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Evaluation of Spacing on Performance of Strawberry cv. Winter Dawn in Central Midlands of Kerala

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Abstract

A research trial was carried out in the experimental field of Department of Fruit Science, College of Agriculture, Kerala Agricultural University, Thrissur, Kerala during two seasons (2016-2018) to evaluate the spacing on growth and yield of strawberry cultivar Winter Dawn. One month old tissue culture plants of strawberry cv. Winter Dawn were planted in open field on raised beds of size 2.1m x 1.6m during last week of September. The design of experiment was randomized block design (RBD) with six treatments and 4 replications. Six different spacings viz., 30cm x 60cm, 30cm x 50cm, 30cm x 40cm, 30cm x 30cm, 30cm x 20cm, 20cm x 20cm were studied using *cv*. Winter Dawn. Among the different spacings, 20cm x 20cm (T_6) recorded maximum vegetative attributes, number of flowers, fruits and yield per plant (100.03 g). Quality parameters such as TSS and TSS/acidity ratio were found to be maximum in fruits harvested from plants grown at a spacing of 30cm x 50cm (T_2) whereas maximum ascorbic acid and anthocyanin content were recorded under spacing of 30cm x 60cm (T_1).

***Key words*:** Strawberry, Winter Dawn, Spacing, Ascorbic acid, Anthocyanin

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most important soft berry fruits cultivated worldwide owing to its exceptional sensory qualities, high nutritional value and remarkable economic potential. The fruit is highly appreciated by consumers for its attractive bright red colour, pleasant aroma, delicate texture, sweetness and refreshing flavour, making it one of the most preferred fruits for fresh consumption as well as processing into jams, jellies, juices, ice creams, yogurts, bakery products and confectioneries [1]. Belonging to the family Rosaceae, strawberry is an octoploid hybrid species derived primarily from the natural hybridization between *Fragaria chiloensis* and *Fragaria virginiana* [2]. The crop has gained immense commercial significance due to its early bearing habit, short crop duration, high productivity per unit area and attractive market price, enabling growers to obtain quick economic returns within five to six months of planting [3]. Globally, strawberry cultivation has expanded rapidly over the past few decades owing to increasing consumer demand for fresh fruits and health-promoting foods. The fruit occupies an important position among berry crops because of its high nutritional composition and abundance of bioactive compounds. Strawberries are excellent sources of vitamins, particularly vitamin C, vitamin A, folates and niacin, besides containing appreciable quantities of minerals such as potassium, calcium, phosphorus, magnesium and iron. They are also rich in dietary fibre, organic acids, pectin and natural sugars, which contribute significantly to human nutrition [4-5]. The fruit is characterized by exceptionally high antioxidant activity owing to the presence of anthocyanins, ellagic acid, flavonoids, quercetin, kaempferol and various phenolic compounds that effectively scavenge reactive oxygen species and reduce oxidative stress [6-7].

In recent years, strawberries have attracted considerable attention as a functional food because of their numerous health-promoting properties. Regular consumption of strawberries has been associated with reduced risks of cardiovascular diseases, diabetes, obesity, certain cancers and neurodegenerative disorders due to their antioxidant, anti-inflammatory, antimicrobial, anti-carcinogenic and anti-diabetic activities [8-9]. The anthocyanins and polyphenols present in strawberry improve endothelial function, reduce lipid oxidation, regulate blood glucose metabolism and enhance immune response, thereby contributing to overall human health [10-11]. Consequently, the demand for fresh strawberries has increased substantially in both domestic and international markets, encouraging diversification of strawberry cultivation into non-traditional production regions. Strawberry is predominantly a temperate crop; however, the development of low-chilling and short-day cultivars has facilitated its successful cultivation under subtropical and tropical environments. Cultivars such as Winter Dawn, Sweet Charlie and Festival have shown excellent adaptability under warm climatic conditions and are increasingly cultivated in southern Indian states including Kerala, Karnataka and Tamil Nadu [12]. Among these, cv. Winter Dawn has emerged as a promising cultivar due to its early flowering, attractive fruits, high yield potential, excellent

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firmness, uniform shape and superior shelf life, making it suitable for long-distance transportation and commercial cultivation [13]. Nevertheless, the productivity and fruit quality of strawberry are highly influenced by prevailing climatic conditions and crop management practices.

Environmental factors, particularly temperature and photoperiod, play a pivotal role in regulating vegetative growth, floral induction, flowering behaviour and fruit development in strawberry [14]. The interaction of these factors with genotype determines the transition from vegetative to reproductive growth, ultimately affecting yield and fruit quality. Besides environmental conditions, several cultural practices such as planting time, nutrient management, irrigation scheduling, mulching and plant spacing considerably influence crop performance [15]. Among these factors, plant spacing is considered one of the most critical agronomic practices because it governs plant population, canopy architecture, light interception, photosynthetic efficiency, nutrient uptake, air circulation and disease incidence, thereby directly influencing vegetative growth, flowering, fruit yield and quality attributes [16]. Optimum plant spacing ensures efficient utilization of available resources including solar radiation, soil moisture, nutrients and growing space, resulting in vigorous plant growth and higher productivity. Excessively close spacing often leads to severe competition among plants for light, water and nutrients, producing elongated plants with reduced crown development, smaller fruits and increased incidence of fungal diseases due to poor aeration [17]. Conversely, excessively wider spacing reduces plant population per unit area, leading to underutilization of land resources and lower total yield despite improvements in individual plant performance. Therefore, identification of an optimum planting density is essential to achieve a balance between individual plant growth and maximum productivity per unit area [12]. Several researchers have reported significant influence of planting geometry on vegetative growth, flowering, fruit yield and quality parameters of strawberry under diverse agro-climatic conditions. Appropriate spacing has been shown to enhance crown diameter, leaf area, number of runners, fruit size, average fruit weight, total soluble solids and marketable yield while minimizing disease incidence and improving fruit quality [18-19]. However, the optimum spacing varies considerably depending upon cultivar, climatic conditions, production system and soil characteristics. Consequently, spacing recommendations developed for temperate regions may not be directly applicable under tropical environments where higher temperature, humidity and rainfall significantly alter crop growth dynamics.

Kerala offers considerable potential for expanding strawberry cultivation, particularly in elevated and moderately cool regions where favourable climatic conditions prevail during winter months. In recent years, cultivation has gradually extended to the central midlands of Kerala owing to increasing consumer demand, availability of quality planting material and better market opportunities. Nevertheless, scientific information regarding optimum plant spacing for commercially important cultivars under this agro-climatic region remains inadequate. Most farmers continue to adopt arbitrary planting densities based on personal experience or recommendations generated under entirely different ecological conditions, resulting in inconsistent yield and fruit quality. Establishing appropriate spacing recommendations specific to the central midlands of Kerala is therefore essential for maximizing resource use efficiency, improving fruit yield and enhancing profitability of strawberry cultivation. Considering the increasing commercial importance of strawberry cultivation in Kerala and the lack of region-specific recommendations on planting density, the present investigation was undertaken to evaluate the effect of different plant spacings on the growth, flowering, yield and quality performance of strawberry cv. Winter Dawn under the central midlands of Kerala. The findings of the study are expected to provide scientifically validated recommendations for optimizing plant population and improving the productivity and economic returns of strawberry growers in the region.

MATERIALS AND METHODS

The present investigation entitled "Evaluation of spacing on performance of strawberry cv. Winter Dawn in central midlands of Kerala" was conducted during two consecutive cropping seasons, 2016-2017 and 2017-2018, at the open field fruit orchard of the Department of Fruit Science, College of Agriculture, Thrissur, Kerala, India. The experimental farm is situated at 10°31′ N latitude and 76°13′ E longitude, at an altitude of 22.25 m above mean sea level (MSL). The region falls under the central midlands agro-climatic zone of Kerala and is characterized by a warm humid tropical climate with high atmospheric humidity and well-distributed annual rainfall. During the experimental period, the minimum and maximum temperatures ranged from 22.65°C to 33.42°C, providing favourable conditions for the successful cultivation of subtropical strawberry cultivars. The experimental soil was sandy loam in texture, well-drained and suitable for strawberry cultivation.

Experimental material and treatments

The experiment was conducted using the commercially important strawberry cultivar Winter Dawn, which is well adapted to tropical and subtropical climatic conditions owing to its early flowering, high yield potential and superior fruit quality. Healthy, disease-free one-month-old tissue culture plantlets of uniform size and vigour were procured from an authenticated commercial nursery and used as the planting material. The experiment comprised six plant spacing treatments representing different planting geometries. The treatments were evaluated under field conditions to determine their influence on vegetative growth, flowering, yield and fruit quality of strawberry.

Experimental design and crop establishment

The field experiment was laid out in a randomized block design (RBD) with six treatments and four replications. Each experimental unit consisted of a raised bed measuring 1.6 × 2.1 m, accommodating plants according to the respective spacing treatment. Uniform cultural practices were followed throughout the experimental period for all treatments except the spacing differences. The field was thoroughly prepared by repeated ploughing followed by levelling to obtain a fine tilth. Raised beds were prepared to facilitate proper drainage and root development. One-month-old tissue culture plants were transplanted during the last week of September in both experimental years. Immediately after transplanting, the beds were covered with black polyethylene mulch, which helped conserve soil moisture, suppress weed growth, regulate soil temperature and minimize fruit contact with the soil surface. Irrigation was provided uniformly to all treatments as and when required to maintain optimum soil moisture throughout the crop growth period. Recommended nutrient management, intercultural operations and plant protection measures were uniformly adopted following the package of practices of Kerala Agricultural University to ensure healthy crop growth.

Recording of observations

Observations were recorded on ten randomly selected and tagged plants from each experimental plot. The same tagged plants were used throughout the investigation for recording growth and developmental parameters.

Vegetative observations

Vegetative growth parameters were recorded monthly from November to March during both cropping seasons. The observations included plant height (cm), plant spread (cm), number of leaves per plant, leaf area (cm^2), crown diameter (cm), number of crowns per plant and number of runners produced per plant, wherever applicable. Measurements were made using standard horticultural procedures.

Floral observations

Flowering parameters were recorded periodically during the flowering season. The observations included days to first flowering, days to 50 per cent flowering, duration of flowering, number of flowers per plant, fruit set percentage and other floral characters relevant to assessing the influence of planting density.

Yield observations

Yield parameters were recorded throughout the harvesting period. Fruits were harvested at full red ripe stage at regular intervals. Data were collected on number of fruits per plant, average fruit weight (g), fruit length (cm), fruit diameter (cm), fruit volume (cm^3), fruit yield per plant (g), fruit yield per plot (kg) and estimated fruit yield per hectare (t ha^{-1}). Marketable yield was determined by excluding malformed, diseased and damaged fruits.

Fruit quality analysis

Representative fruit samples from each treatment were collected at peak harvest for quality evaluation. The quality parameters included total soluble solids (TSS), titratable acidity, TSS : acid ratio, ascorbic acid content, total sugars, reducing sugars, non-reducing sugars and other quality attributes using standard analytical procedures. Fruit firmness and shelf-life observations were recorded wherever applicable.

Statistical analysis

The experimental data collected during the two years were subjected to statistical analysis following the procedures described by Gomez and Gomez [20]. Since the experiment was repeated over two cropping seasons, the data were subjected to pooled analysis using two-factor analysis of variance (ANOVA), considering treatments and years as factors. The significance of treatment effects was tested at the 5 per cent probability level ($P = 0.05$). Wherever significant differences were observed, treatment means were compared using the Critical Difference (CD) test. Statistical analyses were performed to determine the influence of different planting spacings on vegetative growth, flowering behaviour, yield and fruit quality of strawberry cv. Winter Dawn.

RESULTS AND DISCUSSION

Vegetative attributes

Plant height

Spacings had a significant influence on plant height only on 4 MAP and 5 MAP. Among the spacings, during the later stages of the growth, 20cm x 20cm recorded maximum plant height (18.15 cm). The minimum plant height was recorded in plants planted at a spacing of 30 x 60 cm (Table 1). Earlier results revealed that closer spacing between the rows and between plants produced more vegetative growth compared to wider spacing. It is also natural that when more plants are accumulated per unit area, mutual shading will be more and this will lead the plants to grow taller. These results in the present study were similar with the findings of Petersen [21], Legard *et al*. [22], De Camacaro [23], Paranjpe *et al*. [24], Sonkar *et al*. [25], Tariq *et al*. [26], Shahzad *et al*. [27].

Number of leaves

Different spacings had a significant influence on number of leaves per plant. Among the spacings, during early stages of growth, 30 cm x 20 cm recorded maximum number of leaves per plant. However, during the later stages of the growth, 20 cm x 20 cm recorded maximum number of leaves per plant. The minimum number of leaves per plant was recorded in plants planted at a spacing of 30 x 50 cm (Table 1).

Plant spread

Different spacings had a significant influence on plant spread except at 1 MAP. Among the spacings, 20 cm x 20 cm recorded maximum plant spread. However, the minimum plant spread was recorded by a spacing of 30 cm x 60 cm (Table 2). Earlier results revealed that closer spacing between the rows and between plants (20 cm x 20 cm) produced more vegetative growth compared to wider spacing. This may be reason for more plant spread. These results in the present study were similar with the findings of Hughes [28], Petersen [21], Legard *et al*. [22], De Camacaro *et al*. [23], Paranjpe *et al*. [24], Sonkar *et al*. [25], Tariq *et al*. [26], Shahzad *et al*. [27].

Number of crowns

Different spacings had significant influence on number of crowns per plant in the later stages of growth. During the initial stages of growth, different spacings had no significant effect on number of crowns per plant. Spacing of 20 cm x 20 cm recorded maximum number of crowns. Minimum number of crowns was recorded by 30 cm x 60 cm (Table 2). Earlier results showed that spacing of 20 cm x 20 cm had resulted in maximum plant height and number of leaves. This might have a positive influence on increase in number of crowns per plant.

Days to first flowering

Different spacings had no significant influence on days to first flowering (Table 3).

Number of flowers per plant

Different spacings had significant influence on the number of flowers per plant. Spacing of 20 cm x 20 cm recorded maximum number of flowers per plant. Minimum number of flowers per plant was recorded by 30 cm x 50 cm spacing (Table 3). Earlier results indicated that plants grown under spacing of 20 cm x 20 cm recorded maximum plant height, number of leaves, plant spread and number of crowns. This might be the reason for maximum number of flowers per plant.

Number of clusters per plant

Different spacings had significant influence on the number of clusters per plant. Spacing of 20 cm x 20 cm recorded maximum number of clusters per plant. Minimum number of clusters per plant was recorded by 30 cm x 40 cm spacing Table 3). Earlier results indicated that spacing of 20 cm x 20 cm produced maximum number of flowers per plant in both locations. This might have lead to the increase in number of clusters per plant.

Table 1 Effect of different spacings on plant height and number of leaves of strawberry

Treatments	Plant height (cm)					Number of leaves				
	1MAP	2MAP	3MAP	4MAP	5MAP	1MAP	2MAP	3MAP	4MAP	5MAP
T_1	8.05	10.87	13.39	15.26	16.50	7.35	12.88	19.81	25.60	28.04
T_2	8.79	11.47	13.34	15.36	16.75	7.03	11.71	20.21	24.78	27.59
T_3	8.95	11.83	13.98	15.89	17.30	6.27	12.22	19.85	24.96	27.62
T_4	9.18	11.75	14.17	16.16	17.58	7.61	12.46	20.35	27.05	29.46
T_5	8.54	11.64	14.49	16.14	17.81	6.96	14.55	22.39	29.18	31.40
T_6	8.69	12.27	14.55	16.31	18.15	8.26	13.29	22.04	29.42	31.80
CD	NS	NS	NS	0.66	0.59	1.10	1.5	1.72	1.32	1.25

Table 2 Effect of different spacings on plant spread and number of crowns of strawberry

Treatments	Plant spread (cm)					Number of crowns				
	1MAP	2MAP	3MAP	4MAP	5MAP	1MAP	2MAP	3MAP	4MAP	5MAP
T_1	12.28	15.49	20.33	25.16	29.62	1.00	1.28	2.20	2.90	3.88
T_2	12.49	15.79	20.53	24.77	29.51	1.00	1.20	2.15	3.18	3.90
T_3	10.94	15.78	20.02	25.00	29.28	1.00	1.13	2.50	3.48	4.45
T_4	10.80	16.82	22.91	28.21	32.67	1.00	1.30	2.65	3.98	5.23
T_5	11.30	16.65	20.69	25.74	29.78	1.00	1.38	2.68	4.15	5.43
T_6	10.31	19.58	23.79	27.08	30.12	1.00	1.53	3.10	4.63	5.65
CD	NS	1.80	1.91	1.93	1.42	NS	0.21	0.43	0.64	0.68

Fig 1 Strawberry planted in different spacings at Central midlands

Number of fruits per plant

Different spacings had significant influence on the number of fruits per plant. Spacing of 20 cm x 20 cm recorded maximum number of fruits per plant. Minimum number of fruits per plant was recorded by 30 cm x 50 cm spacing (Table 3). As discussed earlier, plant height, number of leaves, plant spread, number of crowns, number of flowers and clusters per plant were maximum in plants grown at a row plant spacing of 20 cm x 20 cm. This may be the reason for maximum number of fruits per plant.

Yield

Plants grown under the spacing of 20 cm x 20 cm recorded the maximum yield per plant of 100.03 g per plant while minimum yield per plant of 50.71 g per plant was recorded by plants grown under the spacing of 30 cm x 40 cm (Table 3). These findings were in conformity with the results of Shahzad *et al.* [27] that yield per plant of strawberry is higher in 20 cm spacing compared to 30 cm or 50 cm.

Quality attributes

Total soluble solids (TSS)

Fruits obtained from plants under spacing of 30 cm x 50 cm recorded the highest total soluble solids (TSS) content of 7.58 °Brix, while lowest TSS content of 4.64 ^{0}Brix was recorded by fruits obtained from plants under spacing of 30 cm x 30 cm. (Table 4). TSS was significantly higher in wider spacing than closer spacing. The positive influence of wider spacing on TSS of strawberry was earlier reported by Awasthi and Badiyala [29], Tripathi *et al.* [30].

Table 3 Effect of different spacings on flowering and yield attributes of strawberry

Treatments	Days to first flowering	Number of clusters	Number of flowers	Number of fruits	Yield per plant (g)
T_1	57.13	5.31	8.50	4.72	61.40
T_2	55.61	5.46	7.34	4.45	51.88
T_3	57.38	4.93	8.16	5.23	50.71
T_4	53.26	5.69	10.11	6.37	68.63
T_5	56.44	6.45	10.57	7.86	74.47
T_6	53.37	6.68	11.38	9.36	100.03
CD	NS	0.30	0.33	0.20	3.95

Table 4 Effect of different spacings on quality attributes of strawberry

Treatments	T.S.S (°Brix)	Acidity (%)	T.S.S/ Acidity	Total sugars (%)	Ascorbic acid content (mg $100g^{-1}$)	Anthocyanin (mg $100g^{-1}$)	β-Carotene (µg $100g^{-1}$)
T_1	6.04	0.55	11.32	5.55	71.61	32.66	1.47
T_2	7.58	0.60	12.79	6.09	46.06	23.63	2.46
T_3	6.24	0.95	6.94	5.38	41.45	30.08	2.80
T_4	4.64	0.57	8.65	5.83	33.83	28.08	3.04
T_5	4.84	0.57	10.55	5.06	30.00	12.79	2.34
T_6	4.81	0.63	8.49	5.70	27.11	16.95	2.37
CD	1.29	0.19	3.41	0.36	1.93	0.5	0.11

Fig 2 Strawberry fruits obtained from different spacings at Central midlands

Acidity

Different spacings had significant influence on acidity of strawberry fruits. The lowest titrable acidity was recorded by fruits harvested from plants under a spacing of 30 cm x 60 cm, while the highest acidity was recorded by fruits obtained from plants grown under a spacing of 30 cm x 40 cm and it ranges from 0.55 % to 0.95 % (Table 4). This result is in consonance with the earlier research findings by Sonkar *et al*. [25] indicated that quality parameters such as acidity was significantly lower in fruits obtained from wider plant spacing than that obtained from narrow plant spacing.

TSS / acidity

Maximum TSS/Acidity was recorded in fruits harvested from plants grown at a spacing of 30 cm x 50 cm. The minimum TSS/Acidity was recorded in fruits harvested from plants grown at a spacing of 30 cm x 40 cm. Maximum TSS was recorded in fruits obtained from plants under a spacing of 30 cm x 50 cm (Table 4). This might have a positive effect on TSS/acidity ratio of fruits obtained from 30 cm x 50 cm spacing. Highest acidity was recorded in fruits obtained from plants grown under a spacing of 30 cm x 40 cm. This might lead to low TSS/acidity ratio in fruits.

Total sugars

Different spacings had significant effect on total sugars content of strawberry. The maximum total sugars content was observed in fruits obtained from plants under spacing of 30 cm x 50 cm, while the lowest total sugars content was observed in fruits obtained from plants under spacing of 30 cm x 20 cm (Table 4). The highest TSS, TSS/acidity were higher in fruits obtained from plants grown under spacing of 30 cm x 50 cm. These might have a positive impact on total sugars content of strawberry.

Ascorbic acid content

Different spacings had significant effect on ascorbic acid content of strawberry. Maximum ascorbic acid content was recorded in fruits obtained from plants grown under spacing of 30 cm x 60 cm. Minimum ascorbic acid was observed in fruits obtained from plants grown under the spacing of 20 cm x 20 cm (Table 4)). Plants grown under wider spacing get sufficient light, nutrients and greater accumulation of photosynthates which leads to the production of more ascorbic acid. Similar findings were given by Awasthi and Badiyala [29], Tripathi *et al*. [30], Sonkar *et al*. [25].

Anthocyanin content

Different spacings had significant effect on anthocyanin content of strawberry. The maximum anthocyanin content was observed in fruits obtained from plants under spacing of 30 cm x 60 cm, while the lowest anthocyanin content was observed in fruits obtained from plants under spacing of 30 cm x 20 cm (Table 4). The maximum air temperature is high and the soil temperature in wider spacing is even higher compared to closer spacings. When strawberry grown at a higher air temperature of up to 30 °C, it had a positive effect on anthocyanin accumulation. Similar findings were also reported in apple and pear [31-32]. It might have be the reason for more anthocyanin content in wider spacing of 30 cm x 60 cm.

Beta carotene content

Different spacings had significant effect on β-Carotene content of strawberry. Fruits obtained from plants under spacing of 30 cm x 30 cm recorded the maximum β-Carotene content and the lowest β-Carotene content was recorded by fruits of plants grown under spacing of 30 cm x 60 cm (Table 4). When temperature increases, Beta carotene content decreases. This might be the reason for the lowest Beta carotene content in wider spacing, which had maximum soil temperature. Beta carotene content of same genotype varies significantly under different agro climatic conditions [33].

CONCLUSION

From the present study it was concluded that maximum plant height, number of leaves, plant spread and number of crowns per plant were recorded under spacing 20 x 20 cm. Spacings had no significant influence on days to first flowering. Spacing of 20 cm x 20 cm recorded maximum number of flowers per plant, maximum number of clusters per plant, fruits per plant and yield per plant. Fruits obtained from plants grown under a spacing of 30 x 50 cm recorded maximum TSS, TSS/Acidity and total sugars content whereas fruits obtained from plants grown under a spacing of 30 x 60 cm recorded maximum ascorbic acid and anthocyanin content. Maximum Beta carotene content was observed from plants grown under the spacing of 30 cm x 30 cm. Thus, optimum spacing should be selected based on the production objective, with closer spacing for higher yield and wider spacing for superior fruit quality.

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