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Evaluation of Growth and Yield of Vertically Trained Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] under Different Levels of Spacing, Training and Pruning under Rain Shelter

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigated the effects of spacing, training and pruning on the growth and yield of watermelon hybrid 'Saraswati' trained vertically under rain shelter. The treatments were factorial combinations of three planting densities (1.50 m × 0.60 m, 1.50 m × 0.45 m and 1.50 m × 0.30 m), two training levels (nipping to one vine, nipping to two vines) and two pruning heights (pruned at 2m and unpruned) arranged in randomized block design with two replications and control with horizontal training of vines in open condition. Spacing, training and pruning levels had varying influence on growth and yield parameters of vertically trained watermelon. Wider spacing of 1.5 m x 0.6 m recorded the highest vine length, highest fruit weight and yield per plant (6.82 kg). Earliness in days to flowering as well as node number was observed in widely spaced plants trained to single vine. Plants trained to two vines exhibited the highest number of fruits per plant, yield per plant and yield per plot. Unpruned plants trained to two vines at closer spacing of 1.50 m × 0.30 m recorded the highest number of fruits per plant and yield per plot (90.10 kg).

Keywords: Citrullus lanatus; watermelon; rain shelter; spacing; training; pruning.

1. INTRODUCTION

Watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai] is an important cucurbitaceous crop grown in tropical and subtropical areas of the globe. It is primarily grown for its refreshing juice and sweet flesh, and it holds the highest global consumption among cucurbits (Goreta et al. 2005). China is the leading producer of watermelon globally. In India, watermelon is cultivated in 1.24 lakh hectares with a production of 35.05 lakh tonnes (GOI 2022).

The idea of using rain shelters for year-round vegetable cultivation is becoming more popular in Kerala, with the financial assistance from the government. Rain shelters are being encouraged to support small-scale farming and reduce the use of harmful pesticides in commercial vegetable cultivation. Currently, only few vegetables like cucumber, capsicum, yard long beans, and tomatoes are cultivated under protected conditions in Kerala. It is important to promote cultivation of more vegetables in protected structures (Narayanankutty et al. 2014).

Watermelon is a highly sought after fruit in Kerala, but its cultivation is limited. Compared to the traditional horizontal method of trailing, growing watermelon plants vertically in rain shelters allows accommodation of greater number of plants in unit area. Managing plant density is crucial for achieving higher number of commercially viable fruits. Altering plant densities through varying levels of spacing is a significant factor in agricultural management. This technique can be utilized to improve crop productivity as it significantly impacts the growth and yield of each plant (Diepenbrock 2000).

An important factor affecting the performance of cucurbits, particularly watermelon, is the number of vines per plant (Gomes et al. 2019). To improve productivity and fruit quality, it is crucial to effectively train watermelon plants in a vertical system. Appropriate training makes it simpler to apply pesticides, improves ventilation for plants, and guarantees that solar radiation is distributed uniformly throughout the canopy. Additionally, this method enables higher plant density, leading to a greater number of fruits per unit area. Several techniques, such as vine and fruit pruning, can be used to control the number of vines per plant and the number of fruits per vine in cucurbits (Campos et al. 2019). A study showed that training to two vines notably boosted the number of fruits and yield per plant when done under a rain shelter. However, it was observed that when training was done in an open environment, it had no discernible effect (Nisha and Sreelathakumary 2020).

Pruning vines is a crucial practice in crop management that offers several agricultural benefits. Primarily, it facilitates mechanical harvesting by ensuring that vines are well-organized and manageable, allowing machines to navigate and harvest effectively. Pruning also supports the production of hybrid seeds, as it helps control the plant's flowering and pollination patterns. By reducing dense foliage, pruning improves air circulation and sunlight penetration, which limits the moist, shaded environments, thereby reducing pest and disease incidence. Additionally, pruning enables farmers to increase plant population per unit area without risking significant yield reduction, as it helps manage vine growth and nutrient distribution, which maintains optimal productivity. Pruning also promotes the production of uniform fruits by directing the plant's energy to fewer, healthier fruits, which leads to consistent size and quality. Adopting pruning as a regular cultural practice can significantly improve crop growth and yield, making it a recommended approach for maximizing production in vine crops (Oga and Umekwe, 2016). In watermelon, best yield of large fruits was obtained on pruning plants to three vines with one fruit per vine (Ndereyimana 2021).

The potential of commercial cultivation of watermelon, especially mini and icebox types, is significant due to their small size. Therefore, it is important to focus on studying plant density and training levels in watermelon under rain shelter. Consequently, this research aims to assess the impact of various spacing, training, and pruning levels on the growth and yield of watermelon under rain shelter.

2. MATERIALS AND METHODS

The experiment was carried out at Department of Vegetable Science, College of Agriculture, Vellayani, Kerala Agricultural University during 2021-22 with the watermelon hybrid Saraswati. The treatments were factorial combinations of three levels of spacing (1.50 m × 0.60 m, 1.50 m × 0.45 m and 1.50 m × 0.30 m), two training levels (nipping to one vine, nipping to two vines) and two pruning heights (pruned at 2 m and unpruned) arranged in randomized block design with two replications and control with horizontal training of vines in open condition.

2.1 Experimental Site

The site of rain shelter was located at $8^0$25'53.5" N latitude and $76^0$59'14.9" E longitude at an altitude of 29 m above sea level. The location of open field was $82^0$5'53.7" N latitude and $76^0$59'15.8" E longitude. The soil of experiment site is red loam of Vellayani series, texturally classified as sandy clay loam.

2.2 Field Preparation and Planting

The experimental area was deeply ploughed up to 50 cm and weeds and stubbles were removed. Farm yard manure @ 25 t ha^{-1} and Rock Phosphate (125 kg ha^{-1}) was applied before last ploughing. Raised beds of one meter width and one foot height were taken with channels of 50 cm between the beds. The beds were mulched with silver on black polyethylene sheet of 50 µ thickness after laying drip lines. Seedlings were raised in protrays using cocopeat and vermicompost as media. Twelve days old seedlings at 2-3 true leaf stage were transplanted at required spacing.

2.3 Training and Pruning

The plants were trained vertically under the rain shelter. In T_1 (nipping to one vine) only the main vine was allowed to grow. In T_2 (nipping to two vines), two vigourously growing laterals were allowed after nipping off the main vine. GI wires were tied over the cropping rows at 2.5 m height and plastic strings were tied on them to trail the plants. The first three secondary branches were removed and the rest were pruned after the third leaf. The plants were trailed horizontally under open.

2.4 Fertigation

Drip lines were laid with a lateral per bed and drippers with a discharge rate of 2 l/hr at required spacing (60 cm, 45 cm and 30 cm) were used. Fertigation was done at three days interval using fertigation pump. Water soluble fertilizers, 19:19:19, 13:0:45, urea and 12:61:0 was used (Nisha 2017). Submains and laterals are flushed prior to fertigation process and continuous drip irrigation was given for five to ten minutes after each fertigation. Disc filter and screen filter were cleaned at regular intervals.

Observations on growth and yield parameters were recorded from five plants selected at random in each replication. The data were analysed statistically by applying the techniques of analysis of variance (Panse and Sukhatme 1985).

3. RESULTS AND DISCUSSION

The length of the vines was significantly influenced by the different plant densities as shown in Table 1. The longest vine, measuring 3.84 m, was observed in D_1 (1.50 m × 0.60 m), while the shortest vine (3.14 m), was in D_3 (1.50 m × 0.30 m). This could be attributed to reduced competition for water, nutrients and light among crops in wider spacing. Unpruned plants exhibited longer vines (5.00 m) compared to pruned ones (2.00 m). These findings are consistent with the research conducted by (Sabo at el. 2013) and (Lemos et al. 2022). The different training levels did not have a significant impact on vine length. A notable difference was observed between the treatments and the control as indicated in Table 2, with the control displaying longer vines (5.85 m) compared to the treatments.

Table 1. Effect of spacing, training and pruning on growth parameters in vertically trained watermelon under rain shelter

Treatments	Vine length (m)	Days to first male flower	Node to first male flower	Days to first female flower	Node to first female flower
Spacing					
D_1(1.50 m x 0.60 m)	3.84[a]	15.56[c]	4.68[c]	22.41[c]	13.64[c]
D_2(1.50 m x 0.45 m)	3.52[b]	16.92[b]	5.55[b]	23.53[b]	14.57[b]
D_3 (1.50 m x 0.30 m)	3.14[c]	18.45[a]	6.37[a]	24.12[a]	15.34[a]
SE_m (±)	0.034	0.035	0.075	0.044	0.070
CD (0.05)	0.106	0.109	0.235	0.138	0.216
Training					
T_1(Single vine)	3.61	16.79[b]	5.36[b]	23.14[b]	14.36[b]
T_2(Two vines)	3.42	17.15[a]	5.67[a]	23.57[a]	14.67[a]
SE_m (±)	0.087	0.029	0.062	0.036	0.057
CD (0.05)	NS	0.089	0.192	0.113	0.177
Pruning					
P_1(Pruned at 2.0 m)	2.00[b]	16.88[a]	5.52	23.24[b]	14.53
P_2(Unpruned)	5.00[a]	17.07[b]	5.55	23.47[a]	14.50
SE_m (±)	0.068	0.029	0.062	0.036	0.057
CD (0.05)	0.087	0.089	NS	0.113	NS
Control (open condition)	5.85	18.9	6.38	26.38	16.62

NS – Non significant

Table 2. Interaction effects of treatments on growth characters in vertically trained watermelon under rain shelter

Treatments	Vine length (m)	Days to first male flower	Node to first male flower	Days to first female flower	Node to first female flower
D × T × P					
$d_1t_1p_1$	2.00	15.33	4.50	22.10	13.50
$d_1t_1p_2$	5.66	15.48	4.48	22.30	13.47
$d_1t_2p_1$	2.00	15.64	4.84	22.47	13.80
$d_1t_2p_2$	5.70	15.78	4.89	22.75	13.76
$d_2t_1p_1$	2.00	16.52	5.37	23.25	14.42
$d_2t_1p_2$	5.04	16.86	5.37	23.45	14.42
$d_2t_2p_1$	2.00	17.05	5.68	23.62	14.70
$d_2t_2p_2$	5.04	17.23	5.75	23.80	14.73
$d_3t_1p_1$	2.00	18.18	6.20	23.75	15.23
$d_3t_1p_2$	4.31	18.39	6.25	24.00	15.10
$d_3t_2p_1$	2.00	18.54	6.50	24.25	15.50
$d_3t_2p_2$	4.27	18.66	6.52	24.50	15.52
SE_m (±)	0.068	0.07	0.151	0.089	0.139
CD (0.05)	NS	NS	NS	NS	NS
Control	4.55	18.9	6.38	26.38	16.62
Control *vs* Treatment	S	S	S	S	S

NS – Non significant

The number of days taken for first female flower opening is a crucial factor in predicting early yield. Planting density had a notable impact on the timing of flowering and the location of the first flower (Table 1). The earliest flowering occurred in plants with wider spacing, single vines, and those that were pruned. This could be attributed to better interception of sunlight and nutrient absorption from soil, leading to the accumulation of more photosynthates and prompting earlier flowering compared to plants with closer spacing. There was a significant contrast between the treatments and the control (Table 2), with the control exhibiting late flowering.

The position of the first female flowering node is an important character in watermelon. First female flower at the lowest node signifies early entry of watermelon into reproductive phase and can potentially capture the market early. The study showed that the spacing and training significantly influenced the nodal position of the first male and female flowers. In D_1 and T_1 plants, the female flower appeared at lower nodes (Table 1). Pruning did not have a notable impact on the nodal position of the flowers, which is consistent with the findings of (Jaffar and Wahid 2014) and (Sharma et al. 2018). While there were no significant differences in treatment interactions, there was a notable contrast between the treatments and the control (Table 2). The control had the first flowers at higher nodes.

All treatments had a notable impact on the average weight of fruit, as shown in Table 3. The highest fruit weight of 2.84 kg was observed when planting at 1.50 m × 0.60 m. Wider spacing allowed the plants to grow longer and develop more branches to accommodate larger fruits. Additionally, the wider spacing provided more room for the developing fruits to grow bigger. These findings are consistent with the research of (Dahake et al. 2020). Single vine training resulted in higher fruit weight compared to double vine plants. Similarly, pruned plants produced heavier fruits than unpruned plants. Pruning facilitates the distribution of assimilates generated through photosynthesis, leading to cell enlargement and improved fruit characteristics. As per the previous research by (Campagnol et al. 2012), training and pruning levels did not significantly influence fruit weight. Vertically trained watermelon fruits under rain shelter were lower in weight than those grown horizontally in open conditions, as indicated in Table 4. The cropping density of mini watermelons trained in a vertical system influenced leaf area and solar radiation exposure, consequently affecting photosynthetic efficiency and fruit mass (Watanabe 2014).

Number of fruits per plant and yield per plot increased with increasing plant densities (Table 3). Lower plant spacing increase competition for water, light and nutrients, producing smaller fruits but increases yield per unit area, since a greater number of plants can be accommodated. Training to two vines recorded higher number of fruits than single vine. Similarly unpruned plants recorded highest number of fruits. Longer vine length and extended crop duration in rain shelter might have led to an increase in the number of fruits. Since, watermelon plants naturally produce numerous branches, pruning is beneficial to maintain proper number of branches, leaves and fruits, allowing for efficient sharing of plant resources (Munoz et al. 2018). Maximum number of fruits per plant and yield per plot (78.37 kg) was recorded in high planting density. Increasing the density of planting can optimize land use effectively without reducing yield. In fact, yield per unit area generally improves as plant density rises, reaching a peak at an optimal population level. Beyond this point, however, yields may decline due to increased competition among plants for resources such as nutrients, water and sunlight. These results are supported by the findings of (Da Silva et al. 2021). Wider spacing of 1.50 m x 0.6 m recorded the highest yield per plant. This might be due to higher fruit setting and fruit retention with increased spacing (Deka et al. 2024). Among interactions, unpruned double vined plants at closer spacing of 1.50 m x 0.30 m recorded the highest value of yield per plot. This is in accordance with the findings of (Anwar et al. 2019), where greater crop density increased the yield and number of fruits per unit area, but decreased yield per plant. Increased yield in watermelon at a spacing of 2m x 1m with black silver polythene mulch was reported in a previous study (Neupane et al. 2023).

The number of fruits per plant and the yield per plot both increased with increasing plant densities (Table 3). Closer planting increased fruit number but lowered mean fruit weight (Filho et al. 2015). Decreasing the distance between plants led to increased competition for water, light, and nutrients, resulting in smaller fruits but a higher yield per unit area, due to accommodating a greater number of plants. Training the plants to two vines resulted in a higher number of fruits compared to a single vine. Similarly unpruned plants recorded highest number of fruits. The longer vine length and extended crop duration in a rain shelter likely contributed to the increase in the number of fruits. The highest number of fruits per plant and the highest yield per plot (78.37 kg) were recorded at high planting density. Increasing the planting density can effectively optimize land use without reducing the yield. In fact, the yield per unit area generally improves as the plant density rises, reaching a peak at an optimal population level. Beyond this point, however, yields may decline due to increased competition among plants for resources like nutrients, water, and sunlight. These results align with the findings of [20]. Among interactions, unpruned double-vined plants at a closer spacing of 1.50 m x 0.30 m resulted in the highest value of yield per plot. This is consistent with the findings of (Anwar et al. 2019), where a greater crop density increased the yield and number of fruits per unit area but decreased the yield per plant.

Table 3. Effect of spacing, training and pruning on yield parameters in vertically trained watermelon under rain shelter

Treatments	Fruit weight (kg)	Fruits per plant	Yield per plant (kg)	Yield per plot (kg)
Spacing				
D_1(1.50 m x 0.60 m)	2.84^a	1.96	5.50^a	55.04^c
D_2(1.50 m x 0.45 m)	2.46^b	2.05	4.82^b	62.61^b
D_3 (1.50 m x 0.30 m)	2.15^c	2.09	3.92^c	78.37^a
SE_m (±)	0.030	0.047	0.134	1.874
CD (0.05)	0.093	NS	0.418	5.482
Training				
T_1(Single vine)	2.84^a	1.50^b	4.21^b	58.36^b
T_2(Two vines)	2.13^b	2.56^a	5.28^a	72.32^a
SE_m (±)	0.024	0.039	0.110	1.530
CD (0.05)	0.076	0.120	0.341	4.762
Pruning				
P_1(Pruned at 2.0 m)	2.56^a	1.81^b	4.46^b	61.21^b
P_2(Unpruned)	2.39^b	2.20^a	5.03^a	69.47^a
SE_m (±)	0.042	0.039	0.110	1.530
CD (0.05)	0.132	0.120	0.341	4.762
Control (open condition)	3.24	2.87	6.308	63.06

NS – Non significant

Table 4. Interaction effects of treatments on yield characters in vertically trained watermelon under rain shelter

Treatments	Fruit weight (kg)	Fruits per plant	Yield per plant (kg)	Yield per plot (kg)
D × T × P				
d1t1p1	3.18	1.33^g	4.22^{ef}	42.23^f
d1t1p2	3.06	1.67^f	5.29^{bcd}	52.94^{ef}
d1t2p1	2.53	2.17^{cd}	5.67^{bc}	56.79^{de}
d1t2p2	2.56	2.67^b	6.82^a	68.22^{cd}
d2t1p1	2.86	1.84^{ef}	5.18^{cd}	67.38^{cd}
d2t1p2	2.65	1.33^g	3.39^{fg}	44.18^f
d2t2p1	2.40	2.01^{de}	4.65^{de}	60.49^{de}
d2t2p2	1.93	3.01^a	6.03^{ab}	78.39^{bc}
d3t1p1	2.65	1.17^g	3.02^g	60.44^{de}
d3t1p2	2.61	1.67^f	4.15^{ef}	82.99^{ab}
d3t2p1	1.82	2.33^c	3.99^{ef}	79.92^{ab}
d3t2p2	1.52	3.17^a	4.50^{de}	90.10^a
SE_m (±)	0.060	0.095	0.269	3.747

Treatments	Fruit weight (kg)	Fruits per plant	Yield per plant (kg)	Yield per plot (kg)
D × T × P				
CD	NS	0.295	0.836	11.664
Control	3.24	2.87	6.308	63.06
Control *vs* Treatment	S	NS	S	NS

NS – Non significant

The study revealed that increasing the plant density to 22,200 per hectare by planting at closer spacing of 1.5 m x 0.3 m can increase B:C ratio to 3.02: 1.00 in vertically double vine trained unpruned watermelon ($d_3t_2p_2$) under rain shelter (Table 5). This treatment provided the highest economic returns owing to the highest number of plants per hectare. Since no protected structures or additional supports for training were used in open conditions, the cost of production was low. But low plant density resulted in a decline of yield per hectare which in turn decreased net returns and hence B:C ratio. Similar findings were reported by (Bindukala 2000) in watermelon and (Kapuriya et al. 2017) in cucumber.

Table 5. Effect of spacing, training and pruning on B:C ratio of vertically trained watermelon under rain shelter

Treatments	B:C ratio
d1t1p1	1.58
d1t1p2	1.90
d1t2p1	2.71
d1t2p2	2.26
d2t1p1	1.79
d2t1p2	2.78
d2t2p1	1.91
d2t2p2	2.58
d3t1p1	1.63
d3t1p2	2.81
d3t2p1	2.88
d3t2p2	3.02
Control	2.21

4. CONCLUSION

The results of the present study revealed that growing watermelon vertically under rain shelter by training the plants to two vines and allowing them to grow unpruned, improves the yield per unit area. A spacing of 1.50 m × 0.30 m and unpruned plants trained to two vines was found to be the best with highest number of fruits per plant and yield per unit area.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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