words: Health status, Hi-tech system, Meristem culture, Seed, Seed plot technique, Virus indexing

Seed is the basic and vital input in agriculture and its timely availability in adequate quantity as per demand decides the strength and growth of agricultural economy in a country. Seed has played a very important role in India's green revolution and shall continue to be the important component in the days to come (Naik and Buckseth 2018). The traditional farmers' practices are to save their own seeds generally selected from healthy plants from fields which are free from diseases and pests, harvest them separately, clean, cure and then store in containers and inspect regularly for any kind of damage; or they get quality seed from other seed producing farmers on barter basis, indicating thereby the importance of seed in their production system.

There is limited accessibility of quality material in case of vegetatively propagated plants in India. Generally, tubers are used as seed in potato (*Solanum tuberosum* L.) (Ranali 1997) overwhelming various problems like low multiplication rates, increased production cost various seed borne diseases befitting the risk of degeneration over the years. Such tubers when planted yield low and diseased plants in future generations. This was coined as 'degeneration' or selenity by the Dutch workers in 1972. Such selenity acts as a major constraint in producing clean potatoes (Badoni and Chauhan 2010). Potato production is constrained by various factors that include availability of suitable varieties, agro-techniques, quality seed and storage infrastructure, especially in tropics and sub-tropics. But most important being the availability of quality seed as it has a direct bearing on crop yield (Singh and Sharma 2018). Potato seed is bulky and the rate of multiplication is slow (5-6 times), this poses a unique challenge to seed production and seed supplying agencies (Young 1990). Since the crop is multiplied vegetatively using tuber as seed, it gets degenerated very fast necessitating replacement of the seed every year (ideally) or after every two years (Naik and Buckseth 2018). Further the seed is either unavailable or out of the reach of farmers owing to high price. The seed related issues are further aggravated because of restricted accessibility of reasonable seed producing regions quality seeds can alone add to the increased yield by 15–20% (Shaheb *et al.* 2016).

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HISTORY OF POTATO CULTIVATION IN INDIA

Spread in India

The precise introduction of the potato in India is not

known. Probably it was brought either by the Portuguese who first opened the trade routes to India, or later by the Britishers. However, the stocks introduced in all likelihood were of those then grown in Europe, and not directly from South America. The earliest reference of the potato occurs in account of the voyage of Edward Terry (1655), who was chaplain to Sir Thomas Roe, British Ambassador to the court of the Mughal Emperor Jahangir from 1615-1619. Terry, in his description of Indian solid and its produce, wrote "In the northernmost part of this empire they have a variety of pears and apples; everywhere good roots as carrot, potatoes, and others like them……are grown'. Terry's account thus places the potato as a crop in the northernmost parts of India, probable in the hills, earlier than 1615. Similarly, Fryer's travel records, (1672–81) mention the potato as a well-established garden crop in Surat and Karnataka in 1675. However, Habib (1963) in his book The Agrarian System of Mughal India (1556–1707) wrote that ordinary (now called Irish) potatoes were not among the vegetables grown. According to him, mention of 'potatoes' referred to in Terry's (1655) and Fryer's (1672–81) travel accounts actually meant varieties of yams which were grown and formed an article of popular diet in northern and southern India during that period.

By late 18th or early 19th century potato was an important established vegetable crop in the hills and plains of India. Early introductions resembled the Andigena potatoes and were adapted to short winter days having long dormancy and capable of withstanding higher temperatures under country stores. They were grown by various names in local dialects depicting some character, viz. Phulwa-flowering in the plains; Gola-round potatoes, Satha-maturing in 60 days, etc. and came to be known as *desi* varieties.

Between 1924 and end of World War II, the State Agricultural Departments and other agencies introduced a large number of European potato varieties with a view to selecting those suitable for local conditions. These efforts, however, proved of little value mainly due to poor adaptation of temperate long day adapted European varieties in the sub-tropical short days available in plains of India. Only few foreign varieties approached the yield levels of local varieties under commercial culture, however, none proved to be a very good yielder. Fast degeneration of seed stocks was another important factor in non-establishment of European varieties in the sub-tropics. Lack of adequate cold storages for storing seed potatoes over long periods of hot summer also posed problems. Whereas, the local old varieties kept well in country stores, the imported varieties could not survive in these conditions. The introductions from Europe thus made no impact on potato culture in sub-tropical plains of India. However, a few introductions such as Magnum Bonum, Up-to-Date, Royal Kidney, Great Scot, Craig's Defiance, etc. survived in the hills. In India till 1950, 16 each of *desi* and European varieties were identified mostly under cultivation.

Origin and domestication

Originally potato was found 8000 years ago as a wild species by the inhabitants of Andes in South America at an elevation of 3800 amsl. The tubers are rich source of energy and large amount of stored carbohydrates made potatoes the food of poor. In India, the potato for the very first time was introduced amid the 17th century by the Portuguese merchants. It has been clearly mentioned in Terrys record of a banquet in Ajmer that it was given to Sir Thomas Roe by Asaph Chan in 1615 (Watt, 1908). It had successfully established in gardens of Karnataka and Surat by 1675. Potato cultivation was introduced in the hills of Dehradun by Major Young, an armed force officer. Whereas, it was introduced in the Shimla hills in 1828, where the householders used to cultivate potatoes in small strips followed by its introduction in Nilgiri hills in 1830. With the course of time trade between the hills and plains developed. It had turned into a profitable source of income by 1839. Potato was likewise traded to Tibet in the early 19th century through India.

Import of foreign varieties

Prior to freedom and during the colonial period, seed potatoes of indigenous varieties were alone utilized for potato cultivation. Whereas the seeds of high yielding potato varieties were first imported from the Netherlands in 1960 and continued thereafter. Import of European varieties was customary for commercial potato production. In the year 1946–1947, almost 1072 maunds of seed potatoes of three distinctive varieties namely Arran Consue, Up-To-Date and Kerrs Pink were distributed to local farmers. However, deterioration of seed stock soon took place due to absence of any seed potato production program. Foreign varieties were imported each year until the point that the world war-II set in, wherefrom, the state needed to scan other avenues for importing seed potatoes. After the stoppage of foreign imports in 1939, varieties available within the nation were tested by Dr B N Uppal and concluded that the assortment of Up-to-date (Numbri) was suitable for cultivation in Bombay. From that point, India has been producing its own seed.

Seed potato in India

For seed production in India, sincere efforts were made to maintain healthy standards of potato seed stocks with in 1933 in UP (Uttar Pradesh) by Agriculture Department. They attempted to increase the pathogen free seed supplies of Dunbar Cavalier and Majestic cultivars imported from England. This aided in anchoring around 100 q of Majestic and 250 q of the other assortment, i.e. Dunbar Cavalier at Almora and Nainital hills of Garhwal district. To conquer the issue of dormancy, a second round of multiplication was done in the mid hills of Bhowali. But this resulted in degeneration of stocks due to occurrence of bacterial brown rot disease in seed tubers and thus the scheme failed (Pushkarnath 1976).

In 1935, a thought was envisioned to establish an undeniable research foundation in India. This provoked the opening of a Potato Breeding Institute in Shimla and

two seed creation farms at Bhowali (Kumar slopes, UP) and Kufri (Shimla Hills) as a piece of Indian Agricultural Research Institute, Delhi. Taking a look at the issue of seed degeneration, a research plan under the Indian (Imperial) Council of Agricultural Research was developed in 1941. It surveyed the various diseases affecting potatoes (Vasudeva and Azad 1952). Potato cyst nematode, popularly known as golden nematode is a 'major constraint to potato production throughout the world and this quarantine pest is restricted to Nilgiri hills of South India. It was first detected in1961 at Ootacamund and brisk execution of isolate estimates confined its further spread to other potato developing areas.

Hills—ideal for seed potato production

A project with the name 'Production of partially disease free potatoes' was set up. The fundamental approach was to clean up all the seed crops present in fields which could be obviously distinguished for viral infection. It brought about threefold increase in the yield of Darjelling Red Round variety. But it was soon realized that potato seed generation on a huge scale requires production and development of India's own varieties (Pushkarnath 1976, Singh and Rana 2014). As the climatic conditions in India were entirely different from North America and Europe from where the potatoes were imported in. The experience additionally brought the acceptance that an association which is specialized in science and excels in the craft of seed production was required for commercial production of potato.

An overview was portrait by Davies in 1934 on the different reasons for seed potato degeneracy, and it was the aphids particularly *Myzus persicae* which was observed to be the fundamental driver. Additionally, with the advancements winning around then, hills were observed to be the perfect location for seed potato production which was pathogen free. According to the guidelines provided by him for the location and maintenance of seed potatoes in hilly areas, the principal seed production station for potatoes was established in the high hills of Kufri (Shimla hills, Himachal Pradesh). It satisfied the states of lower temperature in summers (underneath 20°C) with the inability of aphid migrants to alight the potato crops and their colonization. It was additionally risky to grow potato crops for seed purpose when aphid population transcends above 20 on 100 leaves. Till 1935, the seed potato was being imported from various European countries on yearly basis, but during Second World War, European countries put a blanket ban on the export of potato seed to India.

Establishment of CPRI

European varieties were imported to India and endeavors were made to acclimatize them to the agro-climatic conditions prevailing in India. But soon deterioration of seed stock took place due to absence of any seed potato production program. With this, it was realized that India can't rely on exotic varieties alone and therefore, needs to have its own program for research and development of potato. In 1945, a scheme for developing Central Potato Research Institute was advanced by Sir Herbert Steward, then Agricultural Advisor of Government of India. The plan was implemented by Dr S Ramanujam in 1946 and it was the first occasion when that scientific orientation was given to the seed potato production. In 1946-1947, 1072 mounds of seed potatoes of three varieties- *Arran consue, up-to-date and Kerrs pink* were distributed to local farmers. However, it took three years for the entire scheme to attain a concentrated shape in the form of CPRI, Patna with its first Director Dr S Ramanujam. The three units functioning independently were (i) Potato Breeding Station, Shimla (ii) Seed Certification Station, Kufri (iii) Potato Multiplication Station, Bhowali were now converged into CPRI. The administration of Himachal Pradesh developed a research scheme for producing disease free seed tubers. This venture effectively delivered clones of 'Up-to-Date" which was imported from Northern Ireland. As hills were the only source of pathogen free seed, in 1956 the headquarters were shifted to Shimla. With the course of time, trade was successfully established between the hills and plains.

From 1956 to 1983, a few local research stations were built up in various potato developing zones of the country to address local issues of potato development. The organization has seven territorial research stations situated at Jalandhar (Punjab), Patna (Bihar), Modipuram (Uttar Pradesh), Kufri (Himachal Pradesh), Gwalior (Madhya Pradesh), Shillong (Meghalaya) and Ootacamund (Tamil Nadu). Potato seed creation was confined to high slopes till mid 1960's.

Overdependence on hill seeds

Viruses are transmitted by vectors known as aphids, consequently potato seed started to be produced in the high hills which almost free from aphid during the potato cropping period. This increased the strain on the indigenous seed multiplication systems being practised in the hills. Subsequently, after 22 years in 1966 another research station was setup in Fagu (Kufri, HP), as all hilly areas have not been found suitable for production and maintenance of healthy seed potatoes which can meet the standards. The issue of rapid degeneration had made the plains fully reliant on the hills in order to satisfy their prerequisite for seed. Thus, the entire pressure was laid onto the hills for quality seed potato production which offered ascend to an extensive no. of issues, for example:

(i) Limited areas having elevation of 750 m or above which are technologically suitable for seed production.
(ii) Seeds produced in hills cannot be utilized in plains for sowing in October owing to dormancy.
(iii) Limited means of transporting the freshly harvested tuber but dormant seed tubers over long distances resulting in delay in planting.
(iv) Crop conditions due to irrigation practices: In the Indian hills. viz. Kashmir valley, Kinnaur and Lahul Spiti potato planting takes place during the summer seasons followed by harvesting towards the end of monsoons. However, there was no uniform distribution of rainfall

which is critical for the growth of plant. Therefore, in case of scanty rainfall, it's very difficult to provide required irrigation due to highly uneven topography, exceptionally porous nature and non availability of ground water. Another factor which adds is limited area for cultivation and the seed not being of the right physiological age to be immediately used in plains.

Also, a high rate of degeneration makes the seed break down after a couple of multiplications. Since the eastern, north-eastern, Deccan and South western parts of the nation, have hotter climatic conditions, and were not suitable for customary quality seed production. To overcome these issues, it was important to fabricate another framework for seed production as well as certification in plains which could limit the reliance on slopes. In 1971, an undertaking under the name All India Coordinated Potato Improvement Project (AICPIP) with its headquarters in CPRI, Shimla was set up.

Development of seed plot technique for Plains

Till mid-1960'S the seed potato cultivation was confined to high hills only as it had low aphid population during cropping season. Potato was cultivated as a spring crop in the Indo-Gangetic plains which was totally exposed to aphids bringing about degenerated seeds. Different analyses were led by CPRI for seed potato creation in various agro-climatic areas. A noteworthy achievement underway of value potato seed was culminated through the introduction of " Seed Plot Technique' in 1965. This made India, the only country in South Asia with its own breeding program for potato. This aided in beating seed decline because of aphids as the seed crops could be grown during very little or no aphid population in the plains of northern India. Due to the advancement of Seed Plot Technique, the significant production of disease free seed moved from the slopes to the fields in plains. Despite the fact that the potato was presented as a late spring crop in temperate hills, and it at last turned into a noteworthy winter crop for the plains. The vast stretch of fertile belt reaches out from Punjab to Assam, the seed produced through seed plot method gave 30–40% higher yields free from many soil and tuber borne diseases (Singh and Rana 2014). It was adequate for producing enough breeder seed for the nation every year.

Seed plot technique benefitted Indian agriculturists as well as aided in sparing expansive measure of cash which was generally spent on the import of foreign seeds. The primary guideline of this technique relied on developing healthy seed potato utilizing low intensity of aphid infestation period in between October and starting of January incorporated with coordinated pest and disease management. Though, roguing and dehaulming of the seed crop needed to be completed by the last week of December or mid of January before the aphids infestation reach to the economic threshold level. This strategy opened a window in sub-tropical plains for production of quality seed. The seed production could be taken up in bigger zones under sub-tropical plains including Uttar Pradesh, Bihar, Punjab, Haryana and parts of Madhya Pradesh. Farmers could undoubtedly receive seed of right physiological age at the exact time of planting, with no issue of dormancy.

The selection of seed plot system prompted enormous development in cold stores for storing the produce which in the following season could be used for autumn planting. As a result of the advancement of seed plot method, potato tuber moth (PTM) got eliminated and seed rottage diminished. Thus, seed plot technique met the seed prerequisite as well as prompted higher productivity with minimum losses (Khurana *et al.* 2003).

Virus indexing

Exploiting the seed plot framework, a proficient consistent strategy for outfitting the quality of healthy seed stocks was envisioned after 1970 through clonal choice, tuber indexing and stage-wise field multiplication of healthy tubers. Indexed tubers concept for production of disease free potato seed took shape once diagnostic methods were developed for major potato viruses (Singh and Sharma, 2018). In this method, tubers are selected from storage/ growing crop that are uniform in type, free from detectable diseases, and within an acceptable size range. Each tuber is coded for identification, and an eye, preferably from the stolon end, is removed and planted in the greenhouse. Resultant plants are evaluated for vigour and viral diseases. The tubers which are free from all the viruses are used for production of disease free seed by multiplying them in the field for four (Stage 1, 2, 3, 4) generations (Crissman and Mc Arthur 1993, Singh 2003). This has been made feasible utilizing ELISA (Enzyme Linked Immune Sorbent Assay) with its first use in 1984, by CPRI. In this method, tubers are first screened against different infections like PVX, PVA, PVY PVS, PLRV, PVM, PVY^N and PVY^C using ELISA. Tuber indexing is a system of testing the picked tubers to be free from any disease by growing up their eye plugs in net houses. Another essential technique grasped for virus detection and elimination is Immunospecific Electron Microscopy which is in use since 1987. Scotland pioneered this concept which has since been used world over for potato seed production, including India (Koehnke and Shaughnessy 1942, Upreti 1977). The new diagnostics developed over the years have improved the efficiency of the system.

Seed potato production systems

Conventional system

The conventional method of seed potato production is to repeatedly propagate a sample which has been proved to be free of pathogens in a system called clonal multiplication (Bryan 1981, Struik and Wiersema 1999). The clonal multiplication system has been practiced effectively in the Netherlands, South Africa, Kenya (Crissman and Mc Arthur 1993) and India (Upreti 1977). This potato seed production system is laborious, expensive and time consuming. Because of a low multiplication rate (usually 1:6), it takes many years to produce significant quantities of seed to meet the demand of potato industry. Another constraint is the

degeneration of seed stocks from one generation to another due to accumulation of bacteria, fungi, viruses and viroids. Modern seed programmes tend to minimize the use of clonal systems or use a combination of clonal and rapid multiplication systems. The production of potato seed under conventional system has not been effective in avoiding or reducing the buildup of pathogens and has consequently led to reduced quality potato seed and low crop yields. In this system, seed potato growers select better quality tubers for seed and discard those of poor quality. The diseased and healthy plants are identified and separated and the healthy tubers are used for the next season's production. If the mother potato plant becomes infected with a disease during the growing season, each of the new offspring is likely to be infected as well. During the growing season, growers peep seed fields visually for signs of disease and remove infected plants through the process of rouging. However, visual inspection, particularly for primary infection, is unreliable, time consuming and requires a well experienced eye (Lapierre and Signoret 2004, Phytocultures Ltd. 2008). Inevitably, the quality of seed potato produced in subsequent generation's declines substantially. The conventional method of propagation is one of the slowest methods of seed multiplication. This method has also shown to be done at certain time of the year specific particularly in tropical and sub-tropical regions where potato is a winter crop (Burton 1989). In addition, the method requires a seed producer to have enough land if he has to enter into commercial seed production. This, however, is associated with high labour cost in managing big fields.

Thus, the only way-out to overcome the above said limitations is augmentation of seed potato production through hi-tech seed production system to improve the quality and also to reduce the field exposure.

Hi-tech system

The virus-indexed and pathogen-free mericlones are subjected to a rapid tissue culture plant propagation method to generate abundant clean (pathogen-free) cultures. Several facets of the generic science of plant tissue culture have both current and potential future applications (Naik and Karihaloo 2007). These include micropropagation, i.e. clonal propagation through axillary shoot proliferation using explants (isolated plant tissues, e.g. leaf sections or stem internodes used in *in vitro* culture) containing pre-existing meristems, de novo shoot production following the induction of adventitious meristems by the application of plant growth regulators and somatic embryogenesis, which

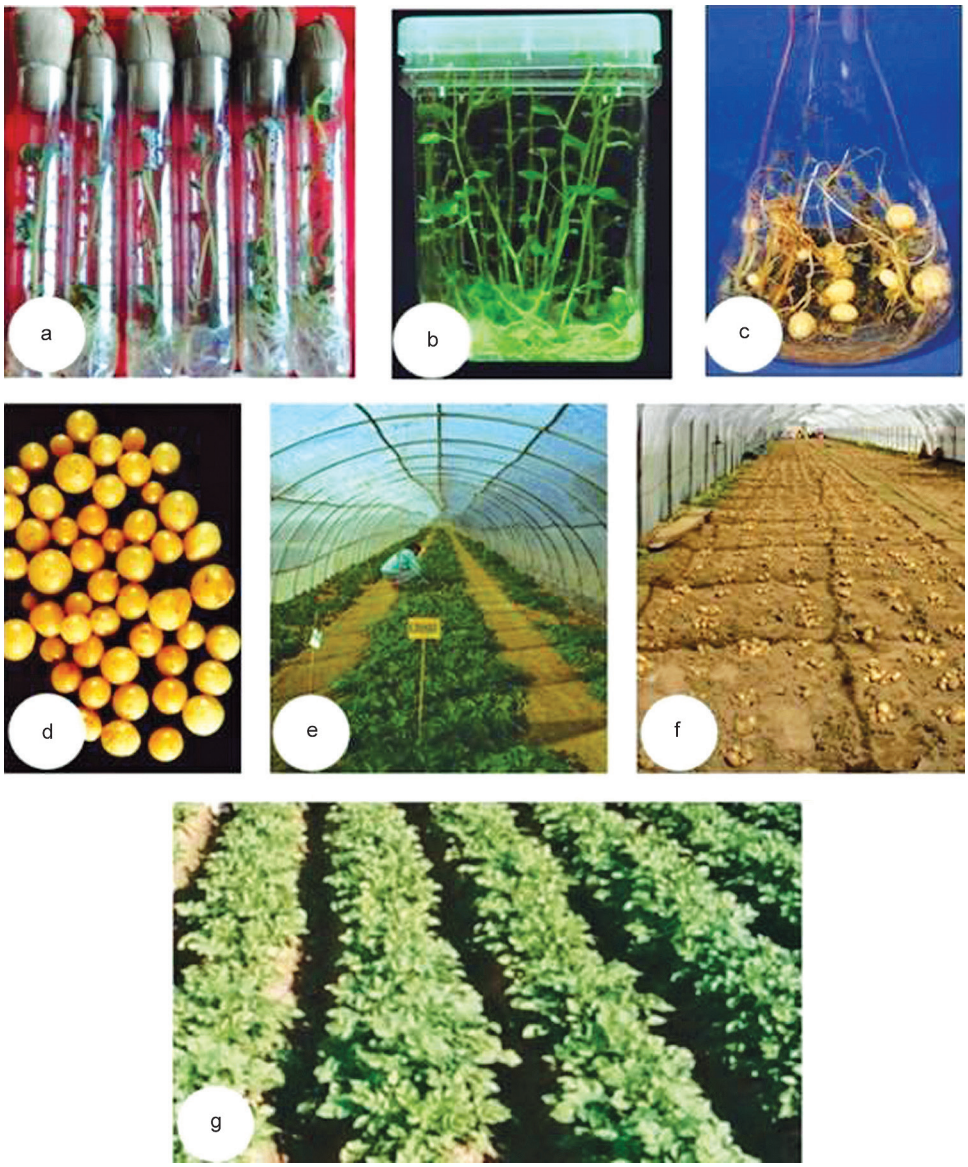

Fig 1 Integration of tissue culture in potato seed production (Naik and Buckseth 2018). (a) Rapid micropropagation of virus-free mericlones on semi-solid medium. (b) Multiplication of micropropagated plants in liquid medium for production of microtubers. (c) Potato microtubers developed under dark in MS medium supplemented with 10 mg/l BA + 80 g/l sucrose. (d) Harvested microtubers. (e) Pathogen-free high-density potato crop raised either from *in vitro* plants or microtubers in net house. (f) Harvested minitubers from high-density net house crop (g) Healthy field crop raised from minitubers harvested in previous season.

is the process of embryo initiation and development from vegetative or non-gametic cells (Millam and Sharma 2007). All these processes hold significant applications in potato biotechnology. The widespread introduction of plant tissue culture to seed potato production during the 1970s enabled the rapid multiplication of disease free seed material and resulted in more productive seed stock. Micropropagation now underpins many seed potato production systems and specifically provides the nuclear stock material, in the form of microplants (plants derived through *in vitro* axillary bud proliferation) or micro-tubers (*in vitro* produced tubers) for their subsequent use in a chain of potato seed production programmes (Millam and Sahrma 2007, Chindi *et al.* 2014).

Micropropagation involving *in vitro* asexual multiplication allows quick and round-the-year production of disease-free good quality pre-basic seed and thus it is a way out to supplement the ever high requirement of quality seed. The use of micropropagation in pre-basic seed production has resulted into mass production of potato plants in a very short period of time (Naik *et al.* 2000). Seed potato production through micropropagation is mostly based on the production of *in vitro* plantlets or microtubers, and on the subsequent production of minitubers as first ex vitro generation (Fig 1) (Ranalli 1997).

Minitubers can be produced from plantlets planted at high densities in the greenhouse in beds (Wiersema *et al.* 1987) or in containers (Jones 1988) using different substrate mixtures, or even in hydroponic culture (Muro *et al.* 1997). Lommen (1995) presented alternative production techniques for minitubers using very high plant densities and non-destructive, repeated harvesting of minitubers by lifting plants carefully from the soil mixture and replanting them after harvest. These techniques allowed minitubers of ideal size to be produced, the number of tubers could be increased considerably, while total yield was reduced. Many seed programmes prefer to use minitubers, defined as the small tubers, (usually 5–25 mm), that can be produced throughout the year under semi *in vitro* conditions in glasshouse and screen-houses using *in vitro* propagated plantlets, planted at high density. Hydroponic and aeroponic techniques have been evaluated and proved suitable for minituber production in greenhouse (Nugaliyadde *et al.* 2005); hydroponic culture in inert aerated substrate (such as wood, perlite, vermiculite), in which film culture, i.e. hydroponic systems in which roots grow directly in either a pure circulating nutrient solution or in a circulating nutrient solution system with very little substrate (Struik and Wiersema 1999).

Recently hydroponic/aeroponic systems have been developed for production of minitubers from *in vitro* plants. In addition to reducing the cost of production, these systems facilitate round the year production and adoption of phytosanitary standards. Production of minitubers using

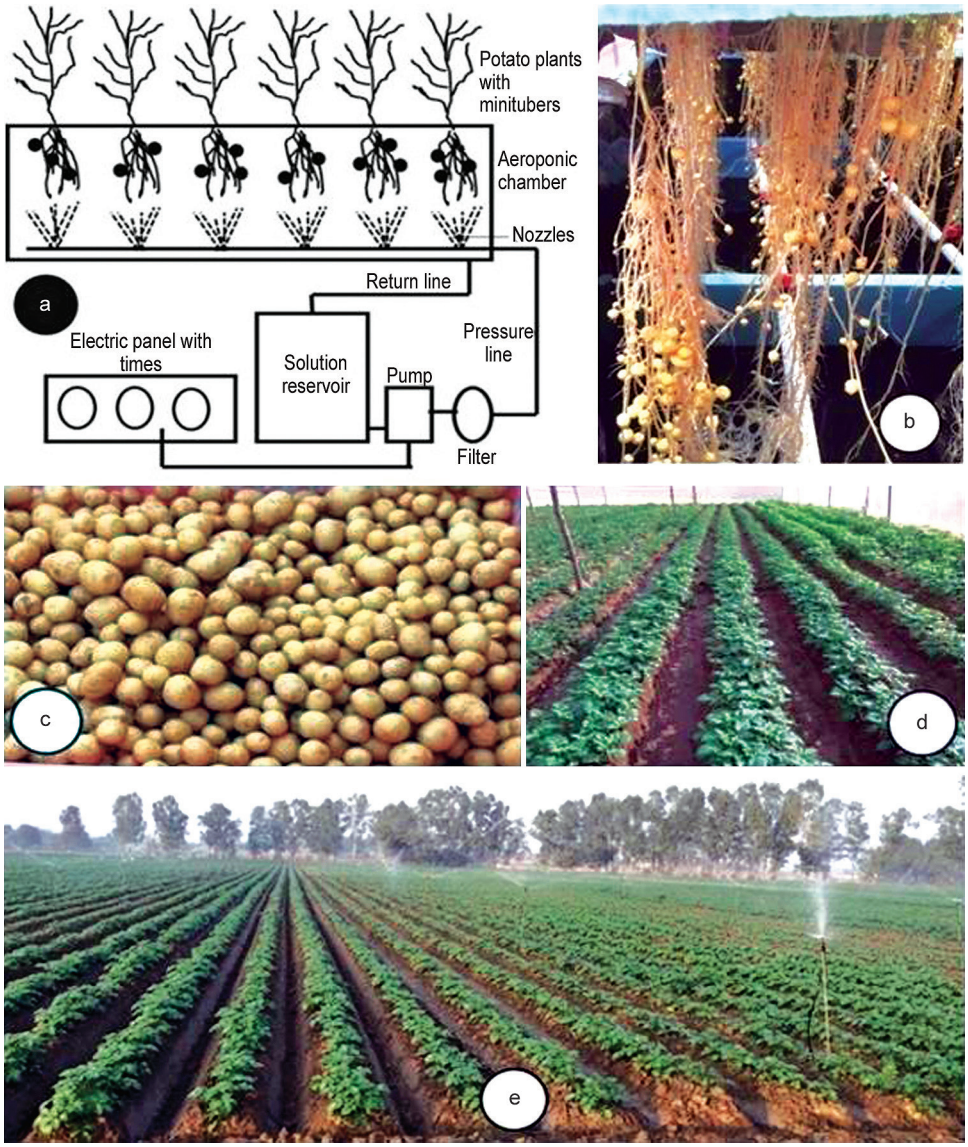

Fig 2 Aeroponics in potato (Naik and Buckseth, 2018). (a) Diagrammatic presentation of aeroponic system. (b) Minitubers developed in aeroponic chamber. (c) Harvested minitubers. (d) Minituber crop in net house, and (e) Minituber crop in the field.

aeroponics is an alternate soil-less culture technology (Fig 2). This technology consists in enclosing the root system in a dark chamber and spraying a nutrient solution on roots with a mist device. The modified device consists of aeroponic chamber, pump, spraying tube, timer and nutrient solution reservoir. Production and utilization of minitubers using aeroponics have been reviewed by Buckseth *et al.* (2016).

The multiplication rate of potatoes is very low compared to other crops, from between four to six times under optimal conditions. For this reason, a large portion of crop area is devoted to the production of seed tubers and it takes a considerable time to build up a sufficient amount of commercial tubers. With every field multiplication, the build-up and transfer of pathogens can increase, leading to seed degeneration. Therefore it is essential to investigate methods of increasing the number of minitubers (G0) produced from disease free *in-vitro* plantlets (Tshisola 2014). Therefore, aeroponic technique offers many interesting opportunities for developing enhanced production systems, mainly for mini-tubers. Although requires some technical knowledge to design, establish and run, the benefits offered are sufficient for such systems which have been widely adopted by seed production companies worldwide (Millam and Sharma, 2007).

Aeroponics seems to have lot of scope for augmenting the existing seed production in the country. Being a relatively new technique for seed potato production in India, optimization of several factors in seed production through aeroponics need to be addressed (Buckseth *et al.* 2016).

The mini-tubers ("Nucleus Seed" or G-0 stage), thus, produced are cold stored and used for field planting in next season. The pathogen-free nuclear seed is multiplied 2 times (G-1 and G-2 stages) under strict sanitary and phytosanitary conditions on research farms to produce "Basic Seed" (produce of G-2 stage). This basic seed is further multiplied by registered growers and other seed producing agencies for 3 more years (G-3, G-4 and G-5 stages) to produce "Certified Seed" (produce of G-5 stage) as per minimum seed certification standards (Indian Minimum Seed Standards, DAC 2013). In all these multiplications, limited generation system wherein the planting of each seed class is limited as per the eligibility by compliance with established disease tolerance levels and the number of field multiplications in particular country is followed. During potato production, the plant is constantly exposed to sources of contamination. The probability of a seed tuber or seed lot, becoming infected with pathogens progressively, and increases every year. To minimize this, seed certification agencies have enacted regulations to basically restrict or limit the number of years the seed lot can be eligible for the seed certification process. A generalized potato seed production system using tissue culture as proposed by Naik and Khurana (2003) is shown in Fig 3.

TPS (True Potato Seed) as an alternative technology

Despite the fact, that the quality seed production had been started yet at the same time, the agro climatic conditions in North Eastern States brought about quick degeneration of stock tubers due to infections. The production zones had to confront numerous different imperatives like high cost and limited availability of quality seed, poor management practices, non-availability of plant protection chemicals and serious diseases of potato prevailing due to favourable agro-climatic conditions. Intense lack of cold stores for preserving the seed potato for adjoining year was further adding to the problem. The idea of true potato seed (TPS) was conceived by Dr. S Ramanujam as early as 1949. TPS produced through sexual mode is used as an alternative planting material. The self pollinated seedlings of indigenous cultivar 'Phulwa' were planted in Patna but the thought was not encouraged due increased rate of trait segregation and low yields. However, the systematic study on utilization of TPS for growing the commercial potato varieties began in 1976-1977 by CPRI and the International Potato Center, Lima, Peru (CIP). The first preliminary trial using TPS was carried out in Tripura by the State Horticulture Department in 1985–1986. It brought about high return potential which additionally urged the state to adopt this feasible technology for potato production on commercial scale. This innovation reduced the amount of seed required for planting per hectare of land. Northern plains have been discovered reasonable for producing seed tubers which are free from virus but have high cost of production. Almost 10% of the total world production (approx. 32 million tonnes) is used as seed which is shear wastage of the food material. To address this issue, the TPS technology was developed and put to use, especially in the developing countries (CIP, 1983; Sikka *et al.* 1994; Almekinders *et al.* 2009; Gupta *et al.* 2004). Only about 50–125 g TPS is sufficient to plant one hectare area and most of the viruses are eliminated during the process of sexual seed formation. TPS is used to grow commercial potato crop by two methods: i) transplanting of seedlings, in which potato seedlings are raised in nursery beds and transplanted in the field at 4–5 leaf stage. This method requires about 125 g TPS and 75 m^2 nursery bed area for growing seedlings sufficient for transplanting in one-hectare area, ii) use of seedling tubers. But the TPS technology was also found to be assisted with certain disadvantages like the seeds are not genetically pure and exhibit heterogeneity; the crop is matures late as compared to the crop grown from seed tubers; the technology is also labor intensive. TPS is also found to be dormant from harvest till half a year, however, this inclination may remain upto year and a half (Simmonds 1963a). In such condition, when other crop seeds ordinarily lose germinability during storage (Thomson 1971). Dormancy of TPS was most certainly not thought to be a noteworthy issue in light of the fact that Gibberellic corrosive (GA) could be utilized to advance germination in recently reaped seeds but the technology could not be commercialized for the seed production (Accatino and Malagamba 1982, Spicer 1981, Bamberg and Hanneman 1984). This technology although is highly desirable but it could not be used on a sustained basis for potato seed production. Reason being, the crop raised through TPS

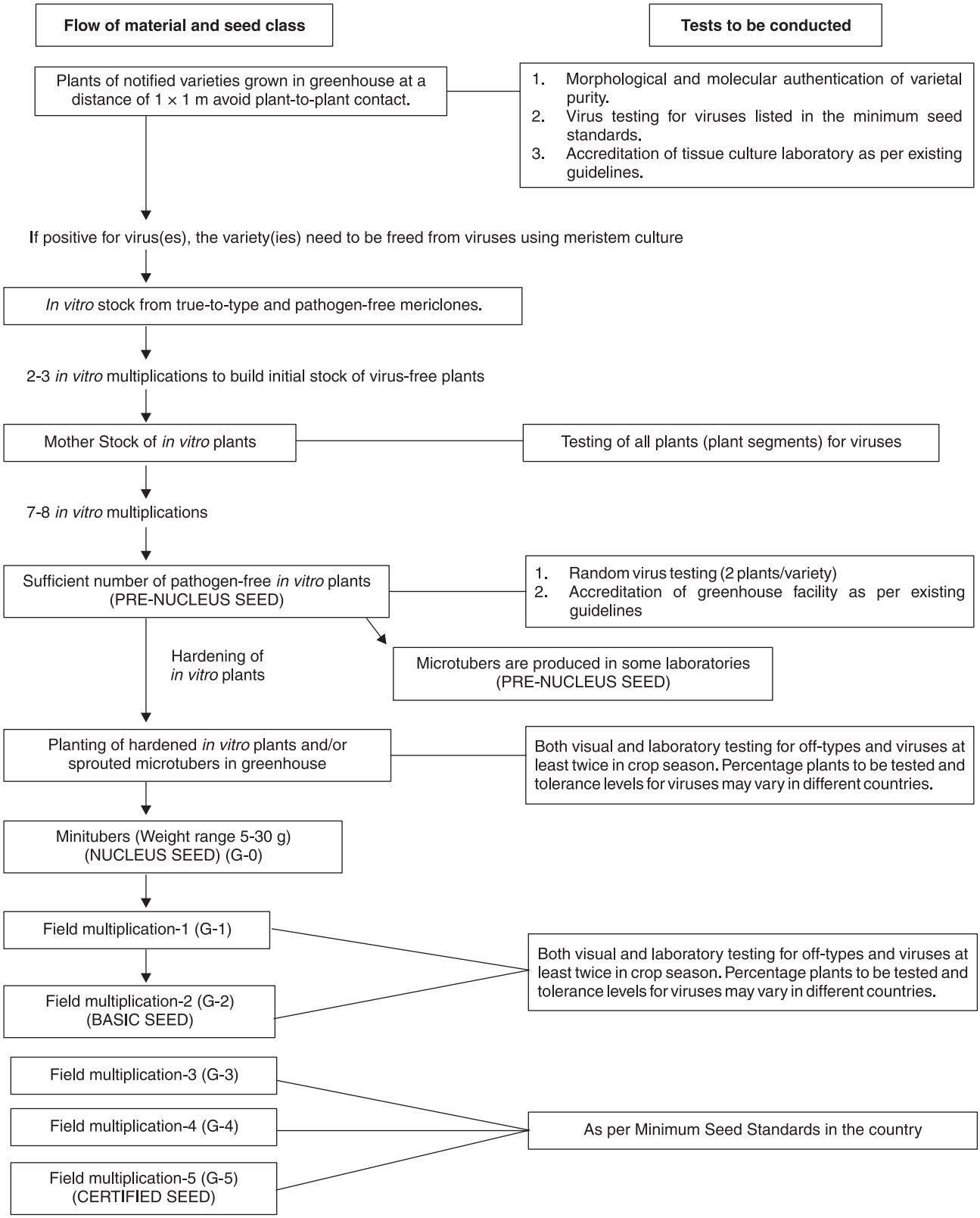

Fig 3 Integration of tissue culture in quality potato seed production

is highly heterozygous, it takes little longer time and the seedling raising is labour intensive.

However, new researches are on to address these issues. Hybrid Potato is one such area which holds promise.

Role of ICAR-CPRI Shimla

The conventional seed production technology based on 'seed plot technique' is successfully being used in India since last five decades for quality potato seed production.

However, the quantity of good quality seed being produced by using conventional method can hardly meet 20–25% requirement. Keeping that in view, ICAR-CPRI, Shimla has standardized a number of hi-tech seed production systems based on tissue culture and micropropagation technologies. Adoption of these systems of seed production will improve the quality of breeder seed, enhance seed multiplication rate and reduce field exposure of seed crop by at least 2 years. The systems were thoroughly tested at seed production farm of ICAR-CPRI before passing them on to farmers and other stakeholders. Adoption of hi-tech seed production systems developed by the institute has led to opening of more than 20 tissue culture production units throughout the country. Several Government/Private seed producing organizations procure virus-free *in vitro* mother cultures of important notified and released potato varieties every year from ICAR-CPRI, Shimla for further multiplication in their hi-tech seed production programmes. The latest hi-tech seed production system standardized by the institute is based on the concept of soil-less, aeroponic technology. The aeroponic system of seed production has the potential to further revolutionize potato seed sector after about 50 years of introduction of "seed plot technique" by the institute. The aeroponic system has been perfected in the year 2011 and so far it has been commercialized to 14 firms from different states like Uttar Pradesh, West Bengal, Punjab and Haryana. Each firm is licensed to produce 10 lakh minitubers by aeroponic system. Even if each firm is operating at half of its potential, about 6.5 million minitubers are currently being produced by those firms. Besides, large number of private companies like Technico, Pepsico, Mahindra-HZPC etc. have developed their own system of minituber production.

Potato tissue culture raised minitubers (PTCMT) have also been included in the "Indian Minimum Seed Certification Standards". The minitubers (hi-tech seed) so derived are treated as equivalent to Breeder seed. The minitubers can be multiplied in three subsequent generations, i.e. foundation 1, foundation 2, and certified by following the prescribed standard. Site requirements, crop inspection and quality standards for foundation and certified seed production have been prescribed in the "Indian Minimum Seed Certification Standards". At present ICAR-CPRI produces ~ 3,187 metric tonnes of nucleus and breeder seed of 25 popular potato varieties; out of which 70% is through conventional system whereas, 30% through hi-tech systems. As there is limited scope to increase quantity of breeder seed production at ICAR-CPRI farms due to limitation of farm land, possibilities are being explored with the help of SAUs/KVKs/Pvt. farmers to identify the new areas of seed production, multiplication of breeder seed into FS-I, FS-II and Certified Seed under MoU and to produce seed through hi-tech systems with the help of entrepreneurs/ private companies.

Future prospects

In mitigating the problem of shortage of good quality seeds, strategies to multiply the seed tubers such as tissue culture in conjunction with aeroponic systems have been tried. These technologies needs to be given serious thought and should be promoted in developing countries so as to increase potato yields. In areas having high disease pressure, the new system of seed potato production based on micro-propagation and aeroponics has the advantage of better health status of seed stocks due to the reduced number of field multiplications over the conventional (clonal multiplication) system. In terms of the need for a greater efficiency of seed potato production and for a reduced energy input, research on soil-free techniques will continue to be the subject of focus in both established and developing potato-producing areas, in the near and distant future. Advances in engineering technology will also assist in the development of more automated and controlled seed propagation systems. However, there are also options for simplifying the seed potato production systems for adaptation to low-technology situations, which has greater scope and relevance towards the increasing trends of potato production in developing countries.

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