REVIEW ARTICLE

Emerging seed production technologies of potato in India

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India, known as the world's second-largest potato producer, understands how crucial good seed is for potato farming. But there are hurdles in the seed production process: high seed rates, slow multiplication, viral infections and problems with storing and moving the seeds. This leads to a lot of edible food being used as seed instead of being eaten and it costs a lot-about 40%-50% of total production expenses. One big issue is that not enough farmers are using newer, better potato varieties because it's tough to get enough good seeds and they have to keep replacing them often. To tackle these problems, scientists are working on faster ways to produce healthy seeds in big batches to meet the demand in India. Around the world, people have been shifting from old-fashioned to high-tech seed production methods since the early 1900s. Especially in hot places, like tropical areas, there's hope that creative ideas can make producing potato seeds easier. In India, there are new ways of making potato seeds that show things are changing. But there are still problems, so it's important to keep researching and improving to overcome them.

Key Words: *Potato; Micro-propagation; Aeroponics; True potato seed; Potato diploids*

INTRODUCTION

India is seeing a rise in the popularity of potatoes (*Solanum tuberosum* L), which account for 11.3% of the world's potato acreage and 12.5% of its total production. India produced an average of 23.77 tons/ha of potatoes during the 2019-2020 harvest season, harvesting about 51.3 million tons from 2.16 million hectares. The creation of improved potato varieties suitable for sub-tropical climates and technological developments have been the driving forces behind the 3.28 and 18.87-fold increases in potato production and productivity in India, respectively, between 1961 and 2020. However, there are still issues with potato production in India. These include a lack of high-quality seed, a lack of different potato varieties with favorable economic qualities for growers and a lack of infrastructure for storage. Crop productivity is directly impacted by inadequate supply of high-quality planting material [1]. The production of seed potatoes and its supply chain face a particular challenge due to the bulky nature of the seeds, high seed rates and sluggish multiplication rates (five to six times). Potatoes degrade quickly due to vegetative multiplication utilizing tubers as seeds, thus it's best to replenish the seeds every year or every two years. Furthermore, because of their high cost, farmers are either unable to afford quality seeds or cannot obtain them in sufficient quantities. The nation's small number of aphid-free, seed-producing locations exacerbates problems associated to seeds. According to studies, using just premium seeds can boost output by 15%-20% [2].

In India, there exists a significant disparity between the demand and supply of certified seed potatoes. Annually, the Central Potato Research Institute (CPRI) under the Indian Council of Agricultural Research (ICAR) produces approximately 2,400 tons of breeder's seed or basic seed. Of this quantity, 80% is distributed to states and other organizations for multiplication purposes. However, the total volume of certified seed generated through the three stages of multiplication-foundation 1, foundation 2 and certified grades-amounts to only around 0.5 million tons. This falls short of meeting the overall seed requirement, assuming a 100% Seed Replacement Rate (SRR), leaving a deficit of nearly 4.9 million tons [3]. Singh et al., [4] illustrate the traditional methodologies employed in seed potato production, involving the generation of breeder's seed after four field multiplications of nucleus seed on ICAR-CPRI research farms. Subsequently, three additional field multiplications are conducted as foundation 1, foundation 2 and certified seed by respective states. However, this conventional system encounters challenges such as low rates of field multiplications, the necessity for a large quantity of disease-free propagules at the outset and the accumulation of degenerative viral infections with each field exposure [5]. Additionally, the breeder's seed provided by ICAR-CPRI often fails to multiply in the three generations recommended by the states.

Approximately 1.2 million tons of properly labeled potato seed are retailed by private seed manufacturers, primarily in Punjab, western Uttar Pradesh, West Bengal and Haryana. Nevertheless, these producers lack the infrastructure and appropriate methodologies to monitor seed quality effectively. Consequently, it becomes imperative to establish a seed production system incorporating advanced techniques to enhance seed quality, diminish field exposures and implement a robust certification and quality assurance framework for seed cultivated and distributed by private producers. This brief overview aims to spotlight ongoing developments in India's seed potato industry.

LITERATURE REVIEW

New developments in the production of seed potatoes

Production of seed potatoes by micro propagation/tissue culture: The integration of micro propagation techniques into commercial seed production has transformed potatoes from laboratory test tubes to actual field cultivation. Initial experiments with tissue culture from potato tubers trace back to 1951. Since then, a wide array of plant tissues from diverse organs including leaves, petioles, internode segments, ovaries, anthers, stems, roots and shoot tips have been successfully cultured [6,7]. The adoption of micro propagation in the production of seed potatoes holds promise for resolving many issues associated with conventional seed production systems [8]. This process typically involves meristem culture to eliminate viruses. To enhance the likelihood of generating virus-free plants, meristem culture is often combined with thermotherapy and/or chemotherapy. Despite meticulous care, obtaining a substantial number of virus-free mericlones is often challenging. Therefore, each mericlone intended for use as a source plant in large-scale micro propagation programs must undergo virus testing

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using techniques such as Polymerase Chain Reaction (PCR), Immune Sorbent Electron Microscopy (ISEM) and Enzyme-Linked Immune Sorbent Assay (ELISA) [5]. Subsequently, a rapid tissue culture method is employed to propagate the virus-indexed and pathogen-free mericlones, enabling the generation of significant quantities of pathogen-free cultures [9].

Micro propagation of potato: To initiate the production of new micro plants, virus-free potato mericlones undergo propagation using single-node cuttings and are cultivated in semi-solid or liquid culture media under sterile conditions [7]. For large-scale *in vitro* potato micropropagation, an optimal medium comprises hormone-free Murashige and Skoog's (MS) medium supplemented with 2.0 mg L-1 D-calcium pantothenate and 30 g L-1 sucrose [10]. These cultures are maintained at a temperature of 20 ± 2°C for 16 hours under a photoperiod of 60 μmol $m^{-2}s^{-1}$ photosynthetic Photon Flux Density (PFD). Typically, each culture tube, measuring 25 × 150 mm, accommodates three single-node cuttings with one or two leaves. These cuttings grow into fully formed plants in three weeks from the axillary or apical buds. These micro plants are then subjected to up to ten more sub-culturing's on new culture media, with a three-week gap between each sub-culture. Hence, under controlled conditions, a single culture tube can yield approximately 59,049 micro plants within 7-8 months. Micro propagation, in particular, yields nuclear stock material in the form of micro plants or micro tubers (tubers produced *in vitro*), which are later integrated into potato seed production pipelines [11]. This serves as the foundation for numerous seed potato production systems. Micro tubers, small tubers cultivated *in vitro* under conditions conducive to tuber development are derived from micro plants [9]. These compact, dormant tubers offer advantages in terms of handling, storage, transportation and germplasm conservation [12]. Each tissue culture flask usually produces 15-20 micro tubers, with an average size of 100-200 mg. Micro tubers are essential for producing mini tubers in greenhouse environments, even if they are not frequently utilized for commercial crop cultivation [6]. On order to create mini tubers, micro tubers are averagely planted at a density of 50 per square meter on nursery beds inside aphid-proof net homes. However, the low crop emergence rate of 50%-60% in nursery beds and the comparatively low survival rate of micro tubers (60-65%) have resulted in limited appeal for this technology. The mass synthesis of micro tubers has been investigated using bioreactors. However, the utilization of bioreactors adds to the production costs of micro tubers and has not gained widespread adoption [13].

Mini tubers, which are tiny seed potato tubers, can be grown from plantlets propagated *in vitro* at high densities in glasshouses or aphid-proof net houses [3]. For mini tuber development, micro plants and micro tubers can also be used as planting materials [14]. Mini tubers are generated through this technique by transplanting hardened, virus-free micro plants or micro tubers into net houses. These mini tubers typically undergo duplication in two additional field generations before being distributed to farmers as seeds. This process reduces the number of field exposures of the initial disease-free material.

Lettuce is highly remunerative crop since its production period is short, yield is high and market prices are very high. It has nutraceutical value and is also used in fast food items however; it is a cool season European vegetable. Cultural practices for which have been standardized best temperate climates thus, cultivation of this crop in plains of north India is a major challenge, also since it is eaten fresh and cooked. Lettuce is potential crop for its economic importance, medicinal, nutraceutical, pharmaceutical value and increasing demand for organic products.

Soil-less aeroponic system of potato: In recent years, aeroponics has emerged as a pioneering technology in the potato industry, leveraging healthy *in vitro* plants to facilitate the production of mini tubers [10]. This approach allows for seasonal production while maintaining compliance with strict phytosanitary regulations [15]. Micro plants are positioned on aeroponic chambers, where a nutrient solution is sprayed onto the root zone [10,15]. These chambers are housed within insect-proof net houses and feature detachable plant placement apertures, simplifying the harvesting of mini tubers at optimal sizes at different intervals. Harvesting typically commences 45-50 days after planting, with mini tubers weighing between 3-10 g. Throughout the crop season lasting four to five months, weekly harvesting cycles yield approximately ten to twelve harvests [16]. Aeroponics significantly enhances productivity compared to traditional methods, generating 40-50 mini tubers per *in vitro* plant [3]. The harvested mini tubers are stored at temperatures between 2°C and 4°C for future planting.

Aeroponics has transformed seed potato production in India by providing high-quality seeds, albeit with specific planning requirements, operational costs and the need for standardized nutrient solutions [17]. Tiwari et al., [18] have observed variations in root morphology and yield characteristics among Indian varieties cultivated using aeroponic systems. Meanwhile, in India, potato breeders have also employed Apical Rooted Cuttings (ARCs), an advanced technique. In contrast to aeroponic technology, which demands significant capital investment and a longer production cycle, ARCs offer simplicity, efficiency and a rapid production turnaround [19].

To initiate the process in Apical Rooted Cuttings (ARCs), healthy micro plant stocks serve as the initial material in nursery beds at a density of 400 micro plants per square meter. Over a span of 35-45 days, sequential cuttings are taken from mother plants every 7-10 days. This practice promotes the development of lateral buds and accelerates the multiplication rates of potato plants. Rooted cuttings are then planted beneath insect-proof net houses using the seed plot technique to facilitate tuber production. Pedigree maintenance, which is based on batch, ensures that contaminated plants are identified and eliminated during testing phases [20]. Remarkably, a single cutting has the potential to yield 7-10 tubers weighing between 10-70 g each, with a multiplication rate exceeding 40 depending on the specific cultivar, as per available data. When standard operating procedures are adhered to ensure seed health within the seed production timeframe, this method holds significant promise [21].

Botanically true potato seeds: Dr. S. Ramanujam introduced the concept of True Potato Seed (TPS) in 1949. Similar to conventional botanical seeds, TPS holds the capability to germinate into fully developed plants, resulting in distinct populations due to genetic variability. Achieving homogeneous TPS populations has been the aim of ICAR-CPRI to ensure consistent tuber yields, disease resistance and crop performance. TPS offers numerous advantages over traditional potato seed tubers, including freedom from pests and diseases, ease of storage and transportation and significantly lower seed rates (around 150 g/ha compared to 2.5-3.0 t/ha of seed tubers). In the 1980s, ICAR-CPRI successfully developed three TPS populations: TPSC-3, 92-PT-27 and HPS-I/13. The Indian Minimum Seed Certification Standards establish quality control measures for TPS production.

The economic viability of True Potato Seeds (TPS) in comparison to traditional seed tubers remains uncertain within the dynamics of the potato production system. TPS holds promise as a solution to the scarcity of high-quality potato seed tubers in impoverished nations, as noted by [13]. However, challenges such as delayed maturity of TPS crops, inconsistent germination and variability in the resulting product impede widespread adoption. Nevertheless, the designation of 2008 as International potato year by the United Nations (UN) and the emergence of diploid F1 hybrid breeding have reignited interest in TPS technology [21].

Diploid hybrid True potato seeds: Potatoes, being auto tetraploid and highly heterozygous, suffer from significant inbreeding depression when subjected to self-pollination. However, reducing their ploidy level to diploid and introducing self-compatibility genes can expedite the attainment of homozygosity compared to tetraploid levels, as demonstrated by [22]. Offspring resulting from sexual crosses produce pure, disease-free true seeds, offering top-notch seed quality for potato farmers' worldwide [23].

Originally, diploid potatoes were outbreeding species with a gametophytic self-incompatibility mechanism that prevented self-pollination. However, these potatoes can be genetically modified to allow self-pollination. This can be accomplished by inducing knockout mutations in the incompatibility locus or introducing a dominant self-incompatibility inhibitor gene (*Sli*). Through this process, diploid F1 hybrid breeding facilitates the creation of genetically uniform potato cultivars by crossing two nearly homozygous inbred lines produced through multiple generations of self-pollination despite the challenges of inbreeding depression [24,25].

The resulting F1 hybrid planting material can be made available to farmers in various forms, including mini tubers, young plants grown from true seeds or as true seeds themselves. ICAR-CPRI, along with numerous governmental and private organizations is actively involved in harnessing heterosis in potatoes at the diploid level and developing diploid inbred lines. While tetraploid tuber-based approaches are less advantageous for F1 diploid hybrid breeding using genuine potato seeds, several challenges need to be addressed before this technology can be widely adopted in agricultural settings [23].

RESULTS AND DISCUSSION

Emerging seed production technologies for potatoes in India offer immense potential to boost productivity, elevate quality standards and address challenges like disease susceptibility and climate variability. Here are several promising avenues.

Tissue culture propagation

By enabling the large-scale production of disease-free potato seedlings in controlled settings, tissue culture techniques ensure consistency in seed quality while minimizing disease transmission risks associated with traditional seed tubers.

Hydroponic and aeroponic systems

These innovative cultivation methods provide controlled environments for potato growth, optimizing water and nutrient utilization. Particularly advantageous in regions with limited land or water resources, soil-less systems enhance efficiency and yield.

Genetic engineering and biotechnology

Ongoing advancements in genetic manipulation empower the development of potato varieties with superior traits such as disease resistance, drought tolerance and increased yields. Biotechnological interventions also aid in producing vaccines against prevalent potato pathogens.

Precision farming technologies

Adoption of precision farming tools like remote sensing, GPS-guided machinery and data analytics allows farmers to fine-tune input utilization, monitor crop health and maximize yields. These technologies promote sustainable and effective potato seed production practices.

Protected cultivation

Greenhouse and polyhouse setups offer shielded environments safeguarding potato crops from adverse weather, pests and diseases. Facilitating year-round production, these systems ensure a consistent supply of top-notch seed tubers.

Integrated Pest Management (IPM) strategies

IPM strategies integrate various control measures, biological, cultural and chemical to manage pests and diseases sustainably. By reducing dependence on chemical inputs, IPM practices minimize environmental impact while preserving crop health.

Seed certification programs

Strengthening seed certification initiatives guarantees access to certified disease-free potato seeds for farmers. By advocating for certified seed adoption, these programs bolster crop health, productivity and market competitiveness.

Public-private partnerships

Collaborations among governmental bodies, research institutions and private enterprises facilitate the dissemination and adoption of cutting-edge seed production technologies. PPP initiatives drive research, expedite technology transfer and enhance farmer capacity, fostering innovation in potato cultivation.

Climate-resilient varieties

Breeding programs focused on developing potato varieties resilient to climatic stressors, such as erratic rainfall and temperature fluctuations, address challenges posed by climate change. Climate-smart varieties demonstrate adaptability to diverse environmental conditions, ensuring stable yields.

Capacity building and extension services

Strengthening extension services and providing farmers with training and capacity-building programs on emerging seed production technologies enhances their expertise and decision-making capabilities. Empowered with knowledge and resources, farmers can effectively implement innovative practices, contributing to the advancement of potato cultivation.

Incorporating these emerging technologies and strategies into potato seed production systems in India holds the promise of transforming the sector, fostering food security, sustainable agriculture and economic prosperity for potato farmers.

CONCLUSION

Farmers have the choice of obtaining F1 hybrid planting material in different forms, such as true seeds, mini tubers or young plants grown from true seeds. Organizations like ICAR-CPRI are actively involved in developing diploid inbred lines, capitalizing on potato heterosis at the diploid level. However, before this approach can be widely adopted in agricultural settings, several challenges need addressing, particularly concerning tetraploid tuber-based methods for F1 diploid hybrid breeding using genuine potato seeds. Looking ahead, soil-free cultivation techniques will remain a priority in both developed and developing potato-producing nations, aiming to boost efficiency and cut down energy consumption in seed potato farming. Progress in engineering technology will enable the development of automated and controlled seed propagation systems. Nevertheless, there are opportunities to streamline seed potato production methods to fit low-cost technological setups, catering to potato farmers with limited resources.

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