International Journal of Bio-resource and Stress Management

https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM December 2023, 14(12):1592-1607 Print ISSN 0976-3988 Online ISSN 0976-4038

Article AR4952a

Review Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2023.4952a

Elements Affecting Seed Potato Quality In India- A Review

Murlidhar J. Sadawarti[1], S. P. Singh[2], Tanuja Buckseth[3], Sugani Devi[4], R. K. Singh[5], Vinod Kumar[3], Subhash Katare[1], Brajesh Singh[3], Priyadarshani A. Khambalkar[6], R. K. Samadhiya[1] and Y. P. Singh[1]

[1]ICAR- Central Potato Research Institute, RS, Gwalior, MP (474 020), India
[2]ICAR- Central Potato Research Institute, RS, Patna, Bihar (801 506), India
[3]ICAR- Central Potato Research Institute, Shimla, HP (171 001), India
[4]ICAR- Central Potato Research Institute, RS, Jalandhar, Punjab (144 003), India
[5]ICAR, Indian Institute of Vegetable Research, Varansi, UP (221 305), India
[6]Dept. of Agriculture, Rajmata Vijaya Raje Sciendia Krishi Vishwa Vidyalaya, Gwalior, MP (474 005), India

Open Access

Corresponding murlidharsada@gmail.com

0000-0003-2469-2075

ABSTRACT

Potato has high potential for food and nutritional security. In India, potato cultivation was spread over different states over diverse agro-climatic conditions. Even though edaphic and climatic conditions are suitable for cultivation in India, national average productivity is very low (24.12 t ha^{-1}) as compared to some of the developed countries in the world. Hence with increasing demand of potato, high quality seed is of utmost importance to increasing the productivity. Quality seed is a critical input in potato cultivation and accounts for about 40–50% of the total cost of cultivation. Most significant constraint in lower productivity is attributed to lack of quality seed tubers especially to small and marginal farmers in India. Varietal purity, seed health, physiological age, prevalence of pest and diseases, change in virus vector relationship and poor knowledge of seed selection and ignorance about Seed Plot Technique are the important aspects which affect the seed potato quality. Pre harvest and post-harvest elements *viz* selection of variety, area of seed production/climatic conditions, agronomy/ agro techniques for seed production, improving tuber size, rouging, plant protection measures, harvesting, post harvest handling and storage are the important elements which affect quality of seed potato production. Therefore, this review mainly focuses on the above said factors for the quality seed potato production and further enhancement of the productivity.

KEYWORDS: Pre-harvest, post-harvest factors, quality, seed potato

***Citation* (VANCOUVER):** Sadawarti et al., Elements Affecting Seed Potato Quality In India- A Review. *International Journal of Bio-resource and Stress Management,* 2023; 14(12), 1592-1607. HTTPS://DOI.ORG/10.23910/1.2023.4952a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 10th October 2023 RECEIVED in revised form on 25th November 2023 ACCEPTED in final form on 10th December 2023 PUBLISHED on 21st December 2023

1. INTRODUCTION

Potato is one of the world's most important non-cereal, high yielding horticultural food crop which is native of Peru-Bolivia in the Andes (South America). Initially, it was established as an import cool-season crop in the hills as well as plains in India and mainly grown in the Indo-Gangetic plains and almost in all the States of India under different agro-climatic conditions (Scott and Suarez, 2011). India is the second-largest producer of potatoes in the world and accounts for 11.3% of the global area and 12.5% to global production (Anonymous, 2021). In 2020–2021, India produced 54.23 mt of potatoes from 2.24 mha area with an average productivity of 24.12 t ha^{-1} (Anonymous, 2023). Potato productivity and production in India witnessed 3.28 and 18.87 fold increase, respectively, during the period of 1961–2020 with an average increase of 2% per year, because of successful breeding programs, quality seed systems, and storage infrastructure that have reduced post-harvest losses (Buckseth et al., 2022).

Sustainable potato production depends on constant renewed supply of disease-free planting material, improving quality seed production and seed distribution. Under potato, cultivation, seed is the highest cost-bearing input accounting for 40–50% of the total cost of its cultivation (Venkataslam et al., 2011, Sadawarti et al., 2021a; Buckseth et al., 2022). Poor seed quality, lack of availability, limited access to high-quality seed, lack of access to preferred and adapted varieties, and inefficient seed systems is the major problem in higher productivity in potato (Anonymous, 2016; Singh et al., 2016; Bentley et al., 2018). More than 90% of seed potatoes in developing economies is produced in the farmer-based category and is of poor quality (Thomas-Sharma et al., 2016). Effective seed systems are generally described as providing access to quality planting material, at the time needed, at a fair price, to all who need it (Sperling, 2008). In wealthier countries, >90% of potato seed is obtained through formal certification systems (Frost et al., 2013; Young, 1990). The seed is also acquired informally by producing it on-farm or by sourcing from local markets, neighbors, traders, or decentralized multipliers (Coomes et al., 2015; Gildemacher et al., 2009) in low- and middle-income countries (Louwaars and de Boef, 2012; Thiele, 1999; Thomas-Sharma et al., 2016). India projects to produce 70 mt of potato from an area of 2.6 mha with a productivity of 27 t ha^{-1} by 2030. Hence there is increasing seed potato demand. To bridge the gap between the demand and supply of seed potatoes, it is imperative to develop seed potato hubs at farmers' level and this would certainly help to meet the future seed requirements (Singh et al., 2016).

Potato is a low temperature crop and grows well between 12 to 28°C in hills and 8–28°C in the plains. The optimum temperature is 18–22°C for foliar growth and 10–16°C is good for tuberization and bulking of the crop. The crop is grown under long days in the hills. A minimum photoperiod of 8–10 hours is necessary for optimum yields under short day conditions in the plains. Potato grows well at pH 5.5.to 8.5 in sandy loam, sandy and clay loam soils but the best soil is with pH 6.0 to 7.0. Vector free period from October to January along with soil free from soil and tuber borne diseases are suitable for seed potato production (Sharma et al., 2021; Sadawarti et al., 2023).

The seed potatoes of positive selection and seed plot technique supplements the high quality certified seed (Huda et al., 2021). The combination technology like application of plastic shade and mulch plastic increases improves the seed quality (Setiyo et al., 2021). Planting potatoes with medium (35–45 mm) seed tubers under Indian condition (Kumar et al., 2021) and 28–60 mm under Ukrainian conditions (Myronova et al., 2023) improves seed yield and quality. Seed potato quality can be maintained by planting the seed crop at appropriate time (Huda et al., 2023).

Appropriate seed tuber size has very important implication on potato production. The highest values of tuber yield was established with planting of seed tuber sizes of 35–45 mm under Angola conditions (de Almeida et al., 2016). The number of sprouts that develop from a seed tuber is influenced by the size of seed tuber. In larger tubers, growth is faster because of greater food reserve availability for each sprout and generally produce more sprouts which may result in the production of too many stems and eventually produce too many tubers (Dagne, 2015). If larger seed is used, a greater quantity of seed is required for planting per unit area. It is avoided because it increases seed costs and reduce planter's accuracy (Singh and Kushwah, 2010). Conversely, smaller seed size tubers have less sprouts per unit due to the lesser amount of reserves available for sprout growth leading to small number of stems that produce only a few tubers, thereby reducing yield (Dagne, 2015). Big size seed will increase cost and seed that are too small may rot before emergence (Wang, 2008). Hence the plantable tuber size for potato production is 30–50 g for gaining maximum production potential from field (Islam et al., 2012). Low variation of tuber size is desirable in seed production (Dimante, 2019)

Nonetheless, potato production in India is still constrained by scarcity of varieties having diverse economic attributes that give better options to the potato growers; inadequacy of quality seed, and shortage of storage infrastructure. Most important among these is the inadequacy of quality planting material, as it has a direct bearing on crop productivity (Singh and Sharma, 2018). Potato being bulky requiring higher seed rate and slow rate of seed multiplication (five to six times) pose a unique challenge to seed potato production and its supply chain (Young, 1990)

2. IMPORTANCE OF QUALITY SEED IN POTATO

Like other crops high yields of potato (*Solanum tuberosum* L.) revolves around use of high-quality seed potatoes. Since potato is a vegetatively propagated plant, fungal, bacterial and especially viral diseases easily affect seed tubers which are responsible for fast degeneration, requiring seed replacement after every four years. Additionally, the quality seed is either unavailable or out of the reach of poor farmers owing to high seed cost. The seed related issues are further intensified due to restricted accessibility to seed producing regions, transportability of quality seeds. One major constraint resulting in lower productivity in the country is the use of poor-quality seeds (Anonymous, 2015).

3. SEED PLOT TECHNIQUE

Technology that revolutionized potato cultivation in India is the innovative technique of producing healthy planting material in the sub-tropical plains of India that is popularly known as "Seed Plot Technique". Technology is based on a simple but profound observation on population dynamics of the virus vector and basic principles of low aphid period of at least 70-75 days for growing seed crop (Sharma et al., 2022). Essentially, the potato seed production programme is based on elimination of the prevalent viruses in a given region from the seed stock and its further multiplication under vector free/low vector pressure conditions (Singh and Sharma, 2018). Seed production is very technical aspect and needs careful attention during all stages like date of planting, spacing, fertilization, top-dressing, irrigation, roguing, weeding, earthing up, spraying of pesticides, date of dehaulming, harvesting, etc (Mahmud et al., 2009). Any mistake or laziness at any stage of seed potato production can hamper the quality of seed. Hence with this background various preharvest and post harvest parameters which can affect seed potato quality are discussed in this review.

4. ELEMENTS AFFECTING SEED POTATO TUBER QUALITY

In India, aspects of seed potato tuber quality like purity, genetic quality, health, size, physical damage and physiological age are serious problem because of varietal mix-up, poor storage mechanisms, prevalence of diseases and pests and poor knowledge of seed selection. According to Hirpa et al. (2010) a quality seed tuber, can be defined as the ability of a seed tuber to produce a healthy, vigorous plant that produces a high yield of good quality within the time limits set by the growing season into which the seed is going to be used. Seed tuber quality is affected by seed health, physiological age and status, seed size. In potato growing areas of India majority farmers use seed potatoes of unknown origin.

In India, ICAR- Central Potato Research Institute (CPRI) produces about 2,400 tonnes of breeder's seed (basic seed) every year and supplies 80% of it to the states and other agencies for its multiplication (Anonymous, 2020; 2021). If this stock has to multiply in three stages, i.e., foundation 1, foundation 2, and certified grades (as per norms), we can produce only about 0.5 mt of certified seed. On the assumption of a 100% seed replacement rate (SRR), it meets only 10% of the total seed requirement, leaving a deficit of about 4.9 mt (Buckseth et al., 2020). The situation is further aggravated by the fact that the breeder's seed supplied by ICAR-CPRI is seldom multiplied in three recommended generations by the states. About 1.2 mt of correctly labeled potato seed are sold by private seed producers, especially those from Punjab, western Uttar Pradesh, West Bengal, and Haryana, without any mechanisms and infrastructure for monitoring the seed quality (NAAS, 2021, Buckseth et al., 2022). Hence there is a huge gap between demand and supply of quality seed.

Farmers in India, especially the marginal and small farmers, rarely store their harvests as seeds for the next growing season. Often, they buy seed potatoes every season, making the seed replacement rate (SRR) almost 100%. Most of the farmers cited the inadequate availability and high price of certified seed as main reason for low SRR. Next in importance was the untimely availability of seed. Distant location of the source of seeds and non-significant perceived difference in yields between certified and quality seeds procured from local traders who were sourcing the seed in turn from Punjab accounted the main reason of, low SRR. Also, quality seed from local trader was available on credit that was not the case with certified seed (Kumar et al., 2004). Farmers in India often have four major sources of seed: seed purchased from a formal seed industry, seed purchased from informal seed industry, seed obtained from other farmers and self-retained seed from the previous year's produce (Kumar et al., 2004). There is no institutional mechanism to monitor the quality of seed potatoes. Most often, degenerated produce is sold as seed, especially to small and marginal farmers who lack finances (National Academy of Agricultural Sciences (NAAS, 2021).

Non availability of quality seed was considered as major problems faced by potato growers in eastern UP (Kumar et al., 2021). In North-Eastern-Hill (NEH) regions, farmers used maximum quantity (about 91%) of self-retained seed from the previous autumn crop for potato cultivation and there is no standard seed supply system (Sidhu et al., 1997). These regions, being situated far from the northern seed producing areas cannot afford to procure healthy potato seeds. Therefore, farmers are compelled to use locally available degenerated seed stocks year after year which results into low yield (Ali et al., 2013). Successive multiplication of seed tubers in the field magnifies the risk of infection and build-up of several bacterial, fungal, nematode and viral pathogens. Degenerated seed lowers the productivity to the extent of about 40% (Salazar, 1996). Production of quality seed locally by the growers is very much important option (Ali et al., 2013) and development of storage, grading facilities, processing centre, institutional and technical support are crucial for success of potato seed production at farmer's level (Layek and Mula, 2021). The most important elements affecting seed are pre and post harvest elements.

4.1. Pre-harvest elements

Postharvest management starts with pre-harvest managements (Guluama, 2020). The quality of potato tuber seed is established in the field and can only be preserved during post-harvest. Thus, it is of utmost importance to consider the pre-harvest factors that allow us to maximize the quality of the vegetables going into storage. Abiotic factors influencing tuber maturity, cultivar- and season-variability have great impact on final quality (Driskill et al., 2007). Vine desiccation is another factor which strongly impacts quality; it triggers both maturation of the tuber periderm and stolon release, and in seed potato production it can also control tuber size. To manage all these variables a multifactorial approach is recommended to mitigate side effects which may affect quality (De Meulenaer et al., 2008). The details of the pre harvest elements that affect the quality of potato seed tuber are discussed as:

4.1.1. Agronomic practices

The aim of crop husbandry varies between seed and ware potato production system. High rate of multiplication, maintaining health and optimum physiological quality of seed tuber are the main focus in seed potato production whereas, in ware potato production system, high yield and disease control up to economic level as well as consumption and processing quality of tubers are given priority. However, the final quality and quantity of potato yield is determined by the quality of the potato seed tuber used at the time of planting (Struik and Wiersema, 1999). Production of better quality seed potato could be achieved by following appropriate practices starting from site selection, timely application all inputs like nutrients, water and crop protection measures.

4.1.1.1. Soil/ field preparation

Potato grows well at pH 5.5.to 8.5 in sandy loam, sandy, and clay loam soils but the best soil is with pH 6.0 to 7.0. Potato crop production demands well prepared soil even than other crops, since expansion of tuber needs enough amount and optimum textured soil and also for ease of harvesting. Moreover, ploughing regulates soil temperature and the moisture level of the soil and the growth of sprout influenced positively as the soil temperature is warmer as far as the soil has adequate moisture level (Pavek and Thornton, 2009). In plains, summer ploughings should be done during May-June and prepare the fields for potato planting in September-October. Three years crop rotation during seed potato production should be followed to prevent build up of soil-borne pathogens in the field. Growing vegetable of solanaceae family like tomato, brinjal, chilli, capsicum, okra and cucurbitaceous crops should be avoided in the potato seed production fields as they are common host for some of the potato viral, fungal and bacterial diseases (Venkataselam et al., 2018). Raising and ploughing under the 45–55 days old green manuring crops of sunhemp (*Crotalaria juncea*) or dhaincha (*Sesbania aculeata*) during rainy season at least one month before potato planting for proper decomposition is beneficial in reducing pest and disease incidence. Dhaincha should be preferred over sunhemp in neutral to slightly alkaline soils however sunhemp should be preferred in neutral to slightly acidic soils. (Sharma et al., 2021).The seed crop is separated from crops meant for "ware' purpose by a distance of at least 25 meters to avoid mixture and spread of viral diseases. An isolation distance of 05 meters is also required between different varieties of the seed crop (Anonymous, 2013; Sharma et al., 2021).

4.1.1.2. Planting time and depth

An appropriate planting time is important since the growing condition, which the crop faces afterwards, determined by the time of planting (Struik and Wiersema, 1999). Planting before the optimum window tends to reduce yields by exposing the crop to abiotic and biotic stresses, such as unfavorable soil conditions and insect vectors particularly thrips and whiteflies which tend to reduce yield. Likewise, planting after the optimum window also reduces potential yield by reducing the days available for plant growth and tuber bulking (Thornton and Nolte, 2005). Moreover, potato crop emergence impeded under hot and cold soil environment resulting with poor crop stand (Struik and Wiersema, 1999). As per seed plot technique schedule of planting, dehaulming and harvesting for different regions is described under table 1 which should be strictly followed for high quality seed potato production. Optimum planting time for potato crop is the period having temperature maximum 30–32°C and minimum 18–20°C. In seed crop, the aphid free period of growth is also an important consideration. Planting must be completed in a time schedule to ensure 75–85 days of low aphid period for crop growth (Sharma et al., 2021).

Table 1: Schedule of planting, dehaulming and harvesting for different regions of India

Location	Planting	Dehaulming	Harvesting
Punjab and Haryana	Oct. 7	Dec. 31	Jan. 15
NW and central plains	Oct. 15	Jan. 10	Jan. 25
Eastern UP and MP	Oct. 31	Jan. 15	Jan. 31
Bihar, WB and Orissa	Nov. 7	Jan. 20	Jan. 31

Appropriate planting depth is one of the main agronomic practices required for potato production. This is because; potato tuber which is the economical part of the crop is produced underground. Early development, below ground morphology, tuber expansion, yield and tuber quality are among the aspects affected by planting depth (Pavek and Thornton, 2009). Moreover, planting depth determines the time and energy the sprout requires to emerge, thereby early establishment and vigour are affected which are vital in seed potato production (Struik and Wiersema, 1999). For instance, deep planting may result in delayed ground cover. Gholipour (1996) reported that the number of generative tubers per plant and unit area decreased with increasing the planting depth like reduction in the number of stems. On the contrary, deeper planting help to overcome tuber greening, exposure of tuber to external environments, water shortage and to reach the expected yield. Planting potato in shallow depth results with declined marketable yield and gross income from potato crop production. This is because, in case of shallow planting depth, rapid sprout emergence restricted by less soil moisture content. Seed tubers should placed at a depth of 5–7 cm from top of the ridges made manually or by tractor drawn implements (Sharma et al., 2021).

4.1.1.3. Plant population/spacing

Potato crop needs to get enough intra and inter row spacing to allow maximum inititation of number of stems / plant as well as an optimum number and better quality tuber formation. The optimizing of plant density is one of the most important subjects of potato production management because it affects seed cost, plant development, yield, and quality of the crop (Bussan et al., 2007, Sadawarti et al., 2021b). An ideal combination of plant population, row width, and in-row seed spacing for a particular variety were the major factors for optimizing tuber size (Rex and Mazza, 1989). Planting of seed tubers on ridges is widely followed method with some modifications from place to place (Mishra, 2013). Under Indian condition, in the plains inter-row spacing for planting seed crop manually, bullock and tractor drawn implements may be kept at 40–45, 50–55 and 60 cm, respectively. Planting of seed-sized tubers of 30–40 g at 60 cm inter and 20 cm intra-row spacing is best for seed potato production under seed plot technique (SPT). However, for best results in terms of net yields (total yield/ seed used), returns and optimum proportion of seed-sized tubers in the produce, the adjustment of spacing according to the size of seed tubers is essential and to keep the seed rate reasonably within limits (32-35 q ha^{-1}) without sacrificing the total tuber yield (Sharma et al., 2021).

A plant population of about 1 to 1.1 lakhs hills ha^{-1} to ensure a stem density of 40-45/m^2 is adequate for best results. Plant the large size tubers by increasing the intra-row spacing from 20 to 30 cm depending upon the size of seed tubers. Small-sized tubers are planted at reduced intra-row spacing (Sharma et al., 2022).

4.1.1.4. Seed tuber size

Size of seed tuber is an important factor to decide the seed per unit area because it affects total yield and graded or marketable tuber yields (Singh and Kushwah, 2010 and Dagne et al., 2019). The approximate intra-row spacing for <25, 25-60, 60-100 and >100 g seed size tubers is 15, 20, 25 and 30 cm with inter-row spacing of 60 cm, respectively is suggested under SPT (Sharma et al., 2021). Potatoes to be used for the seed have specific size requirements. If seed tubers are too small, they will have a small number of stems that produce only a few tubers, thereby reducing yield. On the other hand, too big seed tubers may result in the production of too many stems, which eventually produce too many tubers that may compete for growth factors in soil and become too small. Thus, such tubers will be unmarketable for use as seed potato. Besides, too big tubers will be too bulky and uneconomical to use as seed or increase the cost to transport. Therefore, potato seed producers should aim at producing medium-sized tubers (Devi et al., 2022).

4.1.1.5. Water/irrigation management

A potato crop is sensitive to water shortage. Hence, to meet the water requirement and reach with high quality and quantity of final potato tuber yield, efficient and effective water management is crucial (Pehrson et al., 2010). Irrigation requirements differ with locations, soil types, and cultural practices. Under the condition of limited water supply, higher benefits may be achieved by adopting suitable irrigation and planting techniques. Most potato cultivars are characterized by their shallow rooting system and grown on soil type having low water holding capacity, since this kind of soil is preferable for the ease of potato tuber harvesting. This makes potato crop more susceptible to water stress than a lot of other crop species and tuber yield may be reduced by soil water deficits (Porter et al., 1999, Liu et al., 2006 and Pehrson et al. (2010).

Regular monitoring of soil moisture content, scheduled watering and having water resource and/or irrigation system capable of providing the required amount of water are the most important factors to address effective water management in potato production and thereby to achieve the desired quantity and quality potato tuber production (Pehrson et al., 2010). Pre-planting irrigation before land preparation is beneficial for early and uniform emergence. If pre-planting irrigation is omitted at the time of field preparation, irrigate the crop immediately after planting. First irrigation following planting should be light to minimize damage to the newly formed ridges. Heavy irrigation before emergence leads to anaerobic conditions resulting in rottage of seed tubers, gappy emergence and reduced tuber yields. Second irrigation is given a week after first irrigation. Subsequently, irrigate the crop at 7–10 days' interval depending upon the requirement. Avoid flooding over the ridges while irrigating and irrigate as far as possible in morning and evening hours. In a normal season, potato seed crop 6–8 irrigations are required. Light and frequent irrigations are much better than less frequently given heavy irrigations. Excess moisture makes lenticels prominent due to rupturing and seed tuber quality is impaired. It also promotes certain diseases (Sharma et al., 2022). Stop irrigation at about 10 days before dehaulming in light soil and 15 days in heavy soils. Moisture stress restricts regrowth after dehaulming and hastens curing of peel of seed tubers. The chemical dehaulming is also more effective under moisture stress conditions (Sharma et al., 2022)

4.1.1.6. Nutrient management

Maintaining the fertility of the soil is one of the most important agronomic practices needed to be followed in potato production (Agajie et al., 2007; LeMonte et al., 2009). High nutrient demand on soil for good tuber quality requires high organic matter and nitrogen input (Nesbitt and Adl, 2014). Application of well rotten farmyard manure (FYM) @ 20–25 t ha^{-1} or vermicompost @ 3–4 t ha^{-1} in absence of green manuring is beneficial for seed crop. It improves soils physical, chemical and biological condition, soil fertility and water holding capacity. The FYM/ vermicompost should be incorporated into the soil 20–25 days before planting (Sharma et al., 2021). Reliable supply of recommended amount of fertilizer helps to optimize economics of crop production and minimizes environmental losses (LeMonte et al., 2009). Proper management of N, P, and K fertilizers are considered very important to maximize tuber yield and attain desirable quality. (Gondwe et al., 2020). Potato is particularly sensitive to a steady supply of nitrogen fertilizer (LeMonte et al., 2009). Fertilizer N needs of seed crop are 25–30% lower than the ware crop. Excess N increases the yield of undesirable extra-large size tubers and produces dark green foliage masking the symptoms of viral and mycoplasmal diseases. Masking of symptoms makes detection of infected plants difficult during roguing which is detriment to the quality of seed produced. Crop requires a basal dose of 75 kg N, 60–80 kg P_2O_5 and 100–120 kg K_2O ha^{-1} at planting. The nitrogen fertilizer demands of the potato crop vary between different growing stages which is relatively high during the periods of high tuber growth rates which warrants the importance of split application of nitrogen (LeMonte et al., 2009). Hence Split application through urea is recommended in seed potato production under SPT. The basal dose of N can also be applied through urea by incorporating into the soil at least 48 hrs before planting during field preparation. If seed crop is grown under drip irrigation, nutrient dose in general should be reduced by 25% due to increased nutrient use efficiency on account of splitting/localized applications on demand (Sharma et al., 2021). Recommended schedule of fertilizers for all regions for seed potato production is given in table 2

4.1.1.7. Roguing for healthy seed

Roguing is an important component of seed production, ensuring the desired genetic identity of the subsequent generations that will be used for propagation where fields are carefully examined and off-type plants are removed (Welbaum, 2017). Roguing is an essential practice in the production of healthy seed potatoes in which diseased and off type plants along with tubers and seed pieces are disposed. Such techniques continue to be routinely used by seed producers in seed production systems (Frost et al., 2013).

The affected plants may be diseased, another variety, or simply different. Only plants showing visual symptoms can be rogued. Roguing is particularly important in producing seed potatoes because the crop is clonally propagated. That is, pieces of last year's tubers are planted to produce this year's crop. In most cases, diseases in the seed tubers can infect the developing plants reducing yields and quality. Disease infection during the season, on the other hand, can move to the new tubers and perpetuate the problem. Roguing infected plants breaks this disease cycle, making possible the production of healthy seed potatoes. Since roguing is based entirely on visual symptoms, fields should be in good condition. The crop should be healthy, actively growing, relatively free of weeds, and show no symptoms of frost or herbicide injury, fertilizer deficiency, or water stress; dew and irrigation droplets on the leaves also tend to mask mosaic symptoms.

The plants infected with severe mosaic can be easily identified but it is difficult to identify the plants with mild mosaic symptoms. However, it can be identified by a person who is well trained in identification of virus symptoms. Generally, roguing should be done in the morning hours from 10 to 11 AM after drying of dew and

Table 2: Recommended schedule of fertilizers for seed production

Conventional seed production				Hi-tech seed production			
Stage	Nitrogen (kg ha^{-1})	Phosphorous (kg ha^{-1})	Potassium (kg ha^{-1})	Generation	Nitrogen (kg ha^{-1})	Phosphorous (kg ha^{-1})	Potassium (kg ha^{-1})
Hills							
Stage-I	40	35	35	-	-	-	-
Stage-II	60	50	50	G-0	60	50	50
Stage-III	120	100	100	G-1	120	100	100
Stage-IV	120	100	100	G-2	120	100	100
FS and certified	120	100	100	FS and certified	120	100	100
Plains							
Stage-I	50	30	35	-	-	-	-
Stage-II	75	40	50	G-0	150	60	100
Stage-III	150	60	100	G-1	150	60	100
Stage-IV	150	60	100	G-2	150	60	100
FS and certified	150	60	100	FS and certified	150	60	100
Table potato	180	80	120	Table potato	180	80	120
Processing potato	270	80	150	Processing potato	270	80	150

Venkataselam et al., 2011

evening hours from 3 to 5 PM. Light intensity is to be taken into consideration for better identification of mild mosaic symptoms. In addition to this the direction of movement of person involved in roguing is also important. The person carrying out roguing should always move in the direction of sunlight so that the shadow of his body will help him to judge and identify the diseased plants.

Inspection of the seed crop to remove or rogue out the off type and diseased plants showing mosaic, mottling, veinal necrosis, crinkling and rolling of leaves, marginal flavescence and purple top roll symptoms is essential. The first roguing is done 45 days after planting, Second roguing is done after 60 days after planting and the third is done 75 days after planting or 3–4 days before dehaulming. At each roguing, make it sure to remove the tuber and tuberlets of rogued plants (Sharma et al., 2021).

4.1.2. Climatic factors

Climatic factors influence the production of potato by affecting three phenological phases (Kooman et al., 1996) during pre-harvest. Initially, dry matter is divided between stems and leaves (growth stage II). In the second phase, which starts at tuber initiation, an increasing amount of accumulated dry matter is allocated to the tubers and a decreasing fraction to the leaves (growth stages III and IV). In the third phase all assimilates are allocated to the tubers (growth stage V). Leaf growth stops and photosynthesis eventually stops because of leaf senescence. The duration of the first phase, comprising the development period between emergence and tuber initiation, is shortened by short days and temperatures less than 20°C. Tuber initiation is slower at temperatures over 20°C. The duration of the second phase is affected by temperature with an optimum between 16 and 18°C (Van Heemst, 1986) or 14 and 22°C (Ingram and McCloud, 1984) and by solar radiation. Crop senescence is shortened by high temperatures, especially greater than 30°C (Midmore, 1990). Sarquis et al. (1996) stated that the magnitude of the effect of elevated temperatures on potato growth and final yield is determined by an intricate interaction between soil temperature, air temperature, solar radiation and photoperiod duration

4.1.2.1. Photoperiod /day length

The main climatic factors controlling tuber formation are night temperature and day length (Cutter, 1992). For best yields, potato crop needs long day conditions during growth and short-day conditions during tuberization (Chadha, 2009). Potato plants forms tubers on stolons if conditions for the induction, initiation and subsequent growth of tubers are favorable. Primary stolon's can form branches and can have numerous potential tuber sites. One of the factors determining tuberization is the photoperiod. Tuberization is favored by days shorter than a critical photoperiod (Ewing and Wareing, 1978). The short-day signal triggers a leaf factor that is one of the components of the tuberization stimulus (Struik et al., 1987). Van Dam et al. (1996)

observed that longer photoperiod delayed the onset of tuber growth and the onset of tuber bulking, probably more at higher than at lower temperatures. Longer photoperiods also reduced the relative partitioning rate.

4.1.2.2. Air temperature and light

Potato (*Solanum tuberosum* L.) tuberization is a complex developmental process that requires the interaction of environmental, biochemical, and genetic factors (Kolomiets et al., 2001). Low mean temperatures (15–19°C) under short photoperiod (12 h) are optimal for tuber initiation and early tuber growth (Van Dam et al., 1996). High temperatures interrupt the tuber initiation and bulking, decrease the rate of tuber growth, and assimilate partitioning to the above-ground parts is being favored (Van Dam et al., 1996). Under cool temperatures and short photoperiods, a transmissible signal is activated that triggers cell division and elongation in the sub-apical region of the stolon to produce tuber initials (Amador et al., 2001). Temperatures 15–19°C are optimal for tuber initiation (Van Dam et al., 1996). Tuber induction was influenced mainly by an interaction between cultivar and temperature (Prange et al., 1990). Hence, planting the seed potato crop during favorable temperature is essential for high quality seed production.

4.1.2.3. Soil temperature

Soil temperature has its contribution towards hastening sprout emergence. The rate of development of sprouts from planted seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C, slow at 9°C and is maximized at about 18°C (Guluma, 2020). The time between planting and emergence depends on soil temperature. Accordingly, warmer soil temperature positively affects the emergence as far as the moisture content of the soil is in adequate level. Emergence was linearly related to mean soil temperature and relatively independent of diurnal fluctuations up to an optimum of 22–24°C. At temperatures above the optimum, emergence was inhibited (Sale, 1979).

Management practices, such as planting population density, use of mulch and irrigation might substantially modify the soil temperature regime within the root zone in such a way as to affect stolonization, tuber initiation and bulking, and tuber enlargement at a given site, particularly where solar irradiance availability is shown to be a non-limiting factor for potato production. In order to quantify the effects of organic mulch on soil temperature and soil moisture regimes during the growth of potato, mulch is more effective in cooling dry soils, especially at high irradiance. (Midmore et al., 1986a). Midmore et al. (1986b) showed that mulch increased tuber yield by 20% during the summer in Lima, Peru.

4.1.2.4. Atmospheric humidity and wind

Most of the contributions related to the influence of RH on potato refer to potato storage where RH is an important factor in tuber weight loss and the occurrence and severity of diseases and pests (Guluma, 2020). Wheeler et al. (1989) studied the effect of two RH levels, 50% and 85%, on the physiological responses of three cultivars of potato (Russet Burbank, Norland, and Denali) in controlled-environment rooms under continuous light intensity at 20°C. No significant differences in total plant dry weight were measured between the atmospheric humidity treatments, but plants grown under 85% RH produced higher tuber yields. Leaf areas were greater under 50% RH and leaves tended to be larger and darker green under drier than at more humid atmospheric conditions. The elevated humidity appeared to shift the allocation pattern of photosynthates to favor allocation to the tubers over leaves and stems.

Wind has important effects on potato. Pavlista (2002) reported that leaves injured by lower wind speeds show bronzed areas, brown with a shiny surface, due to the rubbing of leaves against each other. The bronzed areas tend to brittle from drying. When pressed the bronzed areas crack, forming a sharp edged rip through the affected tissue. Under higher wind speeds, leaves not only bronze but also tatter. Tattered leaves typically have a 6 to 25 mm sized tears with irregular brownish borders. Wind also affects transpiration rates and, therefore, photosynthetic activity and crop yield. At sites where winds are frequently strong throughout the year, increased stomatal resistance can cause reduction in potato yield (Pavlista, 2002; Sun and Dickinson, 1997). At such sites, guidelines for the sustainable management of potato cropping systems need an emphasis on windbreak development including height, porosity, and orientation.

4.1.3. Genetic factors

The appropriateness of the variety or genetic quality of the seed is the adaptability to specific growing conditions and biotic or abiotic stresses and its food and processing quality characteristics (Hirpa et al., 2010). Growers have the choice of selecting preferred cultivars prior to planting crop. In potato, a great deal of plant breeding has been done to provide a wide range of varieties with different quality attribute. This can be seen in the wide range potato varieties available to growers for planting based on shapes, sizes, productivity levels, dry matter and taste attributes vary, as well as the ripening times and rates and postharvest longevity (Hewett, 2006). Potato breeding started in India in the 1950s and has contributed significantly to improving production. To date, 70 potato varieties have been released by ICAR-CPRI suitable cultivation in different zones of the country (Sood et al., 2022).

Because of the use of home saved seed, use of seed potatoes of unknown origin from local markets, limited use of resistant varieties, poor storage practices like leaving potato underground un-harvested and only limited adoption of haulm killing and selection practices by farmers, the seed tubers used by most potato producers cannot be healthy (Gulama, 2020).

4.1.4. Pest and disease

Tubers attacked by pathogens undergo gradual degeneration. The degeneration of tubers negatively affects their quality and leads to a yield reduction in subsequent cycles of vegetative reproduction (Thomas-Sharma, 2016). Pathogen and pest build-up in potato seed tubers (seed degeneration) is arguably one of the primary causes of low potato productivity in developing countries (Fuglie, 2007; Gildemacher et al., 2009; Cromme et al., 2010). Potato diseases are caused by fungi, bacteria and viruses, which adversely affect the productivity and quality of the produce. While insects cause direct damage to the crop, they also play an important role in the transmission of viruses. In areas where untreated seeds without proper crop rotation are used, tuber borne diseases like black scurf, common scab, dry rot etc. become serious problems. Among bacterial diseases, bacterial wilt or brown rot is the main problem in some places. Aphids, leaf hoppers, thrips, white flies, mites, potato tuber moth etc. are the typical pests of potatoes.

Essentially, the potato seed production programme is based on elimination of the prevalent viruses in a given region from the seed stock and its further multiplication under vector free/low vector pressure conditions. Earlier six viruses (PVS, PVX, PVA, PVM, PVY, PLRV) and new strains of PVY (PVY^n, PVY^{NTN}) have either been introduced or developed through mutations are major cause of potato plant and tuber degeneration through vector *Myzus persicae*. However, during the last four and a half decades, change in climate, cropping pattern and intensity, expansion in trade and increase in potato acreage has led to drastic change in virus and vector profile. Newer viruses like, potato yellow vein virus, potato yellow dwarf virus, tobacco streak virus, tomato spotted wilt virus, PSTVd were introduced from outside the country. Viruses like apical leaf curl disease of potato and stem necrosis (pea bud necrosis virus) have jumped over from other hosts mainly through overlapping of vector populations (Singh and Sharma, 2018). Fourteen aphid species have been recorded on potato crop in India (Anonymous, 2015) while 65 aphid species have been reported worldwide (Lacomme et al., 2017). Viruses infect potato leaves, stems and tubers. These reduce the size and yield potential of the plants. Two or more viruses may infect a plant simultaneously to cause mosaic symptoms.

Whiteflies are known to transmit *Tomato leaf curl New Delhi virus-potato* (ToLCNDV-potato), also known as potato apical leaf curl virus, posing serious threat to healthy seed potato as well as ware potato production in India. What is more worrisome is that whiteflies are present in nature right from the crop emergence itself. The whiteflies are supposed to have already acquired the virus by the time crop has emerged leading to virus infection right from the crop emergence. Their population starts declining only after the appearance of *Myzus persicae*. This indicates that virus vectors are present all throughout the crop season leaving no growing window for seed production (Singh and Sharma, 2018). Diseases and pest which hampers the quality of seed is given in table 3 and 4

Practicing appropriate crop protection methods are also the other important component of potato production packages to achieve a desired potato seed tuber yield and the overall benefit from the potato production (Laungue, 2020). Additional plant protection measures against aphid, white flies and other vectors transmitting viral diseases are required in the seed crop. Application of granular systemic insecticide, Cartap hyhrochloride 4G @ 20 kg ha^{-1} at the time of planting and again at earthing up takes care of jassids, leafhoppers and white flies at early stages of growth up to 30–35 days. After appearance of aphids sprays of Imidacloprid 17.8% S.L. @ 0.004%, Thiamethoxam (25 WG) @ 100 g a.i. ha^{-1}, Metasystox @ 1 l ha^{-1} alternatively may be repeated at an interval of 12–15 days depending on duration of the crop and infestation. Alternate sprays of these chemicals restrict insects from developing resistance against insecticides. Drenching of the ridges with Chloropyriphos 20EC @ 2.5 l ha^{-1} effectively controls cutworm attack during the early stages of the crop. In white grub prone areas, Chlorpyriphos 20EC @ 4.0 l ha^{-1} should be applied either after mixing with sand or can be sprayed on the ridges before the final earthing up. For control of early and late blight, one prophylactic spray of Mancozeb @ 0.2% is given, it may be repeated at an interval of 7–14 days depending upon the weather condition. It will also take care of other foliar diseases like phoma blight, etc. In case of persistent and severe attack of late blight, spray of systemic fungicides like Curzate M-8 @ 3.0 kg ha^{-1} or Ridomil @ 2.5 kg ha^{-1} may be given and repeat the spray after 7–10 days, if required (Sharma et al., 2021).

4.2. Post-harvest factors

After harvest, tuber quality management aims to delay dormancy break and limit weight loss and sweetening of potatoes. Senescent sweetening is a natural process that occurs as a result of tuber aging; it is irreversible and involves cellular breakdown (Guluma, 2020).

4.2.1. Maturity stage at harvest and time of harvesting

Effects of physiological age on yield are of paramount importance (Gulama, 2020). There are problems in timing of the harvest because of differences in maturity between

Table 3: Diseases affecting seed quality

Sl. No.	Disease	Symptoms
1.	Late blight (*Phytophthora infestans*)	The water soaked patches with whitish cottony growth along the lesion margins on the underside of leaflets in the early morning hours. Skin of tuber become brown, patchy and shrink. Discoloration of underneath tissue of tuber.
2.	Early blight (*Alternaria solani*)	The brown to black, oval, large and circular spots with concentric rings.
3.	Phoma blight (*Phomaexigua, P. sorghina*)	Small spots are brown to black, oval to irregular with variable size.
4.	Leaf blotch (*Cercosporasolani-tuberosi*)	Small chlorotic spots on the upper surface of leaves and a violet mildew on lower surface.
5.	Fusarium wilt (*Fusarium oxysporum*)	Yellowing of margins of lower leaves followed by entire foliage, wilting of few stems followed by entire plant.
6.	Bacterial wilt/brown rot (*Ralstonia solanacearum*)	Dropping and rolling of leaves before wilting, succulent portion of plant becomes flaccid and droops. Wilting becomes permanent. A distinct brown discoloration in the vascular rings of cut tuber with slimy bacterial ooze.
7.	Sclerotium wilt (*Sclerotium rolfsii*)	Light yellowing, dropping and stunting of juvenile plants. Collar region of the stem infected with white mycelium which later on converted into brown mustard like sclerotia. The entire plants wilted and topple.
8.	Charcoal rot (*Macrophomina phaseolina*)	A high temperature disease at harvest. Tubers show black areas around the eyes and lenticels, flesh show black patches.
9.	Wart (*Synchytrium endobioticum*)	Prominent wart like outgrowth on the tubers which resemble cauliflower.
10.	Common scab (*Streptomyces scabies*)	Small radish or brownish spots on tuber surface, spots enlarge into circular or irregular lesions with sunken corky spot or pitted lesions having deep star shaped cracks or russetting of tuber surface.
11.	Powdery scab (*Spongospora subterranea*)	Small coloured blisters like pimples on tuber surface, pustules become dark and epidermis ruptures releasing brown powdery spore mass.
12.	Black scurf (*Rhizoctonia solani*)	Chocolate coloured, crusty scurf like irregular sclerotial mass on the surface of the tubers.
13.	Dry rot (*Fusarium solani*, *F. equiseti*)	Small sunken circular, oval or irregular brown lesions, flesh shows light brown discolouration and white cottony fungal growth.
14.	Soft rot (*Erwinia carotovora*)	Water socked lesions on tuber, tissue turns soft and pulpy/slimy, surfacediscolours with wrinkles and depressions
15.	Pink rot (*Phytophthora erythroseptica*)	Blackening around lenticels and eyes, discolouration of flesh when cut and turns pink after exposure to air within few minutes and later on turns black.

plants. Mature tubers are more desirable for seed and storage than immature ones. In the Indo-Gangetic plains potato digging should be preferably completed by 15th February. Delayed digging beyond February promotes rotting due to soft rot and charcoal rot. Start digging in the plains 10-15 days after dehaulming, when peel is firm to withstand handling operations. Digging may be done either manually by spades or by mechanical potato digger. Exercise care to avoid bruising of tubers during harvesting, handling and transportation. After harvesting, keep potato tubers in heaps on raised beds for about 15 days for hardening of peel and shedding of adhered soil from tuber surface. Heaps of about 1.5 m high and 3.5 m broad at the base and variable length as needed are convenient, effective and economical. Cover the heaps with paddy straw or tarpaulins (Sharma et al., 2021). A wound healing or curing period is necessary to prevent entry of rot organisms and to reduce water loss. Tubers are often bruised and cut during harvesting and pre-storage handling. Regardless of how the stored potatoes are to be marketed, wound healing is essential to minimize the entry areas for ever present disease organisms.

Table 4: Pest of potato affecting seed quality

Sl. No.	Pest	Character/ mode of damage
1.	Aphids (*Myzuspersicae* and *Aphis gossypii*)	Wingless form is green, greenish, yellow or sometimes pinkish with a pair of well developed frontal tubercles. Winged form is with black head and green abdomen with dark patch on dorsal surface.
2.	White-fly (*Bemisia tabaci*)	Tiny, soft, white winged insect found mostly on the lower side of the leaves and suck the sap from succulent leaves.
3.	Thrips (*Thrips palmi*)	Sucking small, slender insect of <1 mm with fringed wings, adhered on the apical portion of the foliage. It will acquire tospo virus only at nymph stage but retain and transmit throughout their life.
4.	Leaf hoppers	Sucking insects and vector for phytoplasmal disease like Purple Top Roll (PTR) and Marginal Flavescence (MF).
5.	Cut worms (*Agrotis ipsilon*, *A. segetum*)	The larval stage causes damage. They are dark grey or dark brown with faint spot/line on the body.
6.	White grub (*Lachnosterna coriacea*, *Melolontha* sp.)	Fleshy, dingy white in color with brown head. Body is curved in an arch.
7.	Tuber moth (*Phthorimaea operculella*)	Larva is 15 to 20 mm with pinkish body and dark brown head. Adult moth has narrow silver grey body with grey body with grayish, brown wings having dark specks. It deposits eggs near the eyes on stored tubers.
8.	Epilachna beetle (*Epilachna ocellata*, *E. vigintiocto punctata*)	Hemispherical, body measuring 5 to 8 mm, posses 12 to 28 black spots on its elytra. The other species have 12 such spots encircled by lighter colour.
9.	Golden/cyst nematode (*Globodera rostochiensis*, *G. pallida*)	The cysts are of golden colour. Adult females are sessile globose or lemon shaped and males are motile and by depleting root cell contents an impair translocation system.

4.2.2. Post-harvest handling

`Potato tubers are harvested, stored, packaged and transported with little care to prevent physical damage to the tuber, most likely because of the low level of knowledge about the consequence of physical damage by all stakeholder involved. Physical damage includes cuts, bruises and holes, inflicted on tubers during harvesting, storage, packaging and transportation. In a study undertaken on seed potato tubers stored on farm by using a traditional storage method, in two districts of the eastern area, Kersa and Alemay, 8% of the tubers were found to be damaged during harvest (Mulatu et al., 2005). The tools used by farmers to dig out tubers from the soil might not be appropriate (too sharp or elongated ending). Physical damage in seed tubers may also occur during storage because of piling of one sack upon the other and lack of ventilation. Potatoes are usually packed in sacks which cannot protect tubers from any external pressure causing bruising and stabbing. Distant transportation takes place by Lorries. In this case, loading and unloading is done by throwing up and down the tuber sacks. The seed tubers may be loaded with other sharp or beneath heavy materials which might cause damage to the tubers (Guluma, 2020).

4.2.3. Potato storage

Proper storage is one of the most important post-harvest criteria that must be met in order to ensure the quality of potatoes. Seed potato storage is a common practice in all potato producing areas. It is very important to save potato seeds from one crop to another, which is about 7–8 months time interval. It is considered most convenient to store seeds in cold storage (Gulama, 2020). Seed potatoes harvested in February have to be stored until October. Thus, cold storage is essential for the storage of seed potatoes. Seed potatoes are best stored at 2–4°C and 90–95% RH, because at this temperature, sprouting does not occur and weight loss is minimum (Ezekiel, 1999, Paul et al., 2016). Under this condition, potatoes remain viable for a long period and therefore these tubers can be used as seed potatoes for planting in the subsequent season (Paul et al., 2016).

The two critical environmental factors involved in properly storing potatoes are temperature and humidity. Storage conditions such as relative humidity, temperature and light affect weight of seed tubers, disease spread, water loss and sprouting (Wustman, 2007, Wustaman and Struik, 2007). Adequate and unrestricted air movement is also necessary to maintain constant temperature and humidity throughout the storage pile, and to prevent excessive shrinkage from moisture loss and decay. High humidity is essential for optimum wound healing during the curing period. It is also essential during the entire storage period to minimize tuber weight loss; weight loss rapidly increases at relative humidity levels below 90%. Do not allow free moisture (condensation) to form during storage. If that does occur, air circulation may be necessary. Thereafter, air movement may be required to maintain the desired temperature and humidity throughout the storage pile. This may also require passing humidified air and/or heated or refrigerated air through the pile.

5. SEED TUBER QUALITY IMPROVEMENT – A WAY FORWARD

There are various ways of campaign the problem of quality of potato tuber seed loss in developing countries like India. The most important of which is improving the skills and knowledge of the stakeholders with respect to Seed Plot technique and the postharvest handling of potato tuber seed. However, the most important, is that appropriate government policies and regulations are needed to be implemented in letter and spirit. Training of all seed potato producers and seed suppliers with respect to the basic science and suitable handling of potato tuber seed at all postharvest stages could significantly reduce quality losses. This training can be delivered by government bodies like ICAR-CPRI, *via* trainings, mass media services, community lectures, demonstration farms, and school curricula. ICAR-CPRI has the mandate of producing of nucleus and breeder seed of potato. It is being done by well established clonal selection of indexed tubers and its multiplication in subsequent stages in field and hi-tech system of tissue culture employed in the micropropagation in which virus free microplants and microtuber followed by minituber production in net house and aeroponic techniques is most important components of high-tech seed production. Aeroponic system is now a days well adopted and being largely used in hi-tech seed production due to various advantages over other system. The percentage of nucleus and breeder seed production in ICAR-CPRI from the conventional system was 72.85 (21204.26 q) and 27.15 (7607.07 q) through hi-tech system during 2022 (Anonymous, 2022). Further Apical Root Cutting (ARC) technology is being standardized at the institute for mass multiplication of apical cuttings for cost effective and farmer's friendly technique for high quality seed potato production.

Moreover, the following points should be considered in improving the quality of potato tuber seed and solving the problems associated with the quality of potato tuber seed.

• Proper technical advice of potato producers regarding Seed Plot Techniques in potato enabling them to produce high quality seed through their own management and use of quality seed leads to increased tuber yields at farm level.

• Top priority should be given to the improvement of seed health in all seed systems.

• Production and supply of quality seed potato should be increased through strengthening private and public sectors enterprises so that farmers can able to replace their existing seeds with quality seed for seed potato production.

• Development of seed potato hubs for increasing quality seed potato production (Singh et al., 2016)

• To remove viral diseases, tissue culture technology (Aeroponic, Apical root cutting) should be disseminated so that farmers can get virus free potato plantlets which they can cultivate within net house for preventing insect vectors to produce quality seed potato. Awareness about Hi-tech seed production methods among farmers.

• Research institutes should take greater initiatives to develop high yielding resistance varieties of potato.

• In climate change scenario, virus-vector relationship is changing, hence there is a need to revisit the Seed Plot Techniques (Singh and Sharma, 2018).

• Concerned authorities and diffusion agencies should give proper attention to disseminate sustainable seed potato production technologies through arranging farmers training followed by establishing seed potato demonstration plots at farmer's field adequately.

• Seed potato growers should be given credit facilities in easy terms and conditions to buy their input materials.

• Besides, sufficient cold storage facilities should be developed in potato producing areas for preservation of their seed potato by utilizing cooperative effort or public private partnership approach

• Organizing farmers into cooperatives also helps to reach more farmers in technology dissemination. (Hossain, 2011, Gulama, 2020).

6. CONCLUSION

Seed potato tuber quality is constrained by both pre harvest and postharvest factors. In the production of potato, quality of seed potatoes is an important determinant of the yield and quality. Hence, improvement of the quality of seed potato within the country is very important for increasing potato production and productivity. Therefore, production system, transportation, storage, marketing and treatment methods should be improved through integrated manner.

7. REFERENCES

Anonymous, 2016. Food and Agriculture organization, Seed security assessment: a practitioner's guide. Rome. Access on 20/06/2023.

Anonymous, 2023. FAOSTAT, Database collection. Food and Agriculture Organization of the United Nations. Access on 22/06/2023.

Anonymous, 2021. National Academy of Agricultural Sciences (NAAS). Innovations in potato seed production. strategy paper No.14 (New Delhi: National Academy of Agricultural Sciences). Access on 12/06/2023.

Anonymous, 2015. Annual report 2014-15. ICAR-Central Potato Research Institute, Shimla, India: 82 pp. Access on 11/06/2023.

Anonymous, 2020. Annual Report Annual Report. Indian Council of Agricultural Research – Central Potato Research Institute, Shimla, Himachal Pradesh, India. Available at: https://cpri.icar.gov.in//11e44298b-584d-4d5c-89ad-c37862d3f9eb.pdf. Access on 11/06/2023.

Anonymous, 2021. Annual Report. Indian Council of Agricultural Research - Central Potato Research Institute, Shimla, Himachal Pradesh, India. Available https://cpri.icar.gov.in//WriteReadData/LINKS/Revised-Final%20annual%20report-2021%20(1)e134bfe2-df23-4cf9-bd20-d252899d1a6e.pdf. Access on 11/06/2023.

Anonymous, 2022. Annual report 2022. ICAR-Central Potato Research Institute, Shimla, India: 47 pp. Access on 10/06/2023.

Anonymous, 2013 Indian minimum seed certification standards. The Central Seed Certification Board Department of Agriculture & Co-operation Ministry of Agriculture Government of India, New Delhi pp 340-345. Access on 19/06/2023.

Anonymous, 2015 National Horticulture Board.. Ministry of horticulture & Farmers Welfare, Government of India. Access on 15/06/2023.

Agajie, T.K., Wachira, M., Gebre, G., Wolde, L., Berga, N., Demeke, 2007. Adoption and impact of potato production technologies in selected districts of Oromiya and Amhara Regions of Ethiopia. Ethiopian Institute of Agricultural Research, Research Report.

Ali, S., Kadian, M.S., Ortiz, O., Singh, B.P., Chandla, V.K., Masood, A.K.H., 2013. Degeneration of potato seed in Meghalaya and Nagaland states in north-eastern hills of India. Potato Journal 40(2), 122–127.

Bussan, A.J., Paul, D.M., Michael, E.C., Drilias, M.J., 2007. Evaluation of the effect of density on potato yield and tuber size distribution. Crop science 47(6), 2462–2472.

Amador, V., Bou, J., Martinez-Garcia, J., Monte, E., Rodriguez-Falcon, M., Russo, E., 2001. Regulation of potato tuberisation by day length and gibberellins. International Journal of Developmental Biology 45(1), 37–35.

Bentley, J.W., Andrade-Piedra, J., Demo, P., Dzomeku, B., Jacobsen, K., Kikulwe, E., 2018. Understanding root, tuber, and banana seed systems and coordination breakdown: a multi-stakeholder framework. Journal of Crop Improvement, 23.

Buckseth, T., Tiwari, J.K., Singh, R.K., Kumar, V., Sharma, A.K., Dalamu, D., Bhardwaj, V., Sood, S., Kumar, M., Sadawarti, M., Challam, C., Naik, S., Pandey, N.K., 2022. Advances in innovative seed potato production systems in India. Frontiers of Agronomy. 4:956667. doi: 10.3389/fagro.2022.956667.

Buckseth, T., Singh, R.K., Tiwari, J.K., Sharma, A.K., Singh, S., Chakrabarti, S. K., 2020. A novel sustainable aeroponic system for healthy seed production in India-an update. Indian Journal of Agriculture Science 90(2), 243–248.

Chadha, K.L., 2009 Handbook of horticulture, ICAR, New Delhi.

Coomes, O.T., McGuire, S.J., Garine, E., Caillon, S., McKey, D., DeMeulenaere, E., Jarvis, D., Aistara, G., Barnaud, A., Clouvel, P., Emperaire, L., Louafi, S., Martin, P., Massol, F., Pautasso, M., Violon, C., Wenc´elius, J., 2015. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. Food Policy 56, 41–50.

deAlmeida Fernando, M., Sanchez, J.A, Noval, W.T., Juan, A., Rodriguez, C., 2016. Effects of different plant spacings and seed tuber sizes on some morpho-productive characteristics of potato in huambo, angola. Cultivos. Tropicales 37(2), 88–95.

Dagne, Z., 2015. Effect of seed tuber size and plant spacing on yield and quality of potato. MSc Thesis Submitted to Haramaya University,Holetta Ethopia

De Meulenaer, B., De Wilde, T., Mestdagh, F., Govaert, Y., Ooghe, W., Fraselle, S., 2008. Comparison of potato varieties between seasons and their potential for acrylamide formation. Journal of Science Food and Agriculture 88, 313–318. doi: 10.1002/jsfa.3091

Devi, S., Sadawarti, M., Kaur, R.P., Singh, S., 2022. Manipulation of tuber size in potato. Advances in Horticulture–25, 31–52. AkiNik Publications, New Delhi.

Dimante, I., Mezaka, Z., 2019. The effect of Minituber Weight on their Field Performance under a Northern European environment. Agronomy Research 17(2), 396–407.

Ezekiel, R., Vijay, P., Singh, J., Shekhawat, G.S., 1999. Potato storage in India. Indian Farming 49(9), 21–25.

Frost, K.E., Groves, R.L., Charkowski, A.O., 2013. Integrated control of potato pathogens through seed potato certification and provision of clean

seed potatoes. Plant Disease 97, 1268–1280.
Gholipour, M., 1996. Desirable to determine the weight and depth of planting apple land, measuring performance and growth analysis. Msc Thesis, University of Tabriz, Iran.
Gildemacher, P.R., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W.W., Struik, P.C., 2009. A description of seed potato systems in Kenya, Uganda and Ethiopia. American Journal of Potato Research 86, 373–382.
Gondwe, R.L., Kinoshita, R, Suminoe, T., Aiuchi, D., Palta, J.P., Tani, M., 2020. Available soil nutrients and npk application impacts on yield, quality, and nutrient composition of potatoes growing during the main season in Japan. American Journal of Potato Research 97(3), 234–245.
Guluma, D.A., 2020. Factors affecting potato (*Solanum tuberosum* L.) tuber seed quality in mid and highlands: a review. International Journal of Agriculture and Agribusiness 7(1), 24–40.
Hewett, E.W., 2006. An overview of preharvest factors influencing post harvest quality of Horticultural products. International Journal of Postharvest Technology and Innovation 1(1), 4–15.
Hirpa, A., Miranda P.M.M., Tesfaye, A., Lommen, W.J.M., Lansink, A.O., Tsegaye, A., Struik P.C., 2010. Analysis of seed potato systems in Ethiopia. American Journal of Potato Research 87, 537–552.
Huda , M.S., Hossain S.M.M., Islam, A.T.M.S., Hannan, A., Hossain, J., Islam, M.R., 2023. Production of disease free seed potato tuber through optimization of planting and haulm pulling time. Bangladesh Journal of Agriculture 48(1), 19–39.
Hudaa, M.S., Islamb, M.R., Hannanc, A., Islamd, S., Hossaind, S.M.M., 2021. Seed quality assessment of farmer's produced seed potato. Plant Physiology and Soil Chemistry 1(2), 41–44.
Islam, M.S., Moonmoon, S., Islam, M.Z., Waliullah, H., Hossain, M.S., 2012. Studies on seed size and spacing for optimum yield of potato in northern region of Bangladesh. Bangladesh Journal of Progressive Science and Technology 10(1), 113–116.
Kolomiets, M.V., Hannapel, D.J., Chen, H., Tymeson, M., Gladon, R.J., 2001. Lipoxygenase is involved in the control of potato tuber development. Plant Cell 13, 613–626.
Kooman, P.L., Fahem, M., Tegera, P., Haverkort, A.J., 1996. Effects of climate on different potatogenotypes 2. Dry matter allocation and duration of the growth cycle. European Journal of Agronomy 5, 207–217.
Kumar, N.R., Pandey, N.K., Dahiya, P.S., 2004. Potato seed replacement in West Bengal. Potato Jouranl 31(1–2), 43–48.
Kumar, V., Aulakh, C.S., Kaur, J., 2021. Effect of planting geometry and potato seed tuber size on weeds and potato tuber yield. Indian Journal of Agricultural Sciences 91(10), 108–111.
Lacomme, C., Pickup, J., Fox, A., Glais, L., Dupuis, B., Steinger, T., Rolot, J.L., Valkonen, J.P.T., Kruger, K., Nie, X., Modic, S., Mehle, N., Ravnikar, M., Hulle, M., 2017. Transmission and epidemiology of Potato virus Y. In, potato virus Y: Biodiversity, pathogenicity, epidemiology and management. Lacomme et al. (eds). Springer International Publishing AG.
Layek, N., Mula, G., 2021. Economics of potato seed production– an analytical study from terai zone of West Bengal. International Journal of Economic Plants 8(3), 149–155.
LeMonte, J.L., Taysom, T.W., Hopkins, B.G., Jolley, V.D., Webb, B.L., 2009. Residual soil nitrate and potato yield with polymer coated urea. Western Nutrient Management Conference 8, 77–81.
Louwaars, N.P., de Boef., W.S., 2012. Integrated seed sector development in Africa: a conceptual framework for creating coherence between practices, programs, and policies. Jornal of Crop Improvement 26, 39–59.
Mahmud, A.A., Akhter, S., Hossain, M.J., Bhuiyan, M.K.R., Hoque, M.A., 2009. Effect of dehaulming on yield of seed potatoes. Bangladesh Journal of Agricultural Research 34(3), 443–448.
Midmore, D.J., Berrios, D., Roca, J., 1986a. Potato (*Solanum* spp.) in the hot tropics. II. Soil temperature and moisture modification by mulch in contrasting environments. Field Crops Research 15, 97–108.
Midmore, D.J., Roca, J., Berrios, D., 1986b. Potato (*Solanum* spp) in the hot tropics. III. Influence of mulch on weed growth, crop development, and yield in contrasting environments. Fields Crops Research 15, 109–124.
Mishra, A.C., 2013. Increasing profitability and resource conservation through paired-row planting geometry in potato. Potato Journal 40(2), 180–183.
Mulatu, E., Osman, E.I., Etenesh, B., 2005. Improving potato seed tuber quality and producers' livelihoods in Hararghe, Eastern Ethiopia. Journal of New Seeds 7(3), 31–56.
Myronova, H., Tymoshchuk, T., Voloshyna, O., Mazur, O., Mazur, O., 2023. Formation of seed potato yield depending on the elements of cultivation technology. Scientific Horizons 26(2), 19–30.
Pavek, M.J., Thornton, R.E., 2009. Planting depth influences potato plant morphology and economic value. American Journal of Potato Research 86, 56–67.
Paul, V., Ezekiel, R., Pandey, R., 2016. Sprout suppression

on potato: need to look beyond CIPC for more effective and safer alternatives. Journal of Food Science and Technology 53(1), 1–18.

Pavlista, A.D., 2002. Environmental effects. Nebraska Potato Eyes 14, 1–4.

Pehrson, L., Mahler R.L., Bechinski, E.J., Williams, C., 2010. Water management practices used in potato production in Idaho. American Journal of Potato Research 87, 253–260.

Rex, B.L., Mazza, G., 1989. Cause, control and detection of hollow heart in potatoes: A review. American Potato Journal 66(3), 165–183.

Sadawarti, M., Singh, S.P., Singh, R.K., Buckseth, T., Katare, S., Kumar, M., Khambalkar, P.A., Singh, Y.P., Sharma, S.K., Gupta, S.K., Singh, S., Samadhiya, R.K., 2021a. Ensuring healthy seed through innovative techniques of seed potato production. Cronicle of Bioresource management 5(3), 081–085.

Sadawarti, M.J., Singh, S.P., Singh, R.K., Katare, S., Samadhiya, R.K., 2021b. Agro-techniques for production of seed size tubers in conventional seed potato production system– a review. International Journal of Bio-resource and Stress Management 12(3), 238–246. https://doi. org/10.23910/1.2021.2272.

Sadawarti, M., Singh, S.P., Singh, R.K., Katare, S., Buckseth, T., 2023. Technological innovations of seed potato systems in India. Kiran, P.B., Kashyap, P., Roy, S.S., Narwade, A.V. (Eds.), Abiotic stresses: challenges and prospective in horticultural crops- Volume I" edited by, published by Today & Tomorrow's Printers & Publishers (accepted for publication).

Salazar, L.F., 1996. Potato viruses and their control. International Potato Center, 1–214

Sale, P.J.M., 1979. Growth of potatoes (*Solanum tuberosum* L.) to the small tuber stage as related to soil temperature. Australian Journal Agricultural Research 30, 667–675.

Sarquis, J.I.H., Gonzalez Lugo, I.B., 1996. Response of two potato clones (*Solanum tuberosum* L.) to contrasting temperature regimes in the field. American Journal of Potato Research 73, 285–300.

Scott, G.J., Suarez, V., 2011. Growth rates for potato in India and their implications for industry. Potato Journal 38(2), 100–112.

Setiyo, Y., Gunam, I.B.W., Harsojuwono, B.A., Yuliadhi, K.A., 2021. Analysis of the impacts of technological implementation on the productivity and quality of seed potato tubers. Journal of Applied Horticulture 23(2), 200–205.

Sharma, A.K., Singh, S.P., Kumar, D., Singh, V., Buckseth, T., Singh, R.K., 2021. Seed plot technique potato in sub-tropics: *In* Chakrabarti, S.K., Bhardwaj, V. (Eds), Potato in subtropics: a saga of success. International Books Periodical Supply Services, New Delhi-110034 (India), 34–49.

Sidhu, R.S., Kumar, S., Vatta, K., Singh, P., 2009. Value chain analysis for high value crops (HVCs), in the Punjab State. Agro Economic Research Centre, Punjab Agricultural University Ludhiana June, 2009.

Singh, R.K., Dubey, S.K., Singh, R.K., Singh, S.N., Buckseth, T., Singh, A.K., 2016. Farmer participatory seed potato production through KrishiVigyan Kendra networking: n action research for enhanced availability of seed potatoes in India. Potato Journal 43(2), 193–199.

Singh, B.P., Sharma, S., 2018. Potato seed production systems: then and now. Potato Journal 45(1), 1–16.

Singh, S.P., Kushwah, V.S., 2010. Effect of size of seed tubers and date of haulm cuttings on production of small seed tubers. Potato Journal 37(3&4), 167–170.

Sood, S., Bhardwaj, V., Kumar, V., Das, R., Gupta, V.K., Mangal, V., Luthra, S.K., Kumar, R., Kumar, S., Singh, R.K., Kumar, M., Rathore, A., Pandey, N.K., Singh, A.K., 2022. Genetic progress in 50 years of potato breeding in India: Where do we stand? European Journal of Agronomy 141, 126620.

Sperling, L., 2008. When disaster strikes: a guide to assessing seed system security. International Center for Tropical Agriculture, Cali, Colombia.

Struik, P.C., Wiersema, S.G., 1999. Seed potato technology. Wageningen Academic Publishers, Wageningen, The Netherlands.

Struik, P.C., Eloy, J., Vreugdenhil, B.D., 1987. Effects of extracellular extracts from leaves on the tuberization of cuttings of potato (*Solanum tuberosum* L.). Plant Physiology 84(2), 214–217.

Thomas-Sharma, S., Abdurahman, A., Ali, S., Andrade-Piedra, L., Bao, S., Charkowski, A.O., Crook, D., Kadian, M., Kromann, P., Struik, P.C., 2016. Seed degeneration in potato: The need for an integrated seed health strategy to mitigate the problem in developing countries. Plant Pathology 65, 3–16.

Thornton, M., Nolte, P., 2005. Risks associated with early potato planting. Paper presented at the Idaho potato conference on, www.cals.uidaho.edu/.../Risks Associated with Early Potato Planting.

Van Dam, J., Kooman, P.L., Struik, P.C., 1996. Effects of temperature and photoperiod on early growth and final tubers in potato (*Solanum tuberosum* L.). Potato Research 39, 51–62

Van Heemst, H.D.J., 1986. The distribution of dry matter during growth of a potato crop. Potato Research 29, 55–66.

Venkataslam, E.P., Pandey, K.K., Singh, V., Singh, B.P.,

2011. Seed potato production technology. Tech. Bulletin ICAR-Central Potato Research Institute, Shimla. 71p.
Venkataslam, E.P., Singh, R.K., Sharma, A.K., Buckseth, T., Rawat, S., Sood, S., Chakrabarti, S.K., 2018. Available from http://14.139.61.83/Ebook_SeedProductionTechniques/Main_Page.html.
Welbaum, G.E., 2017. Seed production encyclopedia of applied plant sciences (Second Edition) 1, 546–552.
Wheeler, R.M., Tibbitts, T.W., Fitzpatrick, A.H., 1989. Potato grow thin response to relative humidity. Hort Science 24, 482–484.
Wustaman, R., Struik, P.C., 2007. The canon of potato science: Seed and ware potato storage. Potato Research 50, 351–355.
Wustman, R., 2007. The canon of potato science: Storage diseases and pests. Potato Research 50, 289–292.
Young, N., 1990. Seed potato systems in developed countries: Canada, the Netherlands and Great Britain (Lima, Peru: International Potato Centre), p 128.