Plant Archives Vol. 25, No. 1, 2025 pp. 1456-1476 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.216

VEGETABLE SEED PRODUCTION TECHNIQUES IN VARIETIES: A REVIEW

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(Date of Receiving-31-01-2025; Date of Acceptance-08-04-2025)

ABSTRACT

Vegetable crops, the annual plants rich in essential nutrients, are cultivated differently depending upon the economic part of crops e.g. production of tubers in potato, bulbs in onion, cloves in garlic, flower buds in cauliflower and broccoli, leaves in cabbage and spinach and roots in carrot, radish, and turnip. The various genetic and agronomic principles that affect quality seed production in these crops may be the temperature, spacing, nutrient application or proper roguing, isolation distance, harvesting and post-harvest ripening procedures. Seed treatment positively affected commercial seed production. This chapter commemorates the effect of several factors in the seed production technique *viz.*, seed to seed, root to seed, bulb to seed, head to seed, etc…as well as the best possible factors that involved the production of quality hybrid seed at commercial level.

Key words : Seed to seed, Bulb to seed, Head to seed, Root to seed, Hybrid seed production, Seed village method.

Introduction

All the people around the globe are dependent upon vegetables and vegetable production is dependent upon healthy seeds. About 12 per cent (11,54,598 thousand tonnes) of the 9.5 billion tonnes of the world production of primary crops are contributed by vegetables (FAO, 2023) and its production value was 17 per cent (542187 million USD) out of 2.8 trillion USD for primary crops in 2021. India produced vegetables worth 41657 million USD in 2021. India harvested 8897 thousand hectares of area under vegetables exported 4492 million USD worth of fruits and vegetables to the world and imported 5924 million USD of fruits and vegetables (FAO, 2023). The production of vegetables in India was estimated to be 212.91 MT in 2022-23 as compared to 209.14 MT in 2021-22 as per the press release of the government of India (http//pib.gov.in). Worldwide India stood first in the production of ginger and okra. Second place had been retained in producing potatoes, onion, cauliflower, brinjal, and cabbages (FAO, 2021). There are 1.5 billion vegetarian people around the globe (Nezlek and Forestell, 2020) that fudge together to make 20-30 per cent of the world's population. Vegetable supply per capita increased due to supply growth outpacing population growth (Motkuri, 2020). However, the average amount of vegetables consumed per person in India is 130 g in rural areas and 172 g in urban areas (NIN, 2016) which is less than the WHO recommendation of 300 grammes per person per day. This creates a greater scope of vegetable production and supply to the people of India. Consuming vegetables daily has been firmly linked to improved digestive and visual health, decreased risk of heart disease, stroke, diabetes, anaemia, gastric ulcers, rheumatoid arthritis, and other chronic diseases and overall well-being (Dias, 2012).

The gaps in vegetable production are due to production constraints, resource constraints, social constraints, adaptation to climate change, non-accessibility to the latest

technology and marketing constraints (Noopur *et al*., 2023). Globally vegetable species are numbered around 1097 (Renna *et al*., 2019) and only 7 per cent of it had been under cultivation.

Unless the farmer received the best quality planting material, he/she could no longer produce the best quality vegetables. Seed is the most basic component of agriculture and crop production. The unavailability of good quality seeds could alone contribute to more than 40 per cent losses in the crops but, more than 70 percent of farmers in India did not had access to quality seeds (Hembram, 2021). Seed is the basic unit producing off-spring. The quality of the seed decides the predictable performance of the progeny. A population grown through vegetative seed/ planting material is exploited to perform in consonance with its variety. However, progeny grown by sowing botanical seed may exhibit some extent of deviation from the expected performance. Depending upon the reproductive potency of the crop, vegetables have been subjected to seed multiplication in numerous ways. All these methods employed are discussed in this review.

A good quality seed could raise the estimated crop production by 45 per cent if best management practices are employed (Singh *et al*., 2019). Vegetable seeds (26 per cent share) were predominated by grain seeds in the Indian seed market (Anonymous, 2020). The worth of a good quality seed was prescribed well in ancient Indian scriptures such as *Atharvaveda*, and *Manusmriti*. The value of good seeds is evident from a verse mentioned in *Manusmriti*: '*Subeejam sukshetre jaayte sampadayate*' (Tiwari, 2021). It also pictured seed treatments with cow dung, cereal and pulse flour for better germination, severe punishments for adulteration of seeds and several *mantras* were uttered while seed treatment with butter and honey was done in some crops (Jugnu, 2004 and Mishra, 2017). The production of pure seeds envisages certain must-do interventions in cultivation practices viz., roguing, isolation, field inspection, maintaining genetic purity; harvesting *viz*., maturity indices, storage methods *viz.*, traditional seed storage, hermetic storage, etc. and quality maintenance following genetic and agronomic principles (Kumar *et al*., 2023). This is momentous for fetching higher prices for seeds in the market. Indian market capitalized on two types of vegetable seeds viz. open varieties and hybrid seeds. The contribution of OP seeds is reduced from 100 per cent in the 1980s to 5.0% in 2023; while the reverse of it holds good for hybrid seeds (own observation). Farmers preferred growing hybrids owing to higher productivity. The global seed market is expected to reach USD 90.37 billion in the forecast period of 2019-24 and notice a CAGR (Compound Annual Growth Rate) of 7.9 per cent (Anonymous, 2019). Further Indian seed industry is reckoned to be growing at a CAGR of 13.6 per cent reaching a value of 9.1 billion USD in 2019-24 (Anonymous, 2019). Andhra Pradesh was known as the "Seed Capital" of the nation since it produces 20,000 quintals of different agricultural seeds annually on an area of one lakh hectares (Radha and Choudhary, 2005). In economic terms seed production is a profitable venture. There were higher net returns gained from seed production over grain production in groundnut and soybean (Pal *et al*., 2016; Deokate *et al*., 2021). However, due to high production costs and low seed output prices (Verma and Deepti, 2016), non-availability of labour (Pal *et al*., 2019), weak linkage and integration among the stakeholders (Mihretu, 2019) and limited choice of improved varieties (Bishaw *et al*., 2007) the seed production of crop fails to attract farmers.

The weather vagaries at the time of the cropping period for seeds and infestation of seed-specific pests added woes to seed crops. The scope of opting for seed production as a venture is not limited. The seed village program has opened new vistas for farmers where the seeds are produced on a mass level (Bhavani *et al*., 2022). Researchers in India reported about 69.01 per cent increase in farmers' profits (Bhavani *et al*., 2022) and a higher seed replacement rate (30.12 per cent in soybean) (More *et al*., 2023) by adopting a seed village programme as compared to non-seed farmers. Also providing skill development training on quality seed production to the farmers increased their net income (68.31 per cent) (Salendra *et al*., 2021; Santhosha *et al*., 2022).

The key factors to drive a successful seed production programme would be a conducive policy environment, availability of credits, technical expertise, community participation and capacity building (Guei *et al*., 2010). In the Indian seed system, there are different classes of seed applicable to OP seeds only *viz*. Nucleus seed (NS)- Breeder seed (BS), Foundation seed (FS)- Certified seed (CS). ICAR took the mandate of breeder seed production by receiving indents from NRC, AICRP, SAUs, NSC, State Seed Cooperation, KVKs, SFCI and non – governmental organizations (Yadav *et al*., 2017). Production of quality vegetable seeds is taken up only by private seed companies and out of 500 seed companies in India, 24 multinational companies alone fulfilled the 50 per cent seed requirement of these high-value crops (Roy *et al*., 2021). About 70 per cent of the vegetable seeds supplied to farmers come from informal systems like the farm-saved seed, and main crops like chilli, brinjal, etc.

which remain confined to kitchen gardens only and local trading, etc. (Roy *et al*., 2021). The data on the actual requirement of the breeder seed of vegetables in the country is unknown as there is no proper documentation of the same. The OP varieties of different vegetables were amenable to different seed production methods viz., bulb/ bulbil/ clove to seed was practised in onion, leek, garlic, shallots, and chive; corm to corm in colocasia; crown to crown in asparagus; root to seed in beetroot, tapioca, rhubarb, carrot, celery; seed to seed in lettuce, chicory, cucumber, bhindi, tomato, chilli, brinjal, pea, and beans; tuber to seed tuber in yam and potato and tuberous root to seed in sweet potato (Pandita *et al*., 2023).

Although the breeder seed production of different vegetables was 15949.81 kg against the 14260.66 kg demanded (2018-19) (Roy *et al*., 2021) which is surplus, still it would take around 3 years to produce certified seed that can be commercially sold. The speed of dissemination of seeds of improved varieties was higher in developed nations as compared to developing (Joshi and Braun, 2022). To understand the gravity of this situation it is necessary to know the situation of quality seed production in vegetable crops and its relevance concerning knowledge dissemination to farmers as well as the adoption pattern of these techniques. This review provides a wholesome collection of almost all the techniques used in the seed production of vegetable varieties.

Commercial seeds available in the Indian seed market should have passed through the seed multiplication chain (NS-BS-FS-CS). Following the genetic and agronomic principles of seed production drove the production of a genetically pure, physically sound, and physiologically better seed. Hybrid seed production follows the same basic principles as those of an OP variety in terms of site selection, season of growing and source of seed, and agro-techniques with special emphasis given to isolation distance, technique and method of pollination. Hybrids merge the advantage of heterosis breeding and are commercialized widely for crop improvement. Hybrid seeds carry the technology of a breeder and the character of its parents and is developed irrespective of the mating and pollination system in the plant system. (Shayamal *et al*., 2023). In India policy factors, geographical factors, market factors and farmer-oriented factors have affected the hybrid vegetable seed industry (Parthiban *et al*., 2019). Involving farmers in hybrid seed production of vegetables through public institutions SHGs/FPOs and establishing Gram Panchayat Level Seed processing-cum- storage Godowns could double farmers' income (Anonymous, 2018).

NAFED- National Agricultural Cooperative Marketing Federation of India Ltd. (***NAFED***), **KRIBHCO**- Krishak Bharati Cooperative Limited, **NFL**- National Fertilizers Limited, **HIL**- Hindustan Insecticides Limited, **IFFDC**- Indian Farm Forestry Development Cooperative Limited

The gaps in large-scale seed production of vegetable crops and higher prices of vegetable seeds in India are because the seeds of vegetable crops are not provided to the public sector seed producers (such as NAFED, KRIBHCO, NFL, HIL, IFFDC) for multiplication rather it had been provided to the private sector. These public parties charged royalties to these private players hence ICAR did not have any control over the price of the vegetable seeds. As a result, farmers received the seeds of the vegetables at a higher price. It is needed that, similar to field crops, the vegetable crops seed could also be distributed for multiplication to the public sector seed producers, which will also control the prices of seed in the market, and discourage the monopoly game played by the private sector seed companies (Anonymous, 2018). Providing farmers with the correct and advanced techniques and skills for the seed production of OP could add up to the objectives of a successful seed production programme in vegetable crops.

Seed production methods employed for open pollinated varieties

Seed to Seed

Down the line, agricultural crop seeds hold paramount importance since managing other inputs using quality seeds alone could raise farm crop production by 45 per cent (Mistary, 2022). Farmer used varieties that have been bred in present condition, hence for the production of high-value vegetable crops such as cole crops and cucurbits, the seeds were not saved by farmers for raising next year's crop (Gary *et al*., 2017). Although the rate of varietal seed turnover was often low consequently farmers faced yield stagnation. The cost of agricultural inputs, equipment, and resources rendered pricey production of improved varieties/hybrids (Anonymous, 2000). Further new varieties failed to match old ones, and dysfunctional varietal release and seed system in India made the adoption of new varietal seeds challenging (Smale *et al*., 2008). Such factors make this system of seed production through the seed-to-seed method obsolete. Henceforth the pre-breeding lines were often utilized for and seed produced for crop improvement and breeding.

Most crops bearing cereals, pods, gourds, siliqua, capsules, and fruits commercially produced seeds through

this method. The technology of seed production is age-old and dates back to the ages of early agriculture on earth. Crop seeds were essentially irreplaceable in the pre-historian era when the remains of seeds of some of the early cultivated crops were discovered (Mittre, 1978). Sowing seeds for raising crops has not been a prevalent practice since slash-and-burn agriculture (Naithani, 2021). Also, the agricultural history of the fertile crescent and Mesopotamian regions revealed that by the 2nd millennium BCE, the invention of ploughs that sowed seeds into the ground was known (Crabben, 2023). The seeds of several wild ancestors of domesticated annual plants had been dispersed through endozoochoric ways. This way of dispersal however was replaced upon interaction with humans that shifted from gathering, transportation, and food preparation of seeds to include deliberate cultivation (Hebelstrup *et al.*, 2023).

Certain innovations used in the production of vegetable seeds such as printed sowing, variable-rate seeding, night-time sowing, bed- and raised-bed sowing, mulching, incorporation of organic matters into the seedbed etc. that improved crop establishment and yield with increased water use efficiency and reduced greenhouse gases (Huang, 2018).

Quality seed material after being procured from authentic seed sources subjected to several treatments before sowing (Table 1). A certified seed showed superior field and crop performance over the seed collected from informal sources (farmer-saved and local markets (Kigambo *et al*., 2023). At a specific seed rate (Table 2) treated seeds could be raised on nursery beds or in portrays or could be seeded directly in the case of okra, cucurbits peas and beans. At the flowering and vegetative stage, seed crops sprayed with chemicals or plant growth regulators (PGR) tend to add to the improvement of seed quality characteristics. It could be the amelioration of seed quality characters. Thakur *et al.* (2022) reported a higher germination per cent, seedling vigour index, and lowered electrical conductivity (dS/cm) when chilli seed crop was sprayed with NAA @40 ppm as a PGR due to more efficient utilization of food for reproductive growth, higher photosynthetic activity, enhanced source-to-sink relationship and accumulation of sugar and other metabolites that attributes for higher dry fruit weight and their seed yield parameters. Lambat *et al*. (2015) and Pranay *et al*. (2019) reported similar results in ridge gourd and okra, respectively.

Rouging the seed crop at certain instances/ crop growth phases *viz*., vegetative stage, flowering and before harvesting stage ensured uniformity in fields and plots (Woods and Ogg, 2023). One additional field inspection at the pre-flowering, stage could be done for cross-pollinated crops. Roguing, a negative selection process removed off-type plants from fields that are in relatively small proportion. Certain characters could be treated as good markers for roguing like leaf shape, flower colour, stem colour/pigmentation, fruit shape and colour with more reliability as compared to certain non-reliable characters e.g. leaf colour, plant height, and earliness of flowering which are strongly affected by environment (Pandita *et al*., 2023). Sultana *et al*. (2019) reported the highest number of filled grains, germination and pure seed percentage with two roguing in rice seed crops.

Integrated nutrient management practices in the seed field that condemn the use of organic and organic sources of plant nutrients NPK along with other bio fertilizers and biostimulants improved seed production. FYM and recommended dose of fertilizer with Vermicompost, and Azospirilium, biofertillizer at the recommended concentration promoted higher seed yield and quality (Pinkee *et al.*, 2023 in Brinjal; Kumar and Pandita, 2016 in cowpea).

The stage of harvest and post-harvest ripening of fruit vegetables for better seed yield and quality could be brought into farming practice. Since stage of maturity of the seed at the time of fruit harvest could be one of the most important factors that can influence the quality seed. Harvesting cucumber seeds from fruit harvested at 40 days after anthesis and kept at the post-harvest ripening period of 14 days performed better in seed recovery, seedling vigour index, per cent filled seed, germination and other seed yield and quality characters (Thakur *et al*., 2018). Similarly, seeds of tomatoes with higher germination and vigour were obtained from the fruits harvested from the last trusses and pre-stored after harvest until the pericarp turned completely red (Dias, 2006). The relevancy of physiological maturity for agronomic purposes highlighted its importance since at this seed development stage plant had lost all the funicular function to transfer the nutrients from the mother plant to seeds (Ellis, 2019) also enlisted in Table 3.

This review does not cover the detailed extraction methods but it just highlights which method is preferred in the vegetable crop. The juicy endocarp and mesocarp of cucurbits (cucumber, pumpkin, musk melon, spine gourd, bitter gourd), tomato, and brinjal is scrapped or scooped out of the fruit and kept for fermentation by the wet fermentation method (Nerson, 2007). The wet method of seed extraction is carried out by employing various chemicals such as Hydrochloric acid (2.0 per cent),

Table 1. Pre-sowing seed treatments as the agronomic principle of seed production

Crop	Seed treatment	Improvement
Preventive seed treatment (Sharma, K.K., 2015)		
Okra	*Pseudomonas fluorescens* @ 10g/kg as seed dresser	Infection of Root knot nematode is reduced
Tomato	*Trichoderma viride* @ 2 g/100 g seed	Reduction in damping off wilt
Pea	Thiram + Carbendazim 2 g/kg seed	Reduced white rot
Crucifers	Seed treatment with *Trichoderma viridi* @ 2 g / 100 g seeds	Lower chances of damping off
Pumpkin	55ºC hot water dip of seed for 15 minutes	Control fusarium wilt (Lancaster, 2014)
Cabbage and cauliflower	52ºC hot water dip of seed for 25-30 minutes	Control black rot, bacterial leaf spot, black leg, damping off and ring spot (Lancaster, 2014)
Chilli/capsicum	*Pseudomonas fluorescens* 1per cent WP, *Paecilomyces lilacirius* and *Verticillium chlamydosporium* 1per cent WP @ 10g/kg as seed dresse	Reduced root-knot nematodes
Carrot		
Dormancy-breaking seed treatment		
Tomato	Pre-sowing seed soaking in 30g/L KNO_3 solution for 24 hours	Highest mean seed germination and breaking seed dormancy (Farooq *et al*., 2005)
Pumpkin and cucumber	Seeds soaked in KNO_3 for 10 minutes and thereafter rinsed	Overcome dormancy and showed improved germination (Godwin, 2018)
Okra	Cold treatment for 7 days at 3°C	break down the seed dormancy and stimulated seed germination (Safdari *et al.*, 2021)
Ash gourd	Warm stratification of seeds at 40–50°C for 5 days and soaking of seeds in 500 ppm ethrel	Improved field performance and dormancy overcome (Selvi *et al*., 2024)
Cabbage	Soaking seeds in 0.03% solution of H_3BO_3 and another 0.04% solution of $ZnSO_4$ for 6 hours	Better germination and related parameters (Smirnova *et al.*, 2021)

Table 2 : Seed rate and seed yield for different fruit vegetables for seed production (Agrawal, 2012).

Crop	Seed rate (kg ha^{-1})	Seed yield (kg ha^{-1})
Brinjal	0.37-0.50	100-200
Capsicum and chilli	1-2	50-80
Cowpea	20-25	1500-2000
Cucumber	2-5	110-130
Muskmelon	3-4	200-300
Okra	8-10	1200
Peas	60-75	2000-2500
Squashes and pumpkin	5	300-500
Tomato	500	100-120
Watermelon	2.5-5	200-250

sodium carbonate (2.0 per cent) (Pozhilarasi *et al*., 2022) etc. Henceforth, a dry method of seed extraction is preferred for chilli pods, beans and peas, fenugreek, and onion as well as some gourds *viz*, ridge gourd, snake gourd etc. Certain field and seed standards used to produce vegetable seeds in the field as presented in Tables 4 and 5, respectively (Anonymous, 2013) improved the quality of seed produced.

Head/Curd to Seed

A commercially utilized method in seed production of crucifers or cole crops *viz*. cabbage, knol khol, late cauliflower, sprouting broccoli, kale and brussels sprout, head to seed method is often termed as the transplanted method. Both production of hybrid seeds as well as local seeds could be practised wherever possibilities are their, since heirloom seeds of cole crops outperformed the hybrids in terms of seed yield and quality parameters in some cases (Osmani *et al*., 2023). Practised on the cole crops hardy crops could tolerate cold temperatures and

Table 3 : Effect of stage of harvest and post-harvest ripening of fruits on seed quality of vegetables.

Crop	Stage of harvest/post-harvest	Effect
Tomato *et al*., 2008)	Seeds harvested at 60 DAA	maximum seedling growth and quality wad obtained (Ibrahim
Brinjal	• Fruits harvested 4-5 days after fruits turn fully yellow or brown depending on the variety • After the harvest fruits should be kept for 2-3 days and the seed extracted	• Seeds maintain viability for a long period in storage • High-quality seeds could be obtained (as per guidelines of IIHR, Bengaluru, https://www.iihr.res.in/stage-fruit-harvest-tomato-brinjal-and-capsicum-better-seed-quality)
Capsicum	• Capsicum fruits harvested at the fully ripe stage • Kept after ripening for 5 days or till fruits attained softness.	
Brinjal	Seeds extracted from fruits harvested 60 or 70 DAA irrespective of any post-harvest ripening period	Achieved the maximum seed germination (Botey *et al*., 2022)
Sponge gourd	Fruits are harvested at the complete brown stage and seed are extracted on the day of harvest	Seeds were superior in terms of seed quality parameters (Jeevitha and Vasudevan, 2019).
Beans	Pod harvested 75 days after emergence	yield and yield contributing parameters significantly influenced by days to harvesting (Shaheb *et al*., 2015)
Okra	Fruits harvested 40 days after anthesis, followed by shade-drying fruits before seed extraction	High seed germinability was found (Kumar *et al*., 2021)
Bitter gourd	Fruits harvested at the complete yellow stage and ripening period of 3 days	Recorded significantly higher seed quality parameters (Vanitha and Vasudevan, 2019)
Kale	Harvested when pods became brown (65 DAP)	Better seed quality parameters (Demir and Balkaya, 2005)
Kale	Pods containingseeds at different maturity stages can be cut and slowly dried as a swath	Seeds that are not atphysiological maturity may be directed into late maturation and still gain quality (Groot, 2022)
Cabbage	Plants cut 100 days after flowering and at a seed moisture content of 30 per cent	Uniform, rapid and highest percentage germination and emergence without loss of seed viability (Gray *et al*., 1985).
Summer cabbage	Racemes with green seedpods harvested and seeds remained in seed pods for a week before threshing.	Optimum seed moisture content, higher mass of 100 seeds, germination, first counting and seedling emergence were obtained (Freitas *et al*., 2007).
Cabbage	Harvesting seeds at 60 days post-flowering	Yielded seeds with stable germinability, highest vigour, germination per cent, etc (Panayotov and Stoeva, 2008).

wet conditions but not hot temperatures (Dhaliwal, 2017). As low as 10-15 ^{0}C day temperature was required during plant growth but a fall in night temperature could cause a reduction in seed yield (Hossain, 2015). A 40 per cent reduction in the yield was found over a time of 25 years with an increase in maximum temperature from 18 ^{0}C to 22 ^{0}C (Priyanka, 2018). These low-temperature loving cole crops multiply through seeds either *in situ* or transplanted depending upon the severity of winters in the area. Sowing at lower temperatures terminated the shoot apical meristem activity in kale causing blindness in seedlings (de Jonge *et al*., 2016). Winter storage of heads is necessary in some parts of the country where temperatures drop below 20ºF (-10ºC) (McCormack, 2005). In biennial brassicas, at the end of the vegetative stage, the fully developed curd/head is ready for overwintering so that it can flower and go to seed production as the temperature rises in the next spring season. Some crops such as crucifers (cabbage, turnip, kale, kohlrabi, cauliflower, Chinese cabbage), onion, red beet, celery, carrots and parsnip must be exposed for a period of low temperatures to aid in the transition of the plant apical meristem to reproductive development called as Vernalization (Phillip and Goldy, 2020).

Overwintering of crops in the field itself and covering

Table 4 : Field standards (Isolation requirement and off type) of some fruit and cole vegetables *(FC- Foundation class, CC- Certified class).*

Crop name	FC (min. dist.-m)	CC (min. dist.-m)	Off types in CC seed (max. per cent)	Plants affected by the seed-borne disease (max per cent CC seed)
Fruit Vegetable				
Brinjal	300	150	0.20	0.20
Capsicum and chilli	500	250	0.20	0.50
Okra	500	250	0.20	-
Tomato	50	25	0.20	0.50
Cucurbits	1000	500	0.20	0.50
Garden peas, cowpea	10	5	0.20	-
Cole Vegetable				
Cabbage, cauliflower, Chinese cabbage, Knol khol	1600	1000	0.20	0.50

Table 5 : Seed standards (certified class seeds) of some fruit and cole vegetables.

Crop name	Pure seed (min. per cent)	Other crop seed (max. per kg)	Germination (min. per cent)	Moisture (max. per cent)	Genetic purity (min. per cent)
Fruit Vegetable					
Brinjal	98	-	70	8	90
Chilli	98	10	60	8	-
Okra	99	-	65	10	-
Tomato	98	10	70	8	
Cucurbits	98	10	60	7	-
Garden peas, cowpea	98	5	75	9	
Cole Vegetable					
Cabbage, cauliflower, Chinese cabbage, Knol khol	98.0	10	70, 65 (for cauliflower)		7.0 -

the head with soil done by the end of October in cold regions or before the onset of snowfall provided a chance for vernalization to act upon the vegetative parts to head them towards flower stalk emergence i.e. bolting. At 5-17 ºC maximum rate of vernalization could be promoted in cole crops (Singh, 2001). However a delay in the temperature of vernalization could lead to poor flowering in cole crops (Ziaf *et al.*, 2017). The most inducive/ optimum temperature for vernalization caused the fastest flower induction. Considering a few crops viz., cabbage and khol rabi few hours of high temperature for even a day could neutralize the effect of vernalization. This phenomenon is called Devernalization. A sudden transfer from inductive to non-inductive conditions of temperature exhibited slow progress towards the floral state of broccoli (Zenkteler *et al.*, 2012) thus affecting fruit set and seed production. Similar results were obtained in kohlrabi (Wiebe *et al.*, 1992). A two-week tratement devernalizaittion could revert the effect of plant to a fully non-vernalized status in Arabidopsis (Shirakawa *et al.*, 2021). In cabbage that is a polycarpic plant, the reversion from reproductive to vegetative growth occurs when vernalization is insufficient (Ito and Saito, 1961). The vernalization processes could be managed for different crops by adjusting the temperature and duration requirement (Table 6).

Seed sowing and overwintering of heads

A seed rate of 350 to 500 g was enough to produce a hectare of crop and it may yield up to 250 to 400 kg seeds per hectare in cauliflower, a seed yield of 500-650 kg ha^{-1} could be obtained from 375-400 g ha^{-1} seeds of cabbage and similarly, for knol khol 375- 400 g ha^{-1} could be enough to yield 5-6 qtl ha^{-1} seed (Agrawal, 2012). Early sowing in June and July may produce curd in October whereas a late sown crop delays curd formation

Table 6 : Effect of different vernalization temperatures on vegetable crops.

Crop name	Vernalisation temperature	Duration of Vernalisation	Response	Reference
Garlic bulb	0-10 ºC	20- 60 days before sowing	Flowers formed at generative phase transformed to bulbils	Azmi *et al.* (2022)
Garlic bulb	4 ºC	60 days	Bolting inflorescence formation and true seed production	Dutta and Talukdar (2020)
Carrot roots (4-8 mm)	2-5 ºC	6-8 weeks	Floral induction	Dutta and Talukdar (2020)
Carrot roots	5 ºC and post vernalization 15 º/21 ºC	10 weeks	100 per cent flowering, viable seeds	Hiller and Kelly (1979)
Onion bulb	5ºC	14 days with 100 ppm GA_3	Highest seed yield (280.42 $kgha^{-1}$)	Khatun *et al.* (2020)
Cabbage	Rooted and headed plants with 8-9 leaves planted in the boxes with perlite and kept in storageat +4°C and 80% humidity	6 weeks vernalization	Synchronizatino of flowering in parent that produced higher seed yield	Murat *et al.* (2018)
Cauliflower	Non vernalized temperature of 18 °C		The optimal transformation of apex development from the vegetative to reproductive stage	Lin *et al.*, 2019

Table 7 : Seed rate and seed yield of major root vegetables.

Crop	Seed rate	Seed yield
Beet root	7-9 kg ha^{-1}	1000-1200 kg ha^{-1}
Carrot	5-6 kg ha^{-1}	500-600 kg ha^{-1}
Radish	9-12 kg ha^{-1}	600-800 kg ha^{-1}
Turnip	3-4 kg ha^{-1}	600-800 ha^{-1}

and consequently delays the formation of flowers next summer. Cabbage seed sown in mid of Aug. and transplanted at spacing 60 × 60cm resulted in maximum germination %, seedling length, seedling dry weight, vigour index-I and vigour index-II of the seeds produced (Kumari *et al.*, 2019). Broccoli seedlings were transplanted in October and the matured head when pinched yielded a maximum number of siliques/ plant (Abou *et al*., 2007). Cabbage seedlings transplanted early (July month) produced seeds that had higher germination percentage, low mean germination time, higher values of germination index and coefficient of velocity of germination (Bute *et al*., 2023). A delay in the sowing time caused a lesser seed set due to a shorter flowering duration in mustard (Devi and Sharma, 2017). The best sowing time needs to be selected to obtain better head/curd as well as seed production. Fertilizer application affected the seed production in cole crops. In broccoli seed production a higher dose of nitrogen (120 kg/ha), potassium (80 kg/ ha) and three split dosages of nitrogen application improved seed yield, and germination parameters and reduced the time taken for heading, flowering, and seed maturity (Gogoi *et al*., 2021). So also field application of potassium fertilizer 70 kg S ha^{-1} as potassium sulphate showed better response concerning seed yield attributes, seed yield, and quality parameters in cabbage seed crops (Bhat *et al.*, 2017). Upon improvement in the magnesium status of plants, increased uptake of nitrogen and phosphorus in rapeseed plants was seen that also contributed to better seed yield, seed quality, and seed vigour (germination) in rapeseed brassica (Geng *et al.*, 2021).

For the head to seed method or stump-to-seed method, the fully developed heads/ curd/ stumps in cauliflower were uprooted and stored in trenches. In October- November inside the underground storage, trenches were made with dimensions (75 cm deep, 3 m long and 11 m wide). This provided optimum storage temperature for these plants and prevented harsh frost injury in open field conditions (Singh *et al*., 2012). Cauliflower heads are covered with soil up to a depth of 5-7.5 cm shielded with wooden planks and topped with about 15 cm layer of soil. A vernalization duration of six weeks yielded higher cabbage seed production (31.93 g $plant^{-1}$) (Dogru *et al.* 2018). However, In knol khol the in

situ method of seed production could be recommended to yield better seed quality than replanting (Bhushan *et al*., 2020; Ranjit and Kumar, 2011). A higher seed yield, test weight and germination per cent was obtained from the head to seed method of planting in cabbage (Malhotra, 1996). As soon as spring season arrives, the overwintered plants/heads/ that have bolted could be transplanted in the field at proper spacing and an isolation distance of 1600 m. Bolting pushed out the stem of the vegetative part to produce a raceme inflorescence in a flowering stalk. This type of inflorescence can be produced in cabbage, kale, Brussels sprouts and kohlrabi. Scooping of cauliflower curd i.e. removing half of the curd from the center with the help of a knife may yield 171. 4 per cent higher yield than any other method (Kumar *et al*., 2000). Curd scooping outyielded no curd scooping for seed yield and other attributes *viz* pods plant^{-1}, length of pod, seeds pod^{-1},1000-seed and seed germination (Moniruzzaman *et al.,* 2022). De-heading of broccoli curd produced a maximum seed yield (675 kg/ha) (Azam *et al.*, 2020; Dawadi, 2023). Peripheral bolting is considered best in the case of cauliflower instead of whole plant turning into flowers. This is because of the reason that the plant that has bolted fully might have produced a loose curd instead of a compact one. Hence such kind of plants are immediately destroyed as they might interfere with the physical quality of the seed. Bolts from compact heads of cabbage resulted in higher seed yield, number of branches, pods, seeds pod, pod length as well as 1000 seed weight, germination per cent etc (Dev, 2012).

Wild pollinators (Diptera, Hymenoptera and Lepidoptera order) with 15-18 beehive boxes per hectare introduced in the seed production field obtained higher seed set, germination, speed of germination and seed vigour indices in the brassica field (Prasannakumar, 2015). Certain plant growth regulators when applied in the seed production fields of cole crops *inter alia* yielded better seed production; spraying cauliflower seed crops with 200 ppm GA_3 three weeks after transplanting resulted in the highest return and benefit-cost ratio (Prodhan *et al*., 2022). With a minimum of 4 field inspections Black leg, black rot and soft rot which are seed-borne diseases common in most of the coel crops could be rogued out (With maximum of 0.10 and 0.50 per cent diseased plants permitted) (Anonymous, 2013). Hot water seed treatment of seeds (50 degrees C) for 30 minutes could control such seed-borne diseases (Nega *et al*., 2003). Plants bolted pre-maturely at higher temperatures (> 15- 20 °C) and longer photoperiod was discarded as high temperatures at later stages led to head splitting and loose head when the crop is grown inside the greenhouse in colder regions (Angmo *et al*., 2020). Amongst the insect pest, an aphid infestation of 15 aphids plant^{-1} in brassica genotype resulted in 87.36% seed yield loss (Khan *et al.,* 2015). Hence it necessitated that integrated nutrient management be practiced in the seed production field as well.

Harvested silique of brassicas is cured and threshing is done to get clean seeds and field and seed standards (Tables 4 & 5) could be followed that yielded better quality seed in cole crops. Different stages of harvest affected the seed yield and quality for cole crops as described in Table 3. Further, the position of seed pod/ silique on the mother plant also resulted in a seed with differential seed quality parameters. The germination (%), speed of germination and vigour status obtained from siliquae positioned at the middle of either the main stem or primary branch remained higher irrespective of the genotypes over the years (Chamling *et al.,* 2017).

Root to Seed Method

Successful seed production of radish has been pre-owned. Shri Bitri Basaringaid, a farmer from Pyndengumiong village, Mairang Block, Meghalaya, a master of radish seed production started successful seed production of radish on his farm from 1993 till date. He produced a bumper crop of 20 kg per 300 plants and sold it at a price of rupees 1000 per kg (https://kvkwestkhasihills.nic.in/docs/success_stories/radish_seed_production.pdf). Root to seed is a method employed in the quality seed production of root vegetables *viz.*, radish, carrot, turnip, beetroot, parsnip, rutabaga, and chervil and taken up in two phases (Bhardwaj *et al*., 2020), while raising the vegetative/ table purpose crop in May to October followed by the cut roots overwintered from October to April and replanted in fields in April (Singh *et al*., 2012) to produce flowers and set seeds. Root vegetables being climate-sensitive crop need the best-suited climate for their growth and development (Verma and Sharma, 1995). For example- in Radish and turnip a temperature of 10-15º C promoted good texture, 20-30ºC yielded maximum root growth, and 25 º C resulted in better vegetative growth (Thamburaj and Singh, 2004) however higher temperatures increased fibres, toughness, and pungency increase in radish roots (Lockley *et al*., 2020). Beetroot possessed pre-mature bolting at 4.5°-10°C for 15 days (Jasmitha *et al*., 2018). Cool climate promoted good colour, texture, and quality of roots, and high temperature caused zoning in the root vegetables (Dhaliwal, 2017). European carrot/turnip is transplanted in April, rest of the temperate root crops are transplanted in November- December (Lutfunnahar *et al*., 2020). A

fairly mild spring that doesn't reach above 35 °C temperature until late in the summer but generally, after the seed is set and near maturity was best for seed production of temperate-type carrot seed production (Bhardwaj *et al*., 2020)). Fertilizer application affected temperate root seed production. A higher radish seed yield, net returns, and B: C ratio was obtained upon nutrient application of Azotobacter (2.5kg/ha) + PSB (2.5kg/ha) + 75% R D of N, P, K (112.5:45:40.5 kg/ha) (Kumar *et al.*, 2013) so also, results were reported by Deepika and Pitagi (2015). However an integrated nutrient approach in carrot seed production promoted better number of secondary umbels, number of umblets per umbel, number of seeds per umbel, number of seeds per umbles, seed yield/umbel (g) and seed yield (qha^{-1}) with application of (FYM 12.5t/ha+ Poultry manure 2t/ha+ Vemricompost 4t/ha+ Azotobacter+PSB) (Monika *et al*., 2022).

Seed sowing and overwintering roots

Carrot seeds (mother root production) soaked in water at 20 ºC for 24 hours followed by drying at 20 ºC as a pre-sowing seed treatment for better seed quality. Seed viability is lost due to the Lygus bug (Bout *et al*., 2019) that attacked seeds and viable seeds remained intact when rubbed in between palms otherwise seeds split apart, and were not pure/ not viable. The desired seed rate for root vegetables (Table 7) yielded per hectare production of roots/seeds upon sowing as mentioned in the table (Agrawal, 2012*)*. For planting carrot stecklings in a hectare at a spacing of 75 × 30 cm a total of approximately 44,500 stecklings were required and a seed rate of 6 kg ha^{-1} for the production of 20-25 T ha^{-1} of carrot roots. These roots were utilized for the preparation of stecklings of weight 75- 100 g each (Kumar *et al*., 2017) utilizing approximately 4500 kg roots ha^{-1} that yielded approximately 3,12,000 stecklings per hectare. Hence, in general, roots produced from one hectare of carrot field after at given rate, would be sufficient to produce roots for transplanting to three to four hectares (Mishra *et al*., 2020). In temperate conditions, radish whole roots produced early flowering and better seed yield as compared to stecklings prepared by cutting $1/3^{rd}$ or $2/3^{rd}$ of the roots (Kumar *et al*., 2007). Increased number of radish seed/pods with better seed size, seedling vigour index and seed yield per plant resulted in replanting of longer steckling (15 cm length) (Manzoor *et al.*, 2021) as well as roots weighing more than 150g (Dev., 2010) and roots uprooted 50 days after sowing (Hoque *et al*., 2015). Radish steckling dipped in PBZ @ 50 ppm at the replanting stage improved seed yield and quality characters.

A temperature of 10 ºC for an aggregate time of 45 days was useful for biennial vegetable seed production (Organic Seed Alliance, 2013). Cold treatment of 2- 5 p C for a period of six to eight weeks during vernalization induces flower emergence in root vegetables. (Dutta and Talukdar, 2020). The roots of beetroot true to type for all major traits inherent in the particular variety, without any physical damage, disease, or insect infestation, and stored by trimming off most of the tops produced superior quality seeds (Bhardwaj *et al.*, 2020)).

At ambient climatic conditions post vernalization i.e. -2 to -4^0C outside temperature in temperate regions) these stecklings measuring 4-8 mm in diameter could be re-planted in field at a spacing of 75 × 30 cm at a 1600 m isolation distance. It bolted and produced raceme inflorescence for seed et (Yadav, 2021). A combination of GA_3 2 ppm (dip), 50 ppm (foliar spray) and GA_3 100 ppm as a foliar spray can also produce higher seed yield (Kuldeep *et al.*, 2007). Often wider stecklings are more vigorous and produce flowers in a lesser number of days to flowering. Similar results were produced when the whole root of radish was transplanted under temperate conditions (Kumar *et al.*, 2007). Some characteristics of the steklings confirming the varietal purity and trueness-to-type are discussed in the following section (Dhaliwal, 2017):

Crop and Variety	**Specific characteristics of roots**
Carrot	
Arka Suraj	Smooth, conical and deep orange roots with self-colour core
Kashi Krishna	Attractive black-coloured roots along with self-coloured core
Solan Rachna	Long tapering attractive roots, round, medium tops, orange coloured, medium length
Carrot root is mature enough to harvest when the root "tip" (the point from which the taproot emanates) has filled and is immature when their tips appear "blunt" (Alliance, 2010)	
Radish	
Arka Nishant	Roots long, marble white in colour with crisp texture and mild pungency
Kashi Lohit	Attractive red colour roots, icicle root shape
Japanese white	Roots are cylindrical, pure white with blunt end
Turnip	
L-1	Roots are round, pure white, smooth rat-tailed
Beetroot	

Crimson Globe	roots are round to flat round and medium red, small shoulders, dark crimson red with indistinct zones

Rouging and field inspection

Three roguing done in the seed production of root vegetables viz., starting from at the mother root production stage (20-30 days after sowing) to check isolation distance, volunteer plants, outcrosses and off types; second at the lifting of mother roots to verify true characteristics of roots. Contaminants *viz.*, off types, early bolters, diseased plants and off type roots (forked, diseased, split or have cavity spot, green or purple shoulder) were removed at first second and third inspection with a minimum of five field inspections recommended (Anonymous, 2013). True nature of umbels/silliqua in the case of radish and turnip, a spike in beetroot could be observed during the fourth inspection. Seed production standards for some of the root and bulb vegetables is presented in Tables 8 and 9, respectively.

Seed harvesting

Shattering pods is a problem in turnip therefore the crop is cut when pods turn 60-70 per cent brown and cured for 4-5 days in the field itself. However, there is no such problem of shattering seeds in radish so pods are harvested when fully ripe, dried and cured. Carrot umbels are harvested in a sequence primary umbel first and subsequent harvesting is done in 2-3 pickings (of open nest-like umbel). Carrot seeds harvested from primary and secondary orders showed higher vigour and germination even at high temperatures (Pereira *et al.*, 2008).

Seed shattering is a major problem in carrots due to high winds and heavy rains. The beetroot spike is ready to harvest when 80 per cent of seed balls get hardened on the plant itself. The optimum conditions for beetroot seed storage were dry, low humidity, and cool environments having temperatures of 35 and 70 ° F for better seed quality (Mall *et al.*, 2020). The seed crop of parsnip harvested 50 days after flowering and at 50-70 % moisture content (Gray *et al.*, 2008) gave maximum seed yield.

Bulb to seed

Bulbous vegetable crops *viz.*, onion, garlic, chive, and shallots hold a very influential rank in both vegetable production and the economy of Indian agriculture. Onion is the queen of the kitchen (Das, 2021) and garlic crises handed out to people at worse times due to its price. Producing disease-free bulbs that can be consumed as well as stored for enough time to meet the demand of the household is mandatory. A small seasonal variation or premature rains also wiped out 75-80 per cent of onion crop in Gujarat (https://timesofindia.indiatimes.com/city/rajkot/unseasonal-rains-damage-75-onion-crop-in-bhavnagar-amreli/articleshow/71911704.cms) that had held highest productivity of this bulbous crop. Hence the initial seed/bulb quality needs to be best. In India Mandore and Khandawa regions of MP, Nasik and Pune of Maharashtra and the Rajkot district of Gujrat proved to be the potential areas for high-quality onion seed production successfully through the seed production pockets under the seed village programme (Mahajan *et al.*, 2017). Onion, a short-day crop needs low temperatures for producing the scape (inflorescence) with a minimum 25 ºC day temperature requirement for tropical onion for flowering and 10-15 ºC night temperature (Tesfay *et al.*, 2011). Whereas temperate-type long-day onion produced flowers at up to 25 ºC temperature (ICAR-DOGR). Cloves and ariel bulbils, the predominant means of garlic multiplication and clonal selection of spontaneous mutants to produce genetic variation were workably exploited for large-scale garlic propagation, however, seed-setting garlic clones that produced fertile flowers were discovered (Kaur and Dhall, 2017). As such lack of fertility restoration hinders true seed production of garlic. A vernalization temperature of 4 ºC for two months (Kaur and Dhall, 2017) along with careful removal of bulbils, and multiple pollination using pollinators (honey bees, houseflies, leafcutter bees) (Simon and Jenderek, 2003) could set the stage for true garlic seed production. TSS or the true shallot seeds produced by vernalization treatment @ 5 º C of tuber seeds of shallot increased the number of umbels per clump, number of flowers per umbel, number of fruit per umbel and other seed characters (Siswadi *et al.*, 2022).

Seed sowing

Bulb crop is produced through both kharif sown seeds as well as rabi sown seeds (nursery raised in mid-October to November) and transplanting the seedlings in mid-December to mid-January). Bulb planting in onion in November resulted in a higher number of seeds per Plant, test weight, germination per cent and graded seed yield (Wankhade *et al.*, 2023; Manna *et al.*, 2016). However early i.e. October planting with larger plant spacing 60×30cm (Kumar *et al.*, 2015) reported better significantly higher, seed scape height, umbel diameter, productive umbellates/umbel, seed set, seed yield and quality characters. Tesfaye *et al.* (2018) envisaged the September planting of bulbs in tropical climates to fetch seeds with higher germination and yield. Early October bulb planting (Teshome *et al.*, 2021) with large-sized bulbs

Table 8 : Field standards (Isolation requirement and off type) of root and bulb vegetables (FC- Foundation class, CC- Certified class).

Crop name	FC (min. dist.-m)	CC (min. dist.-m)	Off types in CC seed (max. per cent)	Plants affected by the seed-b orne disease (max per cent CC seed)
Root vegetable				
Carrot mother root production	5	5	0.20 per cent	-
Carrot seed production stage	1000	800	0.20 per cent	-
Radish/turnip/beetroot mother root production stage	5	5	0.20 per cent	0.50 per cent
Radish/turnip/beetroot seed production stage	1600	1000	0.20 per cent	0.50 per cent
Bulb vegetable				
Garlic	5	5	0.20 per cent	-
Onion mother bulb production stage	5	5	0.20 per cent	-
Onion seed production stage	1000	500	0.20 per cent	-

Table 9 : Seed standards (certified class seeds) of some root and bulb vegetables.

Crop name	Pure seed (min. per cent)	Other crop seed (max. per kg)	Germination (min. per cent)	Moisture (max. per cent)
Root vegetable				
Beet root	96	10	60	9
Carrot	95	10	60	8
Radish/turnip	98	10	70	6
Bulb vegetable				
Onion	98	10	70	8
Garlic	• Average diameter of the bulb should not be less than 2 cm • Seed material should be clean, healthy and firm conforming to varietal purity requirements and free from diseases e.g. bacterial brown rot, bacterial soft rot and basal rot			

also promotes higher seed yield. Often onion bulbs are subjected to vernalization at 5 or 10 ºC for early flower stalk emergence (Ami *et al.,* 2013). Early planter onion performed superior in terms of seed parameters (Tesfaye *et al*., 2018). The bulb of optimum size selected for sowing directly affected the seed production in onion. A 15 g bulb (2.5 -3 cm diameter) planted at 100 plants/6 m^2 bulb weight (Asaduzzaman *et al*., 2012) or 1500 kg bulb per hectare (Shanmugasundaram, 2012) and treated with 0.2% carbendazim solution for 20 to 30 minutes (Mahajan *et al.,* 2017) promoted better onion seed production. For quality seed production the rabi-produced bulbs were stored properly till October and the kharif bulbs required a resting period of 15-20 days after harvest before replanting (Mahajan *et al*., 2017).

The seed-to-seed method for onion seed products envisaged dressing onion seeds with thiram, this overcomes Rhizopus (3.63 cent) and Aspergillus (1.85 per cent) infection in plants (Joshi, 2007). Onion seed primed with ascorbic acid (12.5 per cent) and moringa leaf extract (25 per cent) promotes better germination and field emergence (Aluko, 2020), so also priming with GA_3 50 ppm and *Azotobacter* for 16 hours boosts seed vigour (Brar *et al*., 2020). NAA 100 ppm spray twice at first flower stalk emergence and 10 per cent flowering stage improved the seed yield and seed quality characteristics (Geetharani *et al*., 2008). Also, onion bulb dipped in (Copper oxychloride @ 0.25per cent + Streptomycin @ 200 ppm) + spraying rop with (Mancozeb @ 0.25per cent + Carbendazim @ 0.10per cent + Copper oxychloride@ 0.25per cent) (Gore, 2020) prevented purple blotch or stemphylium blight to promote better seed production. Garlic bulbs weighing not less than 2.5 cm in

Table 10 : Field standards (Isolation requirement and off type) of seed potato and TPS *(FC- Foundation class, CC- Certified class*).

Crop name	FC (min. dist. m)	CC (min. dist. m)	Off types in CC seed (maximum per cent)	Diseased tubers (maximum tolerance per cent for CC)
Seed potato	5	5	0.10 per cent	1.0 per cent for late blight5.0 per cent for common scab and black scurf
TPS hybrids	50	50 and 5 meters in between parent blocks	0.10 per cent	-

Table 11 : Seed standards (certified class seeds) of seed potato.

Seed potato	Mean length and 2 width at middle of tuber		Corresponding weight	
	Seed size	Large size	Seed size	Large size
Hill seed	30-60 mm	> 60 mm	25-150 g	>150 g
Plain seed	30-55 mm	> 55 mm	25-125 g	> 125 g

Table 12 : Seed standards (certified class seeds) of TPS.

Pure seed (minimum per cent)	98
Other crop seed (maximum per kg)	10
Germination (minimum per cent)	80
Moisture (maximum per cent)	8
Genetic purity (minimum per cent)	90

diameter and 25 g and free from cuts, bruises insect damage are selected and cloves are planted in the field at an isolation distance of 5 m. Sowing of garlic cloves is done in October- November in North India and in hills in March- April. The bulb-to-seed method of seed production advocates vigorous selection/ rouging for only good quality true-to-type bulbs which cannot be accomplished in seed to seed method since there bulbs are left in the field itself for seed stalk emergence (yields poor genetic purity). Seed fields were inspected four times (as discussed under root vegetables). to check isolation distance and removal of off-types, multicentric, diseased bulbs, thick necks, double necks, and bottlenecks for quality seed production in bulb crops. As well as at the flowering and harvest stage. Further seed crops should be meeting the field and seed standards as presented in Tables 8 and 9, respectively.

Seed harvesting

Harvesting of onion seeds can be initiated at the stage when 10 per cent of black seeds are visibly exposed in the umbel or seed moisture content of 65 per cent (Ronald *et al.*, 2013). If the seed moisture content is reduced to 50-55 per cent in the umbel there is a huge shattering loss. Early harvest (Shanmugasundaram, 2012) with manually cut 15 cm tall flowering stalks left for shade drying with frequent turning promotes better seed extraction. Threshing is done after the umbels are dry enough. Garlic true seeds were half the size of onion seeds and were harvested similarly to onion, possessing poor germination rates ranging from 65 % to more than 90 % (Simon and Jenderek, 2003). Rabi sown bulb crop is ready to harvest when tops droop down just above the bulb. The harvested bulbs were topped leaving an inch neck and are kept for curing for 3-4 weeks for proper seed drying to optimum moisture content (Agrawal, 2012). The bulbs were stored (to meet vernalization) for next season sowing in case of *Rabi* crop while *kharif* crop is rested for a month before transplanting. Higher seed yield is produced when onion bulbs are kept for vernalization at 10°C for 40 days and then transplanted in October (Hossain *et al.*, 2019.pdf). Temperature raised to 30 ° C and 65-70 per cent RH till the optimum time for transplanting is reached for an initial nine days in storage-restricted sprouting of onion bulbs (POP, 2021). The seed yield of onion crop is 850- 1000 kg ha^{-1}.

Tuber to seed

The successive mass multiplication of potato seed tubers at the nucleus stage could be done by producing an elite certified seed stage (Shiwani, 2021) yielding commercial seed crops. The driving force behind the production of potatoes by its growers is the use of good quality seed tubers that could be achieved by managing the biological quality of seed (Wang, 2008). Pre-planting seed tuber treated with thermal shock at 30 ºC for 5 days resulted in more number of seed tubers per plant (Eremeev *et al.*, 2015). Longer exposure to light caused bigger tuber size while shorter exposure promoted higher tuber number (Skrabule, 2020). However aeroponically raised good quality seed tuber were obtained with higher tuber number and size per plant upon the exposure of plant factory to a Light-emitting diode (LEDs) with a light combination of red: blue: green (70 + 10 + 20) (Rahman *et al.*, 2024). So also seed tuber (30 g) treated with mancozeb (0.2%)+carbendazim (0.2%)+dusting of plaster of Paris (0.5%) (Kumar *et al.*, 2015) and using whole and pre-germinated seed potatoes (Diop *et al.*,

2019) was found best for higher tuber number. Planting seed tubers of Kufri Jyoti and Kufri Giriraj in the third week of April and Kufri Swarna should in the third week of June resulted in a higher number of seed-sized tubers (Muthuraj and Ravichandran, 2014). Following a paired row bed planting technique maximized seed tuber number and benefit-cost ration of it (Kumar *et al*., 2023).

Minhas *et al*. (2007) recorded the optimum photoperiod for TPS production as 12 h and a temperature of 24-26ºC for seed germination and seedling growth and 28-30 ºC for uniform root and shoot growth. A seed rate of 25-30 quintals of seed potato per hectare and spacing of 60 cm row to row and tuber to tuber spacing of 15-20 cm in ridges was followed in the seed plot technique. When the critical aphid population reached 20 aphids per 100 compound leaves the haulms were ready to be cut. The potato plants were inspected critically to produce true-to-type seed tuber critical field inspection and rouging.

Haulm cutting done 90DAP and seed tuber size used as 30-40 g yield highest seed size and total tuber yield (Kumar *et al*., 2009). The highest seed size and total tuber yield were obtained with the treatment combination of >30-40 g seed tuber size and haulm killing at 90 DAP.

Tubers are ready to harvest in March or 10-15 days after the haulm cutting. This allows 6 weeks between the harvest of the tuber and replanting the next season i.e. October. The harvested tubers can be sorted and graded into plain seeds with a diameter of 3.0 to 5.5 cm. The overdependency on the hill seed for potato crop raising as well as other topographical issues associated with the hill seed potato caused the adoption of the SPT of the seed potato production in plains (Singh *et al.*, 2019). However, the subsidiary seed potato quality derived from the informal seeds supply and costly certified seeds; accounting for 40-50% of the total cost of potato cultivation confronts the disadvantage of using high-volume seed tuber and pictures the advocation of microplant, micro tubers, aeroponic mini tuber and apical rooted cutting seed production technique (Sadawarti *et al*., 2021; Wasilewska *et al*., 2020). Another method to propagate potatoes is true potato seed, which bears major advantages over the seed potato such as it can be produced easily, it's non-bulky, easy to store and transport and bears a seed rate of 100-123 g/ ha which is very less as compared to the seed potato i.e. tubers (Pandey and Singh, 2017). As an initial step for hybrid or true potato seed production selection of parents could be done (Naik and Karihaloo, 2007) based on characters e.g. high yielding, disease resistant tuber that bloom under short days, bear high number of bold seeds per berry (Lindhout *et al*., 2011). Flowering was induced by a spray of GA (50 ppm) at the bud initiation stage. Spraying potato crops with Silverthiosulphate (2 mM Ag+) induced flowering for better berry setting and production of viable seeds without affecting pollen viability (Kumar *et al*., 2006). Hill potato is grown during summers hence they flower naturally in the long day conditions. But, in the plains of India the potato crop is taken up in winter hence for flowering induction extended light period of 4-5 hours was needed (Gupta *et al*., 2004). Both longer photoperiods and higher temperatures during flowering promoted the development of more inflorescence positions on the lateral stems of potato plants (Almekinders, 2004). The potato tuber yield by sowing True Potato Seed is 20-25 T ha^{-1}. Seed crops should be rogued and field inspection is done as done for solanaceous plants, except for the third roguing just before halum cutting to ensure the field is free of any virus-infected plants. However, its field and seed standards are different from solanaceous vegetables as presented in Tables 10, 11 and 12. Aeroponics is another high-tech technique to produce disease-free seeds, but due to more dependency on internationally available raw materials for basic setup and high cost, it may be not economical for small and marginal farmers (Buckseth *et al.*, 2016). But in the case of availability of local, non-expensive and good substrates, it can be thought of as a quick, easy and permanent system for getting high-quality seed potatoes (Kumari, 2019). There are studies that this soil-less system of seed potato production holds an advantage over the conventional system of seed production in case of disease pressure (Buckseth *et al*., 2020.).

Conclusion

The ultimate aim of a quality seed production programme is to make available to the farmers seeds of improved quality with breeders' techniques. However varietal seed production demands following the principles of quality seed production judicially using the updated standards of seed and field, following proper isolation distance and other seed production practices. Although these methods are on the verge of becoming obsolete, they are the basis of seed production of vegetable crops. This chapter hence focused on these methods and what effect these have had on the quality seed production chain of the nation.

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