



The Effects of Plant Density on the Productivity of Tomato Hybrids in a Newly Developed Low Cost Naturally Ventilated Greenhouse

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Authors' contributions

This work was carried out in collaboration among all authors. Author SKS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BPS, MK and BRS managed the analysis of the study. Authors MKS and SS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Looking into the variations in the design of greenhouses and cost factor, a two-span saw tooth type low cost naturally ventilated greenhouse (NVG) of 250 m² area was designed and developed. The galvanized iron (GI) framed NVG covered with 200µ ultra-violet (UV) stabilized plastics sheet, consisted of cross and ridge ventilation, shade net, fogging and drip irrigation systems. Effect of spacing and tomato hybrid on yield and yield attributing traits of tomato were studied under NVG. Twenty-three days old seedlings of four tomato hybrids viz. Rupali, Pusa Hybrid-2, Naveen 2000 and Avinash-2 were transplanted at three different spacing (60 x 60 cm, 45 x 45 cm and 60 x 45

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cm) inside the NVG. The results showed that increasing the spacing significantly increased the number of fruits, average fruit weight, fruit yield per plant, yield per unit area (kg/m^2) and marketable fruit yield per plant. It was noted that the significantly highest fruit yield was recorded under wider spacing of 60 x 60cm over other spacings. Among the different tomato hybrids, Naveen-2000 significantly produced higher yield ($12.55 \text{ kg}/\text{m}^2$) and yield attributes over other and statistically at par with Avinash ($12 \text{ kg}/\text{m}^2$). The developed NVG was indigenous, simple to erect and performed well for tomato crop production. The efforts will enhance the application of greenhouse in arid and semi-arid regions of India.

Keywords: Protected cultivation; tomato hybrids; greenhouse; natural ventilation; spacing.

1. INTRODUCTION

The cultivable land area is decreasing daily due to rapid urbanization industrialization and shrinking of land holdings. Worldwide, vegetable production has increased remarkably, but due to the ever growing population, we will require a 60% increase in agricultural and horticultural production in the year 2050 [1]. Cultivation under open field condition does not yield standard quality of vegetables as year-round out door cultivation is mainly restricted by biotic and abiotic stresses. Protected cultivation paves the way for year-round cultivation with the optimum use of land and vertical space for high productivity and high quality. In the present scenario, greenhouse technology is the best way to achieve protected cultivation, where vegetables can be grown under atleast a partially controlled environment. Greenhouses are designed based on the climatic condition of the location using sound engineering principles, design consideration with respect to orientation, size, shape, locally available structural materials, covering materials and ventilation. Due to Dr. Emery M. Emmert's efforts, poly houses were designed and developed replacing the glass houses in 1948 [2]. Later on, efforts were made to develop fan-pad cooled greenhouses in India. Several designs of greenhouses were proposed by [3]. Greenhouse applications are limited to the fruits and vegetables production and can be used for dehydration of leafy vegetables [4,5]. Depending upon the automation level, the greenhouses are classified into three main groups viz. low, medium and high tech [6]. Low tech refers to partially controlled and cost-effective greenhouse. Suitable designs are of utmost important as high cost involved in the construction of the greenhouse limits the farmers' adoption of this technology. A comprehensive review of low-cost greenhouse technologies has been done by [7,2].

Gupta and Chandra [8] analysed various energy conservation measures to achieve different

design features for energy- efficient greenhouses in Delhi, India. Natural ventilation, shading and fogging or misting system can be successfully adopted to control the microclimate and optimum plant development and productivity with reduced solar radiation and air temperature [9]. Ishii et al. [10] found that the air humidity inside a semi-arid greenhouse decreased with an increase in ventilation rate. Singh et al. [11] studied the temperature and humidity regimes in NVG and fan-pad cooled greenhouses and kept that natural ventilation is more effective in mild climatic conditions than fan pad evaporative cooling. Singh et al.[9] developed solar dryer for dehydration of fodder crops and observed 39.8°C temperature under the dryer when the ambient temperature was 29.5°C . Marcelis and de Koning [12] observed an NVG works effectively in a temperature range of $15\text{-}35^\circ\text{C}$. The combination of the ridge (roof) and side (cross) ventilation works more efficiently in reducing temperature and relative humidity compared to roof alone ventilation [13]. Hermanto et al. [14] optimized the greenhouse ventilation area in an NVG under the cropped condition. They reported that the ventilation area of 60% provided at ridge and sides could maintain an encouraging greenhouse environment throughout the year for crop growth. Kittas et al. [15] reported a 50% tomato commercial production under shaded conditions than non-shaded conditions. Arbel et al. [16] tested fog system's efficiency with a droplet size of 2 – 60 μm with high-pressure nozzles inside a greenhouse. They concluded fog system as superior to fan-pad system when temperature and relative humidity variations were less than 5°C and 20% respectively. The naturally ventilated low-cost greenhouses with more vertical space respond slowly to the ambient conditions and provide uniform environmental conditions inside the structure [17]. Pack and Mehta [18] designed the low-cost greenhouse for East Africa to give alternate solutions to high-cost greenhouses. Handarto et al. [19] investigated the effects of fogging duration on the

greenhouse climate and the evaporative cooling efficiency using a single-span greenhouse with ridge and side vents. Ishii et al. [20] investigated the relations between the ventilation rate (as a function of inlet vent configuration) and internal/external environmental conditions in an NVG with a high-pressure fogging system. To sustain maximum agricultural yield, Akrami et al. [21] reviewed the greenhouse ventilation requirement.

Tomato (*Lycopersicon esculentum*) is one of the most popular greenhouse vegetable globally [22]. People realize the importance of tomatoes in their diets because of taste and nutritional quality, which are vital for the body. Under greenhouse condition, determinate and indeterminate varieties of tomato crop can be successfully grown [23]. A detailed review of tomato by-products and their benefits for human beings have been mentioned by [22]. Chandra et al. [24] worked to develop a decision support system for tomato production under a fan-pad cooled greenhouse. Varietal evaluation of tomato regarding suitability in the protected condition is a very important factor for improving the yield and quality of tomato in the present context of changing world. Among the various elements, spacing is an important factor that influences the yield of tomato under protected condition. Shamshiri et al. [25] evaluated the optimum temperature and humidity condition at different growth levels in tomato greenhouse cultivation. Murthy et al. [26] studied tomato production under low cost naturally ventilated polyhouses in Karnataka state, India. They found the tomato cultivation as a profitable venture if the capital cost of the polyhouse is reduced by 60%. Singh et al. [27] reported tomato cultivation under NVG as a profitable venture with a BC ratio of 1.92, a payback period of fewer than 3 yrs, and the net return of Rs. 75/m².

Similarly, [28] analysed the economics of capsicum cultivation under low cost naturally ventilated polyhouse in Northern Karnataka, India and reported the benefit-cost (BC) ratio (3.92). Banaeian et al. [29] evaluated economics of greenhouse strawberry production in Iran's Tehran province and observed the net returns and BC ratio as 151907.91 \$/ha and 1.74 respectively. Chand [30] economically evaluated one such cucumber producing naturally ventilated polyhouse located in Kerala (India) and revealed that if the cucumber was fertilized at the rate of 100% of the recommended dose, the highest BC ratio (3.42) was obtained. Tarannum et al. [31] evaluated the economic

performance of naturally ventilated low-cost polyhouse for carnation (Soto) cultivation located in Karnataka (India) and found the BC ratio of 2.50.

The above background indicates the development of the improved design of NVG and its evaluation for vegetable crops. The scientific information on the structural development of greenhouse and performance of tomato yield and its economics still lacks for semi-arid regions. Therefore, a study was carried out to develop an indigenous design of NVG suitable for India's northern plain and to evaluate its performance for tomato crop at different spacing and hybrids of tomato.

2. MATERIALS AND METHODS

2.1 Development of Naturally Ventilated Greenhouse (NVG)

A low-cost NVG was designed considering the height of the greenhouse, ventilation from sides and ridges, shading, overhead misting system for reducing temperature and maintaining humidity in summer and erected at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, UP (India). Geographically, Meerut is located at 29°01' north latitude, 77°45' east longitude and at an altitude of 219.75 m above the mean sea level. This belt's climate is a semi-arid and sub-tropical region with extreme weather conditions, consisting of hot dry summer and cold winter. The temperature fluctuates from summer to winter ranging from 42 to 45°C (May – June) to 3 to 9°C (December – January). The sketch diagrams of the NVG design are shown in Figs. 1 & 2, and the isometric views of the developed greenhouse are demonstrated in Figs. 3 & 4. The designs and development procedure of different components of NVG have been discussed below:

2.1.1 Structure

A size of 250 m² and two spans saw tooth type shape was selected which permits the incorporation of multi-span feature of the structure and is large enough for vegetable cultivation needed for standardization of greenhouse technology. To provide cross ventilation inside the proposed NVG, the straight portion (length side) should be large enough as compared to the width side. Therefore, the dimension of 25 m x 10 m for the erection of the greenhouse was selected along with the gutter height and centre heights of 4 m and 5 m

respectively. The heights for the left and right straight portions of the NVG were 4m and 5 m above the ground level, respectively, if we see from the front side. Poles of GI square pipes having sizes 47 mm x 47 mm of lengths 4.7 m and 5.7 m were used as side pillars and central posts. The pillars and central posts were spaced at a 2.5 m interval. The side pillars' height on straight portions was 4 m and 5m above the ground level, and the central pillars at 5m above the ground level. The ridge pole was run on the top of the central posts from end to end. A separate central pole was run at one meter below the ridge pole connecting all the central poles. These poles (ridge pole and central pole) were welded at all those locations where central pillars were located. GI pipes were also run on the top of the side pillars on either side at the eve level. The GI square pipes of size 32 mm x 32 mm were used as purlins and hoops. The purlins were welded on each side. The hoops were welded on top extending from the top of one straight portion to the upper central ridge pole (in Ist span) and the other straight portion to the lower central ridge pole (in IInd span). There was a gap of 1m between the upper ridge pole and lower central pole running along the structure's entire length. The gap between the upper central ridge pole and the lower central pole is served as a ridge ventilator.

2.1.2 Cladding material

The structure was covered with a 200 μ UV stabilized LDPE sheet. The sheet was lifted to the structure's height and spread on the right side, running from the lower central pole to the right eve level and fixed in position by nailing all along the length and width. Later, aluminium flats were nailed over the sheet to keep it adhered to the GI pipes and eliminate the sheet's fluttering due to wind. While spreading and fixing the sheet, the folds, wrinkles and irregularities were adjusted and removed. Similarly, on the other side from the left eve level to upper central pole, LDPE sheet was fixed. After completing the cladding on the top, the sides, front and rear sides were covered, nailed with aluminium flats in horizontal position. The ventilator's opening was covered with insect proof net to prevent the accessibility of insects, etc. Over the ridge ventilator, the LDPE sheet was also fixed so that it can be rolled up or rolled down depending upon the necessity. Insect proof net upto a height of 3 m above ground level was fixed on the

straight portions (i.e. length sides) using aluminium flats. On the straight portions, the polyethylene film was fixed over the insect-proof net so that it can be rolled up or rolled down as per the need.

2.1.3 Ventilation

Natural ventilation is used to take advantage of moderately warm climates or in hot arid climates, depending upon the wind's availability and dependability. The two types of ventilation namely, ridge and side ventilation are used, assuring the total ventilation area of 60 % of the greenhouse floor area. The ridge ventilation (ventilation at the top of the structure) running the full length of the greenhouse continuously was provided in such a way that the leeward side of the ventilator is towards the opposite side of the prevailing wind direction in that area i.e. the orientation of these cross ventilators was arranged in such a way that their opening is perpendicular to the direction of the prevailing winds in that area. Side ventilation on each straight portion (3m height x 25m length) was provided by fixing the insect-proof net so that the UV stabilized LDPE sheet fixed over this net can be rolled up or can be rolled down depending upon the necessity. The total opening area of the ridge ventilator and side ventilators were 25 m² and 150 m², respectively, which in total was 70% of the floor area.

2.1.4 Door and isolation chamber

A GI framed door (2 m x 1.2 m) on the front side of NVG along with an isolation chamber (2.5 m x 3 m x 2 m) outside the door covered with UV stabilized insect-proof net were provided to allow the entry of worker and to restricts the entry of insects and pests inside the NVG.

2.1.5 Shading, over head misting and drip irrigation system

To reduce temperature and to maintain optimum humidity level, an over head misting system was provided with the provision of 80% green shading net (during summer) at gutter height. Misting system (250-500 l/hr) was having a timer, 1hp mono-block pump and 1000 litre plastic tank. The drip irrigation system consisted of a 1hp mono-block pump, a screen filter, one plastics tank (500 l), laterals and nozzles.

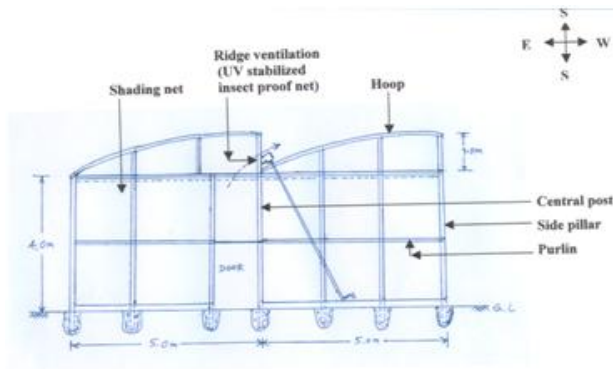


Fig. 1. Sketch diagram of the front view of NVG

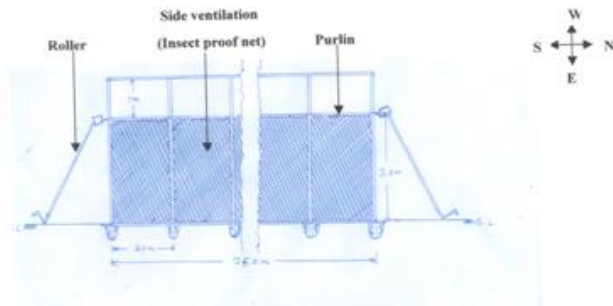


Fig. 2. Sketch diagram of the left side view of NVG



Fig. 3. Isometric side view of NVG



Fig. 4. Isometric front view of NVG



Fig. 5. Views of tomato hybrids inside the NVG

2.2 Evaluation of NVG for Tomato Production

The experiment was laid out using a split-plot design with three replication where under three spacing (60 x 60 cm, 45 x 45 cm and 60 x 45 cm) and four hybrids (Rupali, Pusa hybrid-2, Naveen 2000 and Avinash-2) of tomato were considered as main plot and sub plot treatment, respectively. Twenty-three days old seedlings were transplanted under NVG according to different spacing under different plots, each of the size 5 m². The standard package of practices and plant protection measures were adopted to raise a healthy crop during the crop period. Nylon strings were used for training the plant vertically. The tomatoes' seedlings were raised under plastics bags (10 cm x 6 cm size). Seeds were sown in these plastics bags filled with compost, peat and sand sand in the ratio 2:1:1. Three seeds were sown in each polybage. At 2-4 true leaf stage, seedlings were transplanted. The soil of the experimental field was sandy loam (65.2% sand, 18.8% silt, 16% clay) in texture alongwith the level of nitrogen (205 kg/ha), phosphorus (11.4 kg/ha) and potash (162.5 kg/ha). The soil was alkaline (8.1 p^H) in reaction with electrical conductivity value of 1.93 ms/cm. Weekly pruning and weeding were done. Various growth and yield parameters viz. height of the plant, flowering date, date of fruit set, number of harvests, number of fruit/plant and weight of fruit/plant were recorded from randomly selected five plants from each of the plots. The fruit yield per plant, fruit yield per plot and numbers of fruit per plot were recorded regularly at each harvest. Because of the closed structure and natural ventilation, mostly the tomato fruits were disease free. The diseased free tomato fruits were considered as marketable fruits. Any fruits, affected with insect pests were considered as non marketable fruits. Data were statistically analyzed using computer software subjected to

the standard procedure of the split-plot design as suggested by Panse and Sukhatme [32] for each of the characters separately. Views of tomato hybrids inside the NVG are shown in Fig. 5.

3. RESULTS AND DISCUSSION

The experimental data on different growth stages, yield variations among the hybrids and yield attributing tomato traits as influenced by spacing under the greenhouse are shown in Table 1-2. The bar diagrams produced using these tables are also shown in Fig 6-9. Average maximum plant height (410 cm) was observed after the last picking of tomato. Lekshmi and Celine, [33] also kept 2.8 m height of hybrid Naveen 1. Optimum temperature and better light distribution might have contributed to better crop growth. Ganesan, [34] also reported better plant height in polyhouses as compared to open field conditions. The average number of days to flowering was 26 days among the hybrids. Variation in the number of days to first flowering which varied from 25 to 30 days after transplanting, was reported in previous studies [35] in tomato hybrids.

3.1 The Number of Fruits Per Plant

It is evident from the Fig. 6 that wider row spacing (60x60 cm) significantly recorded more fruits per plants over others. The effects of closer row spacing (45 x 45cm and 60 x 45cm) were statistically inferior compared to wider row spacing. This was because of effective fruit setting in prevailed condition and resulted in more fruit/plants under wider spacing than closer spacing. Among the tomato hybrids, Naveen-2000 performed better by recording a higher number of fruits per plant (60.80) over others (Fig. 7). Still, this variety was recognized statistically at par with hybrid Avinash-2 (58.11)

for the same characters. It might be due to the genetic characters of the hybrids accomplished with protected conditions. The results align with [33] who observed maximum fruits/plant (35.66) for polyhouse tomato F1T30 as 35.66. The results were also supported by [36] in tomato under net house conditions.

3.2 Average Fruit Weight (g)

The individual fruit weight (Figs. 6 and 7) was influenced due to the spacings and the use of different hybrids of tomato. Wider spacing (60 x 60 cm) significantly produced a higher individual weight of fruits (90.3 g) as compared to closer spacings (60 x 45 cm and 45 x 45 cm). Wider spacing is accomplished with more light penetration and open aeration, resulting in more dry matter production and, consequently, more dry weight of fruits than to closer spacing. Hybrid Naveen-2000 recorded higher fruit weight (97.24 g), which was significantly superior over others viz. 75.06g for Pusa hybrid 2, 70.08 g for Rupali and statistically at par with hybrid Avinash (93.74 g) due to genetical characters accomplished with protected conditions. Arora et al., [37] and Cheema et al., [36] also reported similar variations under protected cultivation.

3.3 Fruit Yield Per Plant

The fruit yield per plant (Fig. 8) was found higher (4.01 kg) under wider spacing (60 x 60cm) as compared to closer spacings. Among the hybrids, hybrid Naveen-2000 produced maximum fruit yield per plant (4.40 kg) followed by, Avinash-2 (4.11 kg), Rupali (3.85 kg) and minimum fruit yield per plant were registered with Pusa hybrid 2 (3.54 kg). Maximum fruit yield per plant of tomato hybrids was due to higher fruit set and higher retention of matured fruits/ plant. The high yield recorded by Naveen 2000 might be due to plant's genetic potential to produce fruits in less number but larger. Similar results were observed by [38] and [36] in green house tomato. The possible reason for increasing the tomato yield in the present study might be that crop inside the NVG was free from pest and disease

incidence. Increased fruit yield per plant under greenhouse condition due to pest and insects' minimum incidence was reported by [39] in tomato and capsicum. Similar results were reported by [40] in brinjal and [34] in tomato.

3.4 Fruit Yield (q/ha)

Wider spacing of 60 x 60 cm gave the highest fruit yield (1211.29 q/ha) which was significantly superior over other closer spacings because all the yield attributes positively correlated with wider spacing. Among different hybrids, hybrid Naveen 2000 had been registered with the highest fruit yield (1255.44 q/ha) which was significantly superior over other hybrids and statistically at par with Avinash-2 (1200.73 q/ha) under the investigation. Higher yield in the hybrids as attributed to the cumulative effect of more fruits per plant, fruit weight and more fruit yield per plant. In a related study, phenological development and productive ability of tomato were observed. The results obtained revealed high fruit yield under polyhouse condition (810 q/ha) which was higher than 570 q/ha in the open field as earlier reported by [41] Similarly, recorded average fruit yield of tomato in a range of 135.10 – 1046.80 q/ha and that genotypes with large numbers of fruits per plant produced more fruit yield as compared with those with a smaller number of fruits per plant as reported by [41] in tomato.

3.5 Marketable Fruit Yield Per Plant (kg)

Among the spacings, wider spacing (60 x 60 cm) exhibited minimum quality damage of fruits, resulting in more marketable fruit per plant than closer spacing. Among hybrids, Naveen-2000 produced more marketable yield per plants followed by, Avinash-2. The results are in line with [42] they reported 40-45% higher marketable yield in greenhouses than with open field conditions. These findings demonstrate the suitability as well as the economic feasibility of NVG in semi- arid regions.

Table 1. Stages of growth

Stage	Initial stage	Final Stage	Duration (Days)	Days after sowing	Plant Height (cm)
1	Seed sowing	Transplanting	23	23	11
2	Transplanting	Flowering	26	49	30
3	Flowering	Fruit setting	25	74	80
4	Fruit setting	First Picking	44	118	220
5	First Picking	Last picking	105	223	410

Table 2. Yield attributes and yield of tomato with respect to spacing

Spacing	Fruit yield (kg/ plant)	Tomato yield (q/ha)	Marketable fruit yield (kg/plant)
60x60 cm	4.01	1195.83	3.98
45x45 cm	3.07	1180.52	2.77
60x45 cm	3.32	1211.29	3.21
CD(p=0.05)	0.31	49.19	0.26

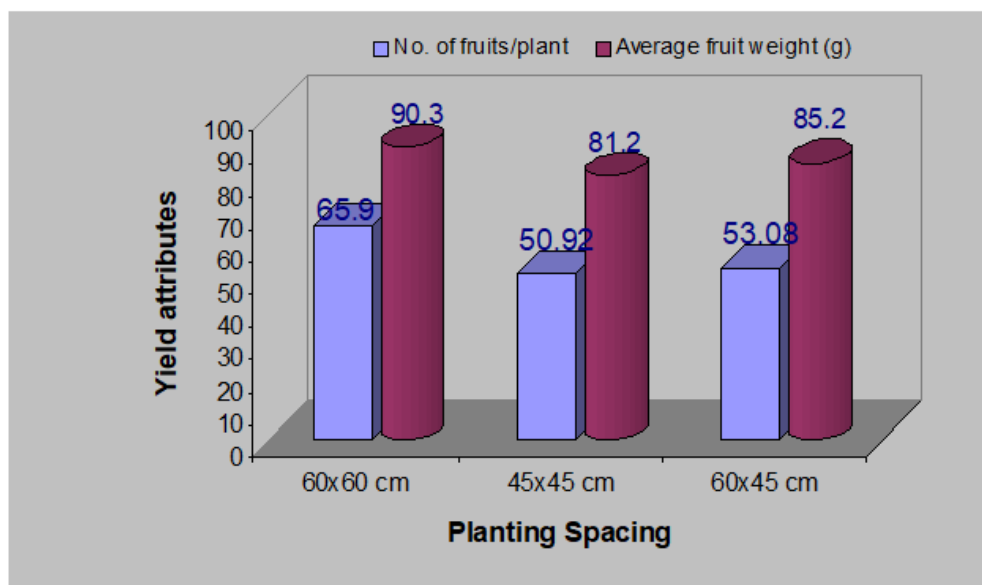


Fig. 6. Effect of planting spacing on yield attributes of tomato under NVG

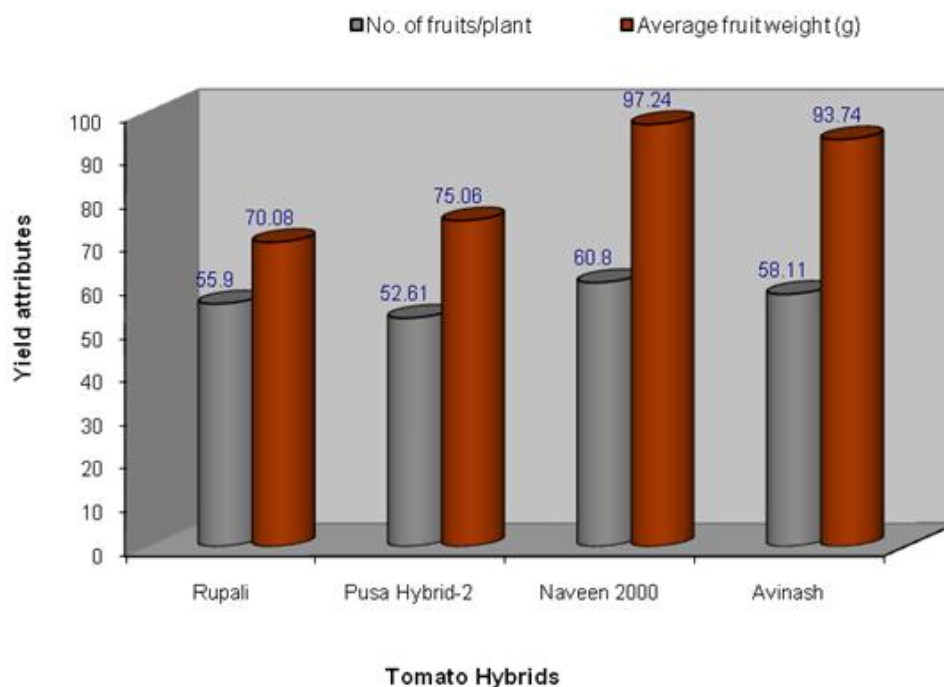


Fig. 7. Yield attributes of tomato for different tomato hybrids under NVG

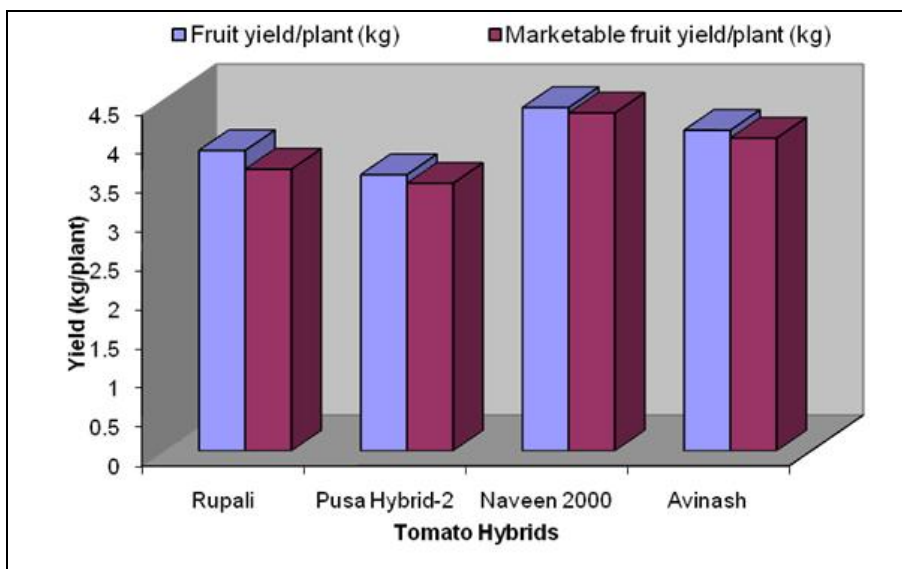


Fig. 8. Fruit yield and marketable fruit yield of tomato hybrids under NVG

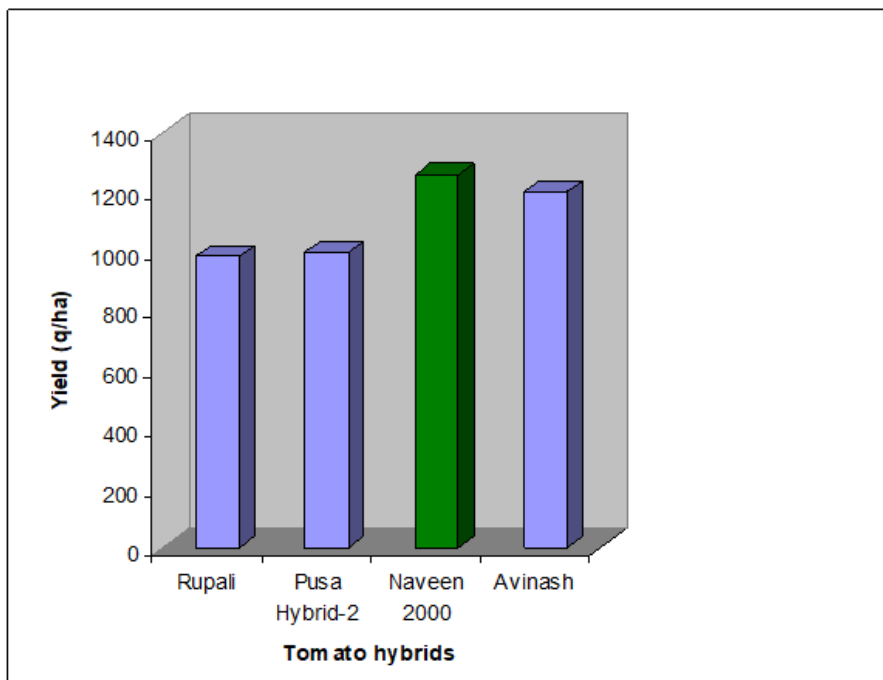


Fig. 9. Greenhouse tomato productivity with respect to tomato hybrids

4. CONCLUSIONS

A NVG has been designed and developed which is simple to operate. Tomato hybrids Naveen-2000 showed superiority in terms of fruit yield (1255.44 q/ha) and fruit yield/plant (4.40 kg/plant) which were at par with Avinash-2 with respective values of 1200.73 q/ha yield and 4.11 kg/plant

fruit yield followed by Pusa hybrid-2 and Rupali. Wider spacing of 60 x 60cm showed the highest yield of 1211.29 q/ha. Therefore, it may be concluded that the developed NVG will serve the purpose of protected cultivation. It will replace the medium and hi-tech greenhouses as it is a less expensive tomato cultivation option in arid and semi-arid regions of India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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