Plant Archives Vol. 26, Supplement 1, 2026 pp. 1211-1216 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

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

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.160

INFLUENCE OF PLANT SPACING AND NUTRIENT MANAGEMENT ON GROWTH, YIELD AND POST-HARVEST QUALITY OF BROCCOLI (*BRASSICA OLERACEA* VAR. *ITALICA*)

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(Date of Receiving : 05-09-2025; Date of Acceptance : 22-11-2025)

ABSTRACT

The present study was carried out during Rabi 2022–23 at the Department of Horticulture, University of Agricultural Sciences, Bangalore, to assess the effect of plant spacing and nutrient management on growth, yield and post-harvest quality of broccoli (*Brassica oleracea* var. *italica*). The experiment was laid out in a Factorial Randomized Complete Block Design with three spacings (45 × 30 cm, 45 × 45 cm and 45 × 60 cm), two levels of major nutrients (100% RDF: 120:80:60 kg NPK ha^{-1} and 125% RDF: 150:100:75 kg NPK ha^{-1}) and two micronutrient combinations (Boric acid, $ZnSO_4$ and $MnSO_4$ at 0.20%, 0.30%, 0.15% and 0.40%, 0.60%, 0.30%, respectively). Wider spacing (45 × 60 cm), higher NPK level (125% RDF) and the higher micronutrient combination significantly improved plant height, leaf number, chlorophyll content and yield attributes. The treatment combination of 45 × 60 cm + 150:100:75 kg NPK ha^{-1} + foliar application of 0.40% boric acid + 0.60% $ZnSO_4$ + 0.30% $MnSO_4$ recorded the highest yield (205.04 q ha^{-1}), head compactness, vitamin C content, TSS and shelf life. The results indicate that optimum plant spacing along with balanced macro and micro-nutrient management enhances growth, yield and post-harvest quality of broccoli under open field conditions.

Keywords **:** broccoli, plant spacing, nutrient management, micronutrients, yield, quality.

Introduction

Broccoli (*Brassica oleracea* var. *italica*) is one of the exotic vegetables belongs to the family 'Brassicaceae' (previously Cruciferae) with chromosome number 2n=18. Cabbage, Cauliflower, Broccoli, Brussels sprouts, Collards, Kale and Chinese cabbage are few other members of Brassicaceae. Among cole crops, broccoli is a highly nutritious vegetable that is a great source of antioxidants, vitamins and minerals. It contains minerals such as calcium, phosphorus, potassium and iron, also rich source of vitamin A (130 times and 22 times more than cauliflower and cabbage, respectively), thiamin, riboflavin, niacin and vitamin C (Manoj *et al.,* 2013). Due to the presence of cancer-fighting components such as phytochemicals, β-carotenes, indoles and isothiocyanates, it reduces the prevalence of several types of cancer in humans.

Judicious use of nutrients is essential for broccoli cultivation to get maximum yield of high-quality heads. In terms of growth and quality, broccoli responds significantly to major essential elements such as nitrogen, phosphorus and potassium. Phosphorus fertilization can affect broccoli curd initiation and development whereas, phosphorus proved to be a key component in increasing broccoli yield and various micronutrients also play an important role in enhancing quality broccoli curds. Boron (B), Zinc (Zn) and Manganese (Mn) play an important role directly or indirectly in improving the growth, yield and quality of broccoli in addition to checking various diseases and physiological disorder.

Among the various agronomic practices influencing the production, plant density and nutrition found to exert a great influence on growth, yield, quality and economics of broccoli in open field condition. Balanced use of both macro and micro nutrients are two key factors for enhancing productivity of these crops. Therefore, the objective of the experiment was to know the effect of plant spacing and nutrition on growth and quality of broccoli in open field condition.

Material and Methods

The field experiment was conducted during *rabi*, 2022-23 in the Medicinal crops field of the Department of Horticulture at the University of Agricultural Sciences, Bangalore. The Factorial Randomized Complete Block Design (FRCBD) was used to plan and layout the three different spacings, S_1 (45 cm x 30 cm), S_2 (45 cm x 45 cm) and S_3 (45 cm x 60 cm) and two levels of major nutrients, N_1 (120: 80: 60 Kg NPK ha^{-1} (100 % RDF)) and N_2 (150:100:75 Kg NPK ha^{-1} (125% RDF)) as well as two levels of micronutrient combinations, M_1 (Boric acid (0.20%) + Zinc sulphate (0.30%) + Manganese sulphate (0.15%)) and M_2 (Boric acid (0.40%) + Zinc sulphate (0.60%) + Manganese sulphate (0.30%)) replicated thrice. The land was ploughed and harrowed to a fine tilth. After clearing the land, the layout was carried out in accordance with the treatments. Seedlings that were thirty days old and had grown uniformly were used for transplanting. The different spacing and nutrient levels were combined while transplanting. 50 per cent N, full dose of P and K were applied as basal dose, while remaining 50 per cent N was top dressed 20 days after transplanting. Micronutrients were applied as foliar spray at 30 and 45 days after transplanting.

The growth and quality parameters were recorded using standard methods. The experimental data recorded were subjected to statistical analysis as outlined by Gomez and Gomez (1984). The significance of treatment mean was tested using F-test at 5 per cent level of significance for comparing the significant difference among the treatment means.

Results and Discussion

Growth parameters

Effect of plant spacing

Among the different plant spacing followed, S_3 (45 cm × 60 cm) showed maximum plant height of 65.55 cm, plant spread (77.56 cm N-S and 70.28 cm E-W), number of leaves per plant (26.96) and chlorophyll content (77.31 SPAD value). While the lowest plant height (61.26 cm), plant spread (68.73 cm N-S and 65.12 cm E-W), number of leaves per plant (24.96) and chlorophyll content (63.87 SPAD value) was recorded in S_1 (30 cm x 30 cm) (Table 1).

Effect of major nutrients

The highest plant height (64.04 cm), plant spread (74.19 cm N-S and 68.28 cm E-W), number of leaves per plant (26.31) and chlorophyll content (73.22 SPAD value) was recorded in N_2 (125% RDF). Whereas the lowest plant height (62.08 cm), plant spread (71.44 cm N-S and 66.52 cm E-W), number of leaves per plant (25.98) and chlorophyll content (68.91 SPAD value) was recorded in S_1 (30 cm x 30 cm) (Table 1).

Effect of micronutrients

The plants which are treated with 0.40% boric acid + 0.60% zinc sulphate + 0.30% manganese sulphate (M_2) had recorded maximum plant height (63.89 cm), plant spread (74.00 cm N-S), number of leaves per plant (26.20) and chlorophyll content (71.59 SPAD value). Whereas, minimum plant height (62.23 cm), plant spread (71.63 cm N-S), number of leaves per plant (26.09) and chlorophyll content (70.54 SPAD value) was recorded in M_1 (0.20% boric acid + 0.30% zinc sulphate + 0.15% manganese sulphate) (Table 1).

Interaction

Maximum plant height (67.25 cm), plant spread (82.33 cm N-S and 74.04 cm E-W), number of leaves per plant (27.18) and chlorophyll content (82.15 SPAD value) was observed in treatment T_{12} consisting of 45 cm x 60 cm spacing + 150:100:75 kg NPK ha^{-1} + boric acid (0.40%) + $ZnSO_4$ (0.60%) + $MnSO_4$ (0.30%). While the minimum plant height (57.91 cm), plant spread (65.01 cm N-S and 63.51 cm E-W), number of leaves per plant (24.69) and chlorophyll content (61.15 SPAD value) observed in T_1 [45 cm x 30 cm + 120:80:60 kg ha^{-1} + Boric acid (0.20%) + $ZnSO_4$ (0.30%) + $MnSO_4$ (0.15%)] (Table 1).

Maximum plant spread was observed in the treatment consists of 45 cm x 60 cm and 125% RDF with higher concentration of micronutrient combinations. This might be due to the fact that major nutrients and micronutrients are very much helpful in improving the growth of plants by playing a crucial role in cellular oxidation which is the fundamental process involved in the cell metabolism and respiration. Zinc, boron and manganese helps in stomata and guard cell regulation and in assimilation of nitrogen which ultimately helps in chlorophyll formation and directly involved in photosynthesis. This ultimately increases the growth. The similar results were also reported in the study by Singh *et al.* (2015), Gogoi *et al.* (2016), Madumathi *et al.* (2017), Shivran *et al.* (2017) and Lavanya *et al.* (2022) in broccoli.

Yield parameters

Effect of spacing

The data with regard to yield per plant, yield per plot and total yield due to plant spacing showed significant variation. Broccoli plants in S_3 (45 cm x 60 cm) recorded maximum yield per plant (527.21 g), yield per plot (10.38 kg) and total yield (195.26 q ha^{-1}). Whereas, the minimum yield per plant (187.92 g), yield per plot (8.78 kg) and total yield (139.20 q ha^{-1}) was observed in S_1 (45 cm x 30 cm) (Table 1).

Major nutrients

The results with respect to different concentration of major nutrients was found significant for yield per plant, yield per plot and total yield. Significantly maximum yield per plant (404.74 g), yield per plot (10.92 kg) and total yield (193.07 q ha^{-1}) was observed in N_2 (150:100:75 kg NPK ha^{-1}). While the minimum yield per plant (363.61 g), yield per plot (9.96 kg) and total yield (173.90 q ha^{-1}) was seen in N_1 (120:80:60 kg NPK ha^{-1}) (Table 1).

Micronutrients

The effect of varying concentration of micronutrient combinations sprayed was found significant on yield per plant, yield per plot and total yield of broccoli. Maximum yield per plant (401.20 g), yield per plot (10.86 kg) and total yield (191.80 q ha^{-1}) was recorded in plants sprayed with 0.40 per cent boric acid + 0.60 per cent zinc sulphate + 0.30 per cent manganese sulphate (M_2). While the minimum yield per plant (367.14 g), yield per plot (10.03 kg) and total yield (175.18 q ha^{-1}) was observed in plants sprayed with 0.20 per cent boric acid + 0.30 per cent zinc sulphate + 0.15 per cent manganese sulphate (M_1) as shown in Table 1.

Interaction

The three-way interaction effect of plant spacing, major and micro nutrients on yield per plant, yield per plot and total yield of broccoli was found significant. Maximum yield per plant (553.62 g), yield per plot (10.85 kg) and total yield (205.04 q ha^{-1}) was noticed in treatment T_{12} [45 cm x 60 cm spacing + 150:100:75 kg NPK ha^{-1} + boric acid (0.40%) + $ZnSO_4$ (0.60%) + $MnSO_4$ (0.30%)]. While minimum the yield per plant (173.43 g), yield per plot (8.24 kg) and total yield (128.47 q ha^{-1}) was observed in T_1 [45 cm x 30 cm + 120:80:60 kg ha^{-1} + Boric acid (0.20%) + $ZnSO_4$ (0.30%) + $MnSO_4$ (0.15%)] (Table 1).

The interaction between plant spacing, major nutrients and micronutrient application (T_{12}: 45 cm × 60 cm spacing + 150:100:75 kg NPK ha^{-1} + Boric acid 0.40% + $ZnSO_4$ 0.60% + $MnSO_4$ 0.30%) resulted in the highest yield. This combination provided an optimal environment for plant growth by addressing spacing, nutrient needs and micronutrient requirements. The synergy between these factors led to better growth conditions, enhanced photosynthesis and efficient nutrient utilization, which contributed to the maximum yield. Micronutrients play crucial roles in various physiological processes, including photosynthesis, enzyme activity and plant metabolism. The enhanced availability of boron, zinc and manganese likely improved nutrient uptake and utilization, thereby enhancing total yield of broccoli. Conversely, the combination of suboptimal spacing, lower nutrient concentrations and reduced micronutrient application (T1: 30 cm × 30 cm + 120:80:60 kg NPK ha^{-1} + Boric acid 0.20% + $ZnSO_4$ 0.30% + $MnSO_4$ 0.15%) resulted in lower yields due to the limitations imposed by crowded plant conditions and insufficient nutrient and micronutrient availability. Similar results were also observed by Singh *et al.* (2015), Tudu *et al.* (2020), Lavanya *et al.* (2022) in broccoli and Kaur *et al.* (2020) in cauliflower and Verma and Nawange (2013) in cabbage.

Quality parameters

Effect of plant spacing

Treatment with wider spacing S_3 (45 cm x 60 cm) showed maximum TSS (8.82 ºBrix), vitamin C content (105.48 mg $100g^{-1}$), head compactness (23.67 g cm^{-3}), and shelf life (1.78 days). Whereas, minimum TSS (6.12 ºBrix), vitamin C content (101.91 mg $100g^{-1}$), head compactness (22.52 g cm^{-3}) and shelf life (1.18 days) were observed in plants which are planted at S_1 (30 cm x 30 cm) spacing as depicted in figure 1.

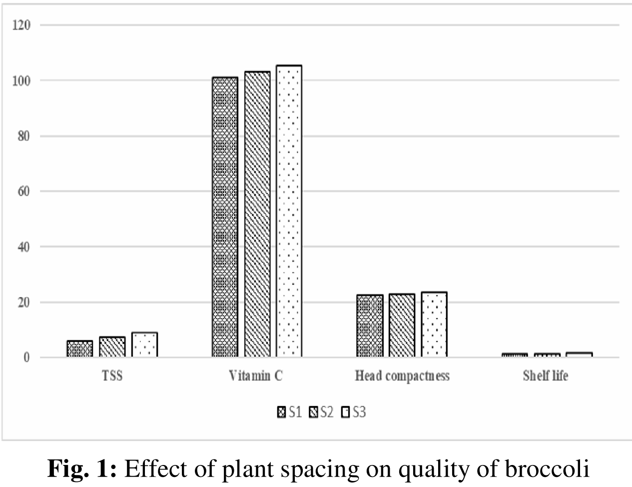

Fig. 1: Effect of plant spacing on quality of broccoli

Effect of major nutrients

Plants treated with N_2 (150:100:75 kg NPK ha^{-1}) showed highest TSS (7.73 ºBrix), vitamin C content (103.89 mg $100g^{-1}$), head compactness (23.53 g cm^{-3}) and shelf life (1.53 days). Whereas plants treated with N_1 (120:80:60 kg NPK ha^{-1}) showed lowest TSS (7.10 ºBrix), vitamin C content (102.65 mg $100g^{-1}$), head compactness (22.54 g cm^{-3}) and shelf life (1.33 days) (Figure 2).

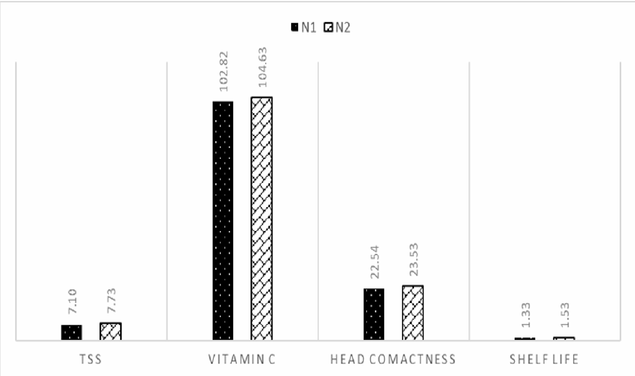

Fig. 2: Effect of major nutrients on quality of broccoli

Effect of micronutrients

Broccoli plants treated with M_2 (Boric acid (0.40%) + $ZnSO_4$ (0.60%) + $MnSO_4$ (0.30%)) showed maximum TSS (7.60 ºBrix), vitamin C content (103.62 mg $100g^{-1}$), head compactness (23.22 g cm^{-3}) and shelf life (1.47 days). Whereas plants treated with M_1 (Boric acid (0.20%) + $ZnSO_4$ (0.30%) + $MnSO_4$ (0.15%)) showed lowest TSS (7.23 ºBrix), vitamin C content (102.91 mg $100g^{-1}$), head compactness (22.84 g cm^{-3}) and shelf life (1.40 days) as shown in figure 3.

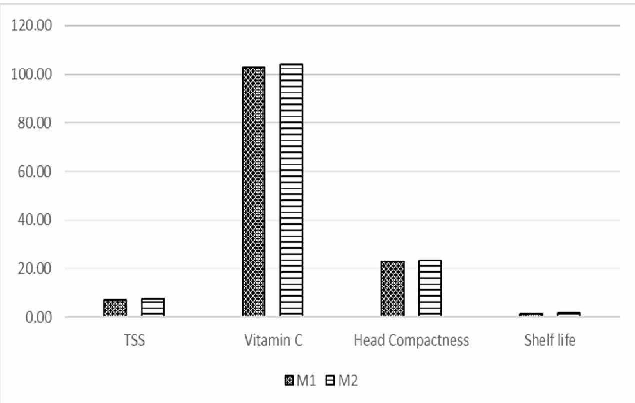

Fig. 3: Effect of micronutrients on quality of broccoli

Interaction effect

The interaction effect of plant spacing, major nutrients and micronutrient combination showed the highest TSS (9.91 ºBrix), head compactness (24.20 g cm^{-3}) and shelf life (2.00 days) in $S_3N_2M_2$. Whereas lowest TSS (5.92 ºBrix), head compactness (21.61 g cm^{-3}) and shelf life (1.00 day) in $S_1N_1M_1$ (Figure 4).

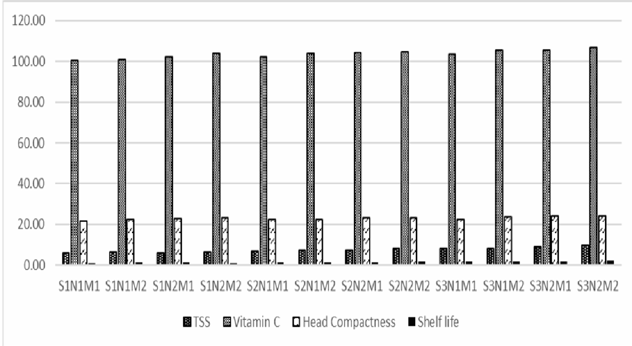

Fig. 4: Effect of interaction on quality of broccoli

The effect of optimum plant spacing, higher dose of major nutrients and micronutrients led to the highest quality parameters, with increased shelf life, vitamin C content, head compactness, TSS. This indicates that these advanced agronomic practices work synergistically to optimize plant growth and quality. The plants grown with optimal spacing and nutrient management were able to utilize available resources more effectively, resulting in enhanced nutrient uptake, better plant development and higher quality broccoli heads. The micronutrient combinations play a vital role in enzymatic activities, chlorophyll synthesis and overall plant metabolism, directly influencing the production of vitamin C, TSS, and head quality. Conversely, the lowest quality parameters in the $S_1N_1M_1$ treatment could be attributed to the combination of insufficient spacing, lower nutrient levels and limited micronutrient availability, which hindered the plant's overall growth and quality potential. These results were in line with those of Saha *et al.* (2010), Singh *et al.* (2017), Mohanta *et al.* (2018), Chowdhury and Sikder (2019), Minz *et al.* (2023) in broccoli and Young (2015) in cabbage.

Conclusion

The study concluded that plant spacing, major nutrient levels and micronutrient application significantly influence the growth, quality, yield and nutrient uptake of broccoli. Wider plant spacing (45 cm × 60 cm), along with the application of 125% RDF (150:100:75 kg NPK ha^{-1}) and higher concentrations of micronutrients (boric acid (0.40%), zinc sulphate (0.60%), manganese sulphate (0.30%)), resulted in the best overall performance, including higher shelf life, vitamin C content, head compactness, total soluble solids (TSS) and yield. The highest yield per plant (553.62 g) and total yield (205.04 q ha^{-1}) were achieved with these treatments. Additionally, these conditions enhanced the nutritional status of broccoli curds because of high uptake of both macronutrients and micronutrients. The findings emphasize the importance of advanced agronomic practices for improving broccoli shelf life and production, suggesting that these practices can be adopted for higher yield and better quality in field condition.

Table 1: Effect of plant spacing and nutrition on growth and yield of broccoli

Treatment	Plant height (cm)	Plant spread (cm)		Number of leaves per plant	Chlorophyll content (SPAD value)	Yield per plant (g)	Yield per plot (kg)	Total yield (q ha^{-1})
		N-S	E-W					
Spacing (S)								
S_1	61.26	68.73	65.12	24.96	63.87	187.92	8.78	139.20
S_2	62.36	72.15	66.82	26.52	72.01	437.39	12.17	215.99
S_3	65.55	77.56	70.28	26.96	77.31	527.21	10.38	195.26
S.Em±	0.09	0.10	0.26	0.06	0.18	6.08	0.15	2.68
CD (5%)	0.28	0.30	0.77	0.19	0.53	17.83	0.44	7.86
Major nutrients (N)								
N_1	62.08	71.44	66.52	25.98	68.91	363.61	9.96	173.90
N_2	64.04	74.19	68.28	26.31	73.22	404.74	10.92	193.07
S.Em±	0.08	0.08	0.21	0.05	0.14	4.96	0.12	2.18
CD (5%)	0.23	0.24	0.63	0.15	0.43	14.55	0.36	6.41
Micronutrients (M)								
M_1	62.23	71.63	67.32	26.09	70.54	367.14	10.03	175.18
M_2	63.89	74.00	67.49	26.20	71.59	401.20	10.86	191.80
S.Em±	0.08	0.08	0.21	0.05	0.14	4.96	0.12	2.18
CD (5%)	0.23	0.24	NS	0.15	0.43	14.55	0.36	6.41
Interaction (S x N x M)								
T_1 - $S_1N_1M_1$	57.91^{e}	65.01^{i}	63.51^{e}	24.69^{e}	61.15^{h}	173.43^{e}	8.24^{e}	128.47^{f}
T_2 - $S_1N_1M_2$	62.15^{c}	68.86^{g}	65.25^{e}	25.42^{d}	61.81^{gh}	183.06^{e}	8.60^{e}	135.6^{f}
T_3 - $S_1N_2M_1$	61.08^{d}	67.86^{h}	63.99^{e}	24.84^{d}	62.77^{g}	182.83^{e}	8.59^{e}	135.43^{f}
T_4 - $S_1N_2M_2$	63.89^{b}	73.21^{d}	63.83^{e}	24.87^{d}	69.76^{f}	212.37^{e}	9.68^{d}	157.31^{e}
T_5 - $S_2N_1M_1$	62.27^{c}	72.97^{d}	68.33^{cd}	26.03^{c}	71.34^{e}	380.64^{d}	10.75^{c}	187.97^{d}
T_6 - $S_2N_1M_2$	62.07^{c}	71.72^{e}	67.40^{d}	25.96^{d}	71.86^{de}	428.39^{c}	11.94^{b}	211.55^{bc}
T_7 - $S_2N_2M_1$	61.23^{d}	73.04^{d}	67.77^{d}	26.16^{c}	72.12^{de}	455.50^{bc}	12.62^{ab}	224.94^{ab}
T_8 - $S_2N_2M_2$	63.86^{b}	70.86^{f}	67.67^{d}	26.38^{c}	72.71^{d}	485.02^{b}	13.36^{a}	239.52^{a}
T_9 - $S_3N_1M_1$	63.96^{b}	73.07^{d}	65.03^{e}	26.41^{c}	76.05^{c}	461.97^{bc}	9.20^{de}	171.10^{e}
T_{10} - $S_3N_1M_2$	64.09^{b}	77.01^{c}	69.62^{c}	26.76^{b}	71.24^{e}	544.77^{a}	10.69^{c}	201.76^{cd}
T_{11} - $S_3N_2M_1$	66.90^{a}	77.84^{b}	72.41^{b}	26.80^{b}	79.79^{b}	548.49^{a}	10.76^{c}	203.14^{cd}
T_{12} - $S_3N_2M_2$	67.25^{a}	82.33^{a}	74.04^{a}	27.18^{a}	82.15^{a}	553.62^{a}	10.85^{c}	205.04^{c}
S.Em±	0.19	0.20	0.52	0.13	0.36	12.16	0.30	5.36
CD (5%)	0.57	0.60	1.55	0.38	1.02	135.66	0.88	15.72

Note:

Spacing (S)	Major nutrients (N)	Micronutrients (M)
S_1 – 45 cm x 30 cm S_2 – 45 cm x 45 cm S_3 – 45 cm x 60 cm	N_1 – 120:80:60 kg NPK ha^{-1} N_2 – 150:100:75 kg NPK ha^{-1}	M_1 – Boric acid (0.20%) + Zinc sulphate (0.30%) + Manganese sulphate (0.15%) M_2 – Boric acid (0.40%) + Zinc sulphate (0.60%) + Manganese sulphate (0.30%)

Significance @ 5% level, NS – Non significant
N–S–North–South direction
E–W–East–West direction

Acknowledgement

I gratefully acknowledge the Department of Horticulture, UAS, GKVK, Bengaluru, for providing the necessary facilities that greatly contributed to the success of this research.

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