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Vegetable seed production under protected and open field conditions in India: A review

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ABSTRACT

Vegetable crops faces tremendous challenges in the production of disease free, healthy and genetically pure seed for commercial cultivation. Conventional practices of seed production in open fields' faces common problems like lack of sufficient isolation, insects, diseases and a virus free environment. Compared to conventional practices, protected cultivation can deliver higher seed yield with better quality. Insects and viruses are the most devastating problems for quality seed production in most of the vegetable crops in open fields, and if the insect vectors are checked by using protected structures this problem could be solved with less application of pesticides. An innovation applicable in a very practical manner is always likely to get popularity to the assumed potential resulting in significant profit to the stakeholders. Seed production under protected conditions is a best example of it. A decade ago, research on seed production under protected conditions was initiated in India and tremendous work has been carried out to standardize the technology, i.e. for quality seed production realizing the various biotic and abiotic stress problems encountered in open field seed production programmes. The present review provides comprehensive information on significant research work done in India in hybrid seed production of vegetables under various protected and open field environment. This concept has shown significant results not only in quality seed production but also in increasing the per unit seed yield in different vegetables. The protected cultivation models has proved to be highly economical and profitable with limited resources and man power to provide best quality seeds of numerous vegetables cultivated in India and across the globe.

Key words: Abiotic and biotic stress, Cucurbitaceous and solanaceous vegetables, Insect proof net and naturally ventilated greenhouses, Productivity, Seed quality

India is the second largest producer of vegetables next only to China. Despite our all efforts in field of vegetable research and development, vegetable production in India has reached only 162.18 million tonnes from an area of 9.20 million ha with an average productivity of 17.6 tonnes/ha during the year 2012-13 (NHB 2013). The average vegetable productivity in India is much lower than developed and even developing countries in the world. The main reason for low productivity in vegetables in India is certainly non-availability of quality seed of improved open pollinated varieties or hybrids and the second reason could be very high cost of hybrid seed of different vegetables and more specifically in case of high value vegetables like tomato, sweet pepper, chilli and major cucurbits. High cost of seed is mainly due to poor seed yield in different vegetables in open field seed production programs. Suitable areas for quality seed production of important vegetables are also limited and in these areas too climate change and biotic and abiotic stresses have become a major problem in the way of quality seed production in open field conditions. The threat of climate change and its impact on agriculture is increasing and becoming a common phenomenon day by day and under such situation quality seed production in vegetables is going to be a major challenge. Therefore, it is of utmost importance to develop advanced technologies or methods for quality seed production, increasing the seed quality and seed yield in major vegetables in the event of continuously changing climatic conditions and increasing threat of new viruses, insects/pests and diseases in the country. Looking at these problem, recently there has been a technical shift towards the production of high quality hybrid seeds of important high value vegetables under protected conditions. With time it has also been proved that protected cultivation is a better technology to enhance land productivity and quality of the produce by providing a logical and technical solution to manage the major biotic and abiotic stresses encountered in open field cultivation of vegetable crops. The effectiveness of the technology has been observed world over for commercial cultivation of various horticultural crops. Hence, the area under protected cultivation in the

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last decade in various parts of the world has increased exponentially particularly in countries like China due to adoption of various protected cultivation technologies in different forms like mulching, use of temporary plastic walls in open fields, low tunnels, walk-in-tunnels, insect proof net houses, shade net houses and greenhouses. But, the selection criteria of protected structures to be used for vegetable seed production certainly depends upon few important factors, viz. climatic conditions of the area selected for seed to be produced, vegetable crop, type of seed crop, season of seed production and targeted quantity of seed production. Although, very limited work has been done throughout the world for comparing the seed yield and quality of the seeds of various vegetables grown in open field vs under protected conditions. But whatever work has been done on this aspect clearly reflects that there is a definite gap in the seed yield and seed quality grown under protected conditions in comparison to open fields. The review of the work done on these aspects of seed production of various groups of vegetables either of hybrid varieties or open pollinated varieties is summarized here as under.

Healthy nursery raising of vegetables for quality seed production

Healthy and virus free seedlings of the seed crop in case of OP varieties and healthy seedlings of the parental lines in case of hybrid seed production is utmost important for quality seed production in vegetable crops. Plug tray nursery raising technology has been standardized for different groups of vegetables under greenhouse conditions. In case of cucurbits off-season nursery raising technology of the major crops has also been standardized (Singh *et al*. 2007a). Studies on the effect of plug cell size, shape and cell volume in tomato crop has also been conducted and it has been clearly established that Tomato seedlings raised in round cells with cell volume of 68.2 cm^3 produced the highest shoot fresh weight (12.8 g), root fresh weight (5.2 g), root length (3.8 cm), leaf area (25.6 cm^2), stem diameter (3.1 mm), true number of leaves (3.0) and seedling dry weight (156.0 mg) followed by the seedlings raised in inverted pyramid shaped cells having a cell volume of 18.4 cm^2, whereas, seedlings raised in the smaller size inverted pyramid shaped cells of 8.6 cm^3 were poorest in quality (Singh *et al*. 2007b).

Cucurbits

*Pumpkin***:** Flemine (2009) and Flemine *et al.* (2012) compared two conditions, i.e. insect proof net house and open field for hybrid seed production of variety Pusa Hybrid 1 of pumpkin (*Cucurbita moschata* L.) and its parental lines during year 2008 and 2009 at IARI, New Delhi. The percentage of fruit set and extended production for pollination was almost doubled under insect proof net house in comparison to open field grown seed crops. Further seed yield and its contributing characters were significantly higher in insect proof net house as compared to open field. Seed yield/fruit (76.87 g), seed yield/plant (269.05 g), seed yield/ha (1452.87 kg) were also significantly higher under insect proof net house in comparison to open field. The physical parameters of seeds, i.e. seed width and seed coat weight was significantly superior in insect proof net house. The seed quality attributes under insect proof net house, immediately after harvest were significantly superior except germination percentage. Similar trend was also recorded for most of the seed quality attributes after 8 months of ambient storage. Moreover, no incidence of mottle mosaic virus and fruit fly was recorded under insect proof net house, whereas the incidence of MMV was very high under open field seed crop along with light incidence of fruit fly. Almost similar trend of results was also recorded in the parental lines of the variety Pusa Hybrid 1 under two sets of growing conditions as reported by Singh *et al.* (2010) in pumpkin under Delhi conditions.

Bitter gourd: In a similar study on hybrid seed production of bitter gourd (*Momordica charantia* L.) under insect proof net house and open field conditions. Jat (2011) recorded significant difference in seed yield and its contributing characters under insect proof net house as compared to open field grown seed crop. In bitter gourd, the hybrid seed yield/fruit (9.40 g), seed yield/plant (27.28 g), seed yield/ha (232.00 kg) were significantly higher under insect proof net house in comparison to open field (54.00 kg). The physical parameters of seeds, i.e. seed width and seed coat weight were significantly higher in insect proof net house. Similarly, the seed quality attributes under insect proof net house, immediately after harvest were significantly superior over open field seed crop (Anonymous 2008c). Similar trend was also recorded for most of the seed quality attributes even after 8 months of ambient storage. Moreover, no incidence of yellow mosaic virus and fruit fly was recorded under insect proof net house, whereas, the incidence of bitter gourd yellow mosaic virus and fruit fly was very high under open field crop. Similar results in bitter gourd seed production were also recorded by Basu *et al.* (2013) while conducting experiments on two bitter gourd hybrids (Pusa Hybrid 1 and Pusa Hybrid 2) during spring-summer and monsoon season under net house and open field conditions. They also reported that hybrid seed production of bitter gourd under open field conditions was affected severely due to heavy incidence of insect pests and the seed yield and quality was poor, whereas under insect proof net house conditions the seed crop was vigorous, insect free and exhibited higher fruit and hybrid seed yield with better quality seed. It was further reported by them that under net house conditions, on an average, 14-16 fruits/vine with fruit and seed weight of 160-200g and 3.01-4.10g/fruit respectively were borne/vine with high seed quality (> 94% germination) and seed yield of 2.5 kg of hybrid seed/100 sq m area of net house could be achieved per season. Joshi *et al.* (2013) further reported that reduction in pollen viability was more pronounced in open field conditions as compared to insect proof net house conditions in hybrid seed production experiments in bitter

gourd. Yadav (2013) and Yadav and Malabasari (2014) conducted an experiment on standardization of hybrid seed production techniques in bitter gourd under two sets of conditions, i.e. shade house and open field conditions in bitter gourd cv. Pusa Hybrid 2 and reported that shade house conditions are more favorable for higher seed yield and quality. Behera (2014) reported that gynoecious bitter gourd variety developed at IARI, New Delhi, India is suitable for protected cultivation which is resistant/tolerant to abiotic stresses and it is well suited for its seed production only under protected conditions Basu *et al.* (2014) also conducted several experiments on hybrid seed production of bitter gourd.

Summer squash: Seed production of summer squash (*Cucurbita pepo* L.) is normally limited upto the northern hills of India mainly due to high incidence of summer squash mosaic virus under northern plains during summer season. Therefore, an attempt was made by Aheer (2012) and Singh (2012) to assess the possibility of summer squash seed production under Delhi conditions in northern plains by growing crops under insect proof net house conditions taking Pusa Alankar, an F1 Hybrid developed by IARI, New Delhi, India. Aheer *et al.* (2012) studied the effect of growing conditions, time of pollination and fruit retention on hybrid seed production of summer squash. During the study, it was clearly recorded that seed crop of summer squash could be raised successfully under insect proof net house conditions in comparison to open field under Delhi conditions during summer season. It was reported that seed yield and its contributing characters were significantly higher under insect proof net house as compared to open field grown seed crop. Seed yield/fruit (38.47 g), seed yield/plant (73.09 g), seed yield/ha (1 096.42 kg) was significantly higher under insect proof net house in comparison to open field (316.88 kg). The physical parameters of seed quality, i.e. seed width and seed coat weight were significantly higher in insect proof net house. The seed quality attributes under insect proof net house, immediately after harvest were significantly superior over open field seed crop except germination percentage. The maximum percentage of fruit set (100%) was attained at 6.00 and 8.00 AM pollination in insect proof net house as compared to open field condition. The fruit weight and fruit length was significantly higher under both the conditions when pollination was done at 6.00 AM as compared to 8.00 and 10.00 AM. The incidence of summer squash mosaic virus was very high under open field as compared to insect proof net house grown hybrid seed crop. Similar results were also recorded by Singh (2012) for the OP seed production of summer squash variety Australian Green under Delhi conditions by using both the sets of conditions for seed crop cultivation. In the above study, seed yield and its contributing characters were significantly higher under insect proof net house grown OP seed crop as compared to open field grown seed crop. Seed yield/fruit (57.66 g), average number of fruits/plant (1.2), seed yield/ha (691.92 kg) was significantly higher under insect proof net house in comparison to open field (115.25 kg). Moreover, no incidence of summer squash mosaic virus was recorded under insect proof net house whereas the incidence of summer squash mosaic virus was very high (60%) in the open field grown seed crop.

Cucumber: Among the several cucurbits grown in India, cucumber (*Cucumis sativus* L.) is an important salad vegetable crop widely grown throughout the country. Quality seed production of cucumber under open field conditions is a major challenge due to high incidence of several biotic and abiotic stresses more specifically during rainy and post rainy season. Among the biotic stresses cucumber mosaic virus, insects like fruit fly and red pumpkin beetle and fungal diseases are the major challenges in open field cultivation of the seed crop. Similarly among the abiotic stresses, extreme temperatures (both sides lower and higher) is another major challenge in the northern plains of the country. Looking the problems and challenges encountered in quality seed production of the cucumber under open field conditions, hybrid seed production of the cucumber (var. Pant Sankar Kheera 1) was taken up under three sets of conditions, i.e. naturally ventilated green house, insect proof green house and open field conditions during two seasons (summer and *kharif*) with the clear cut objective to compare the effect of different growing conditions on the seed yield and seed quality in cucumber (Kaddi 2013). In all growing conditions, vine length and number of leaf nodes were significantly more in *kharif* season as compared to the summer season. Number of fruits reached to maturity was significantly higher in *kharif* (2.15) than summer season (1.90). The vine length, number of leaves, fruit weight, fruit length and fruit width were significantly higher under naturally ventilated greenhouse and insect proof net house conditions compared to open field during both the seasons. The number of seeds/fruit was significantly higher in insect proof net house (204.15) and naturally ventilated greenhouse (188.35) as compared to open condition (126.05). The seed yield/fruit, seed yield/plant and seed yield/1000 sq m were significantly higher in *kharif* season as compared to summer season. Whereas, higher seed yield was recorded in insect proof net house followed by naturally ventilated greenhouse and open field condition. The seed quality attributes, viz. germination percentage, seedling length, seedling dry weight, vigour index I and II and seed moisture content immediately after harvest were also significantly superior under naturally ventilated greenhouse and insect proof net house in comparison to open field conditions (Kaddi *et al.* 2014). Kishore (2005) also studied the effect of season, spacing and planting time on seed yield and quality in cucumber and reported significant differences among different treatments. Seed yield and number of seeds/fruit increased with decrease in spacing up to (1.25 m × 0.30 m) irrespective of season. The germination percentage was recorded lower in summer than *kharif.* Seed yield/fruit, 1 000-seed weight, seed yield/ha, seedling length, seedling dry weight and vigour sowing gave higher seed yield/ha (63.13 kg) with good germination

(81.38%) during spring summer. 31 index-I was recorded higher in summer than *kharif*. 20th July and 7th August sowing gave higher seed yield/ha (31st July, 41.58 kg and 7th Aug 39.37 kg) and germination (31st July, 93.31% and 7th Aug 87.31%).

Bottle gourd: Kalyanrao *et al.* (2015) studied the effect of pollination time on fruit set, seed yield and seed quality in bottle gourd **(***Lagenaria siceraria* (Molina) L.*)* cv Pusa Hybri 3 and reported that pollination at 2.00 PM gave higher fruit set percentage (78.84), number of fruits developed to maturity (20.70) along with significantly higher seed quality in terms of germination percentage (98.03), seedling length (32.36 cm), seedling dry weight (0.4108 g), seedling vigour index-I (3172.48) and seedling vigour index-II (40.26). Kalyanrao *et al.* (2012) studied the influence of vertical trailing on seed yield and quality in hybrid seed production of bottle gourd (cv Pusa hybrid 3) and recorded significantly higher vine length and number of nodes per vine at flowering period under vertical trailing system as compared to traditional method of growing bottle gourd seed crop. Kalyanrao (2012) and Kalyanrao *et al.* (2014) studied the effect of stage of harvest and post-harvest ripening of fruits on hybrid seed yield and seed quality in bottle gourd (variety Pusa Hybrid 3) during *kharif* season of 2009-10 and 2010-11, respectively, and reported that there is a significant increase in fruit weight, fruit length, number of filled seeds/fruit and seed yield/fruit, higher germination, seedling length, protein content in kernel and oil content in seed kernel in the fruits harvested at 60 days after anthesis (DAA). Significantly higher fruit weight, fruit length was recorded with 10 days of post-harvest ripening period, whereas number of filled seeds per fruit was higher at 40 days of post-harvest ripening period during both the years of experimentation. A similar study was undertaken by Kumar *et al.* (2014) to find out the effect of post-harvest ripening and drying methods on seed quality and seed storability of pumpkin (variety Pusa Hybrid 1) and this study was carried out during 2008-09 and 2009-10, at IARI, New Delhi. The results showed that seeds obtained after 20 days of post-harvest ripening followed by shade drying gave superior quality seeds with higher germination, seedling length, vigour index-I and electrical conductivity as compared to other treatments of post-harvest ripening and drying. Among all the treatments, seeds stored for 12 months showed maximum germination followed by significant reduction in germination after 18 months of storage. The germination percentage was maintained above the Indian Minimum Seed Certification Standards (MSCS) of 60 percent up to 18 months of storage in all the treatments. Kalyanrao *et al.* (2013) suggested that hybrid seed production of bottle gourd under protected conditions is highly remunerative. Pham (2006) and Pham *et al.* (2007) conducted experiments on hybrid seed production in bottle gourd under two sets of climatic conditions, i.e. open field and poly house conditions and reported that poly house conditions are more favorable for higher hybrid seed yield and seed quality. Kumar *et al.* (2014) also suggested that hybrid seed production of pumpkin is a highly economical venture under insect proof net house conditions in comparison to open field under Delhi conditions.

Melons: In muskmelon *(Cucumis melo* L.*),* mostly andromonoecious varieties or hybrids are grown worldwide either in open field conditions or under protected conditions. Under both the conditions honey bees are the pollinators for melon crop. Singh (2002) reported that among different bees, honey bees (*Apis mellifera* L.*)* are the most effective insect pollinators for greenhouse grown muskmelon crop either for commercial production or for seed production programs.

Solanaceous vegetables

Tomato: In India, seed production of tomato (*Solanum lycopersicum* L.) is mostly limited to southern states of the country like Karnataka, Telangana, Seemandhra etc. due to availability of long period for optimum pollination and fruit set, which otherwise is not available in Northern plains of the country. In tomato, the stigma receptivity, pollen viability, fruit set and seed yield are greatly affected by temperature and humidity. Several workers reported reduced fruit set and weight due to low pollen production and pollen viability under low temperature. The pollination in hybrid tomato seed production programmes are usually done in morning hours in southern and western parts of India (Anonymous 2008a). Temperature, RH, wind velocity and presence of moisture on stigma influences fruit set. Generally pollination is practiced during morning time in hybrid seed production of tomato. In northern plains, during rainy and post rainy season severe incidence of tomato leaf curl virus (TYLCV) is a major constrains, whereas during winter season extreme low temperature (from end of November to mid-February) and thereafter, sharp rise in temperature during summer season is another major limitation for tomato seed production. Therefore hardly mid-February to maximum mid-March is the optimum period for maximum pollination and fruit setting. To solve the above problems encountered in tomato seed production, in the last decade lot of work comparing protected and open field conditions has been carried out in various institutions more specifically at IARI, New Delhi. Manjunath (2008) and Manjunath *et al.* (2010) conducted extensive research work on tomato hybrid seed production in Pusa Divya an F1 hybrid, under two sets of conditions, i.e. open field and naturally ventilated greenhouse during *rabi* 2005-06 and 2006-07, at IARI, New Delhi (Anonymous 2007). The results showed that pollination could be done even in the evening time, if the temperature is not too high. Pollination at 9.00 AM and 5.00 PM is better for higher fruit set and seed yield. However, under naturally ventilated greenhouse conditions, pollination could be done throughout the day, starting from 8.00 AM, as the fruit set was above 90% and there was not much variation among the treatments except 7.00 AM which recorded significantly higher fruit set (53.5%) and seed recovery (4.75%) per plant with 11.00 AM pollination followed by 10.00 AM and 12.00

noon pollinations. Kumar *et al.* (2008) also recorded higher fruit yield, fruit set, seed yield, 100 seed weight and germination with higher seed vigour, if pollination is done at 10.00-11.00 AM under Southern Indian conditions.

Patta (2010) and Patta *et al.* (2013) conducted experiments to compare the effect of two sets of growing conditions, i.e. naturally ventilated greenhouse and open field on hybrid seed yield and seed quality in tomato (variety Pusa Hybrid 4) during *rabi* 2005-06 and 2006-07, at IARI, New Delhi. The effective tomato crossing period under greenhouse conditions was started two weeks before and extended four weeks beyond the normal crossing period under open field conditions. Total number of days available for pollination was almost double under greenhouse condition in comparison to open field making tomato hybrid seed production highly economical. The effect of pollen storage, pollen viability and methods of pollination were also studied to assess their effect on hybrid seed yield and seed quality. It was further recommended that this research can greatly help Indian seed industry to make an effective and efficient planning of tomato hybrid seed production under North Indian conditions during *rabi* season with the help of greenhouse protected technology. A study was undertaken on hybrid seed production of tomato by taking three hybrids, viz. Pusa Hybrid 1, Pusa Hybrid 2, Pusa Hybrid 4 and four growing conditions, viz. semi-climate controlled green house, naturally ventilated green house, insect proof net house and open field conditions The study revealed that seed yield varied under various growing conditions in Pusa Hybrid 4 and it was found highest under semi-climate controlled green house (3.16 kg/100 sq m) followed by naturally ventilated green house (1.87 kg/100 sq m) and insect proof net house (0.59 kg/100 sq m), respectively (Anonymous 2009).

Max *et al.* (2009) studied the effect of greenhouse cooling methods on growth, fruit yield and quality of tomato and reported that greenhouse conditions are more favourable for higher seed yield and quality in tomato. Banda and Paxton (1991) reported that bumble bees were found to be the most effective pollinators for greenhouse tomato seed production crops in comparison to honey bees. Singh (2002) also reported that bumble bees are the most effective insect pollinators for greenhouse grown tomato as well as cherry tomato either for commercial production or for the seed crop.

Cherry tomato: Vidyadhar (2013) and Vidyadhar *et al.* (2014a) conducted experiments to compare the effect of four sets of growing conditions (semi-climate controlled greenhouse, naturally ventilated greenhouse, insect proof net house and open field) on seed yield and seed quality of cherry tomato **(***Solanum lycopersicum* var. *cerasiforme)* (variety Pusa Cherry Tomato 1) during *rabi* season of 2010-11 and 2011-12, respectively at IARI, New Delhi. Among the structures semi-climate controlled greenhouse gave higher berry weight (7.67 g), number of seeds/berry (60.66), 100-seed weight (0.1328 g), seed yield/berry (0.0912 g), germination (84.90%), vigour index-I (650.64), vigour index-II (1.47) and lower EC (0.0086 µS/g/cm), as compared to naturally ventilated greenhouse and insect proof net house growing conditions. The retention of 5 truss/plant (V1=5 truss/plant) recorded higher berry weight (7.37 g), number of seeds/berry (63.25), 100-seed weight (0.1319 g), seed yield/berry (0.0886 g), germination (84.68%), vigour index-I (640.97), vigour index-II (1.43) and lower EC (0.0083 µS/g/cm), as compared to (V2= 7 truss/plant) and (V3= 9 truss/plant). In cherry tomato the thinning of berry, i.e. B1=10 berry/truss has also given significantly higher mean berry weight (8.21 g), number of seeds/berry (61.53), 100-seed weight (0.1323 g), seed yield/berry (0.0913 g), germination (86.01%), vigour index-I (651.96), vigour index-II (1.46) and lower EC (0.0080 µS/g/cm) in comparison to 15 berry/truss and 20 berry/truss. Vidyadhar *et al.* (2014b) further investigated the influence of stage of fruit maturation on seed yield and seed quality traits in cherry tomato (variety Pusa Cherry Tomato 1) under four sets of growing conditions and reported significant increase in berry weight, seed yield/berry and seed quality traits from 15 days after anthesis (DAA) to 65 days after anthesis (DAA). It was further recorded that majority of the seed yield and seed quality traits were significantly higher under semi-climate controlled greenhouse conditions as compared to naturally ventilated greenhouse, insect proof net house and open field conditions. Vidyadhar *et al.* (2015) also conducted an experiment to study the effect of method and time of pollination on seed yield and seed quality parameters in cherry tomato grown under different protected conditions. During the experimentation it is clearly apparent that semi-climate controlled greenhouse conditions are highly suitable for producing highest fruit set of mature berries (40.99%) in comparison to naturally ventilated greenhouse (40.51%) and insect proof net house (39.25%). Among the methods of pollination use of air blowers were recorded most efficient for highest fruit set (41.76%) followed by other seed quality parameters.

Capsicum: In capsicum (*Capsicum annuum* L.), the incidence of viruses, insect pests and extreme temperatures (i.e. minimum and maximum) are the major problems in quality seed production under open field conditions. Protected conditions in form of insect proof net houses and greenhouses provides the best opportunity for virus free quality seed production of capsicums. Although, very scanty and limited research work has been done for comparing the cultivation of capsicum seed crop under open field conditions vs. under protected conditions throughout the world. But several private seed companies across the world are producing high value low volume hybrid seed of capsicum only under protected conditions. Therefore, at IARI, New Delhi a research experiment was conducted for comparing open field, poly house and net house conditions for hybrid seed production of capsicum variety KTCPH 3 and it was found that poly house and net house conditions are always better and economical for hybrid seed production of capsicum under Delhi conditions (Anonymous 2008b). Similar work for comparison of open

field vs. protected conditions for capsicum cultivation has also been conducted by Singh *et al.* (2011) under Uttarakhand conditions of India and it was reported that protected conditions are always better for higher yield and quality in capsicum crop. Singh *et al.* (2005) also compared open field and insect proof net house conditions for capsicum cultivation under Delhi conditions and it was reported that nylon mesh screens reduced leaf curl virus incidence and improved the yield of capsicum. Dag *et al.* (2008) studied the effect of honeybee pollination on various fruit characteristics of several cultivars of sweet pepper under net house conditions in Israel and reported that in all the 16 cultivars examined during two growing seasons, bee pollination in net house increased the number of seeds per fruit, had a significantly positive effect on fruit placenta weight, fruit weight, fruit width and fruit-wall thickness. Terry (2000) reported that greenhouses and screen houses are routinely used in pepper breeding programmes as they are a convenient way to obtain controlled self-pollination in pepper without covering plants in the open field.

Brinjal/Egg plant: In brinjal (*Solanum melongena* L.), seed production programmes, shoot and fruit borer and extreme temperatures (i.e. maximum and minimum) are the major challenges under open field conditions more specifically during rainy and post rainy season. Therefore, experiments were conducted for comparing open field and protected growing conditions on hybrid seed yield and quality of brinjal (Singh *et al.* 2013). They found that the seed crop under insect proof net house was much superior in terms of seed yield and seed quality due to very low incidence of insects like shoot and fruit borer and little leaf disease of brinjal. Basu *et al.* (2010) reported that hybrid seed production of brinjal can be undertaken successfully in Northern India under insect proof net house during *kharif* season. Under net house conditions where the crop was more vigorous, insect free, had longer stigma receptivity, pollen viability, higher fruit and seed yields and better seed quality as compared to that of open field conditions. An average hybrid seed yield of 2.0 kg could be achieved from an area of 100 sq m. Singh and Tomar (2006) compared seed production of OP variety of brinjal under insect proof net house and open field conditions and reported that insect proof net house condition is highly suitable for quality seed production of brinjal in northern plains of India.

Singh *et al.* (2013) outlined that the major objectives of vegetable seed production under insect proof net houses are to grow virus free seed crops, protect the seed crops from major insects/pests like shoot and fruit borer in brinjal, fruit borer in okra and tomato, fruit fly and red pumpkin beetle and leaf minor in cucurbits and solanaceous vegetables. Insect proof net house also provides protection to the seed crop against mild frost condition. Low cost protected structures like walk in tunnels and plastic low tunnels could be used for off season seed production or advancing the season of seed production, but these structures are technically suitable only for northern plains of India during winter season. The Centre for Protected Cultivation Technology, IARI, New Delhi has standardized the technology for quality seed production of vegetables and hybrid seed production of important vegetables like pumpkin, bitter gourd, cucumber, summer squash and brinjal under insect proof net houses. Hybrid seed production using insect proof net houses was found to be highly profitable venture for progressive farmers in various regions of the country.

The above studies has clearly demonstrated the advantages of hybrid seed production of vegetables under protected conditions which are summarized below.

The major advantages of vegetables seed production under protected conditions are: (i) High seed yield generally 2-4 times more compared to open field in major vegetables. (ii) Quality of seed is always high compared to open field produced seed. (iii) Requirement of large isolation distance in cross pollinated vegetables can be minimized under protected conditions. (iv) Problem of synchronization of flowering in parental lines can be minimized. (v) Maximum plant population can be maintained along with appropriate ratio of male and female parents for higher hybrid seed yield. (vi) Seed production under adverse climatic conditions is possible where it is not possible in open field conditions. (vii) Duration of seed crop is more under protected conditions when compared with open field seed crops. (viii) Field standards could be enforced well under protected conditions and healthy virus free seed crop can be grown, which is very difficult under open field conditions. (ix) Training, pruning and hand pollination practices are very easily manageable under protected conditions compared with to field seed crop. (x) More number of seed crops could be grown under protected conditions. (xi) By using soil less media, seed crops can also be grown even under saline and acidic soil conditions. (xii) Protected conditions provide the best opportunity for organic seed production in vegetables. (xiii) Judicious use of natural resources like soil and water is possible for seed production under protected conditions. (xiv) Virus free healthy seedling production of the parental lines is possible under protected conditions. (xv) Grafting technology in seedling could be easily applied to overcome soil borne problems in solanaceous and cucurbitaceous vegetables. (xvi) Quality seed production of vegetables could be under taken by agri-entrepreneurs in various regions of the country and this in turn could generate lot of employment opportunities in rural areas. (xvii) Seed production cost of vegetables could be reduced by growing seed crop under protected conditions. (xviii) In hybrid seed production, emasculation of female parents is not required as there are no insect pollinators inside the protected structures. (xix) Complete protection of the crop from rodents and birds compared to open field seed crops. (xx) Seed crops will not be damaged by un-seasonal rains at the time of their maturity unlike open field seed crops. (xxi) Off type plants, objectionable weeds or plants affected by designated diseases cannot pose problems in the seed crops raised

under protected conditions. (xxii) Seed viability and seed vigour could be extended through better nutrient management in seed crops under protected conditions.

The present review on vegetable seed production (both in open field and under protected conditions) has clearly revealed that seed yield and quality is always better when seed production is undertaken in protected conditions. Semi climate controlled greenhouses were found to be ideal for indeterminate type hybrids/varieties of standard tomato, cherry tomato, sweet pepper and parthenocarpic cucumber. Seed yield of such crops could be increased 2-3 times compared to the open field. Beside the quality of seed is also superior. Similarly, zero energy naturally ventilated greenhouses have also been found equally suitable for hybrid seed production of high value vegetable crops. Here also the seed yield is also usually 2-3 times more than open fields, but the cost of seed production could be only half (1/2) of the seed produced under semi-climate controlled greenhouse conditions. Naturally ventilated green houses with good side and top ventilation could be used in northern and central plains of India, whereas insect proof net houses could be used for large scale seed production programs in low rainfall areas including arid and semi-arid regions of the country.

Insect proof net houses were found to be most efficient among the low cost protected structures suitable for quality hybrid or seed production of OP and hybrid varieties of a large number of vegetables, viz. tomato, sweet pepper, chilli, okra, brinjal and important cucurbits. The major advantages of seed production under insect proof net houses are virus free seed crops, protection of seed crop against other major insects/pests like shoot and fruit borer in brinjal, fruit borer in okra and tomato, fruit fly in cucurbits, leaf minor in cucurbits and solanaceous vegetables and red pumpkin beetle in cucurbits. Not only this, insect proof net house also provides protection to the seed crop even under mild frost conditions. Insect proof net houses can be developed as temporary or permanent structures according to regional requirements. Low cost temporary protected structures like walk in tunnels and plastic low tunnels could be used for off season seed production or advancing the season of seed production, in northern plains of India during winter season.

The above mentioned findings clearly reflect the advantages of vegetable seed production under protected conditions. The above review clearly outlines the excellent potential of insect proof net houses and naturally ventilated greenhouses for quality hybrid seed production of crops like pumpkin, bitter gourd, bottle gourd, summer squash, cucumber, tomato, cherry tomato, brinjal and capsicum. Protected cultivation provides the necessary environment to overcome the biotic and abiotic stress enhance yield as well as the quality of seeds. Disease free planting material is a pre-requisite for harvesting high yield, and protected cultivation offers very congenial environment for producing healthy, virus free, genetical pure hybrid seed with higher seed yield per unit area. The studies reviewed were mainly conducted in the sub-tropical and semi-arid conditions of India. But these models could be replicated in other parts of the world where similar situation prevail and vegetable seeds are in high demand. The beauty of vegetable hybrid seed production under protected conditions is that it could be implemented at a micro or macro level depending upon the need, space and seed crop requirements. Enterprise establishment in form of vegetable seed production under protected conditions can be the future of the country as day by day biotic factors are breaking the genetic resistance of the genotypes/varieties/hybrids which will certainly increase the cost of per unit seed. But for getting high success rate of the technology, an effective management and maintenance of the protected structures is very much needed and it is also an effective approach for showing versatile potential of protected cultivation technology for hybrid seed production in vegetables.

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