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EFFECT OF BUNCH THINNING, GROWTH REGULATORS AND MICRONUTRIENTS ON GROWTH AND PHYSIOLOGICAL ASPECTS OF GRAPES CV. MANIK CHAMAN

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ABSTRACT

The Manik Chaman seedless variety of grapes, is an important crop in India, valued for both domestic consumption and export. In recent years, its popularity has increased due to its bold berry size and superior quality. However, the quality of the produce from North Karnataka region is not up to the desired standard. A study was conducted to investigate the impact of bunch thinning and use of growth regulators and micronutrients on the growth, yield and quality of grapes cv. Manik Chaman. The experiment involved two factors: the first being different levels of bunch thinning and the second comprising various treatment modules involving growth regulators and micronutrients. The study assessed vegetative growth and physiological parameters, both of which have a positive correlation with yield and fruit quality. The results showed that lesser bunch load had better vegetative growth and physiological activity. The best results in terms of managing excessive fruit production, achieving a balance between vegetative growth and improving the physiological characteristics of the grape. Overall, maintaining 35 bunches per vine and combination of GA_3 at 150 ppm + micronutrients spray ($ZnSO_4$ at3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm) is recommended for obtaining maximum vegetative growth.

Keywords **:** Grapes, bunch thinning, growth regulators and micronutrients.

Introduction

Grape (*Vitis vinifera* L.), a member of the Vitaceae family, is native to the riverbanks of Asia, North America and Europe. It ranks among the most important fruit crops globally, valued for its rich content of essential minerals like calcium, phosphorus and iron, as well as vitamins B_1 and B_2. In addition to their nutritional significance, grapes possess several medicinal properties. Grape juice exhibits mild laxative effects and supports kidney function, while the fruit itself is a valuable source of antioxidants, antimicrobial and anti-inflammatory compounds. In India, 78 per cent of grape is produced for fresh consumption and about 17-25 per cent for raisin production and remaining 2 per cent collectively used for juice and wine production. Presently, grapes are grown in India over an area of 1.75 lakh ha with production of 31.25 lakh MT and productivity of 21.27 t/ha (Anon., 2024). India ranks first in the world for grape productivity and 7th position for table grape export with the quantum of exported fresh grapes 3.43 lakh MT. Over 50 per cent of Indian grapes are exported to the European Union. Top importing countries for Indian grapes remain the Netherlands (51%), Russia (36.53%), United Kingdom (13%), Bangladesh (9%) and Germany (8%). In India, grapes are primarily grown in the semi-arid tropical regions, with over 90 per cent of the cultivation area located in the states of Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh. Among these, Maharashtra ranks first, contributing more than 67 per cent of the

country's total grape production and having the highest productivity. Karnataka is the second-largest producer, accounting for around 28 per cent of the output (Anon., 2024). The major grape-producing regions in Karnataka fall within the Northern dry zone, encompassing districts such as Vijayapura, Belagavi, Bagalkot, Koppal, Gadag and Raichur. The quality of table grapes is typically evaluated based on bunch size, berry uniformity, symmetry and the distinctive color, flavor and texture of the variety. Grape quality is largely influenced by factors such as soil management, irrigation, fertilization, pruning and climate. Additionally, various other vineyard practices including bunch thinning, defoliation, application of growth regulators, girdling, micronutrient application and canopy management plays a significant role in improving berry quality. Its production is driven by advanced key agronomic techniques such as bunch thinning and the use of growth regulators like GA_3 (Gibberellic Acid), CPPU (Forchlorfenuron) and brassinosteroids play a crucial role in enhancing fruit quality.

Material and Methods

The present investigation was carried out at Main Horticultural Research and Extension Centre, University of Horticultural Sciences, Bagalkot in the grape vineyard during 2023-25. The treatments were imposed to eight years old vines raised on Dogridge rootstock and trained on Y trellis system. The experiment was conducted in factorial randomised block design with three replication and 5 plants per treatment were used. The experimental design consists two factors, 1st factor consists of 2 treatments, 2nd factor consists of 4 treatments. I Factor includes different bunch thinning (Cluster thinning) treatments such as 35 bunches/vine and control (55 bunches per vine). The bunch thinning was done at prebloom panicle stage. Factor II includes different doses of GA_3 along with same micronutrients and growth regulators such as CPPU and brassinosteroids.

Table 1: Treatment's detail

Module	GA_3 Dose	Micronutrients (foliar spray per L)	CPPU	BRs	Application Stages
M_1	GA_3 100 ppm	$ZnSO_4$ 3g + $FeSO_4$ 2g + $MnSO_4$ 2g + Boric Acid 1g	2 ppm	0.5 & 1.0 ppm	10 ppm @ Parrot green stage (21 DAFP) 15 ppm @ Pre-bloom stage (23–25 DAFP) 40 ppm GA_3 + micronutrients + CPPU + BR @ 3-4 mm berry size 35 ppm GA_3 + micronutrients + CPPU + BR @ 6-7 mm berry size
M_2	GA_3 120 ppm	$ZnSO_4$ 3g + $FeSO_4$ 2g + $MnSO_4$ 2g + Boric Acid 1g	2 ppm	0.5 & 1.0 ppm	10 ppm @ Parrot green stage 15 ppm @ Pre-bloom stage 20 ppm @ 50% flowering stage 40 ppm GA_3 + micronutrients + CPPU + BR @ 3-4 mm berry size 35 ppm GA_3 + micronutrients + CPPU + BR @ 6-7 mm berry size
M_3	GA_3 150 ppm	$ZnSO_4$ 3g + $FeSO_4$ 2g + $MnSO_4$ 2g + Boric Acid 1g	2 ppm	0.5 & 1.0 ppm	10 ppm @ Parrot green stage 15 ppm @ Pre-bloom stage 20 ppm @ Pre-bloom stage (28–32 DAFP) 35 ppm @ 50% flowering stage 30 ppm GA_3 + micronutrients + CPPU + BR @ 3-4 mm berry size 40 ppm GA_3 + micronutrients + CPPU + BR @ 6-7 mm berry size
M_4	GA_3 100 ppm				10 ppm @ Parrot green stage 15 ppm @ Pre-bloom stage 40 ppm GA_3 dip @ 3–4 mm berry size 35 ppm GA_3 dip @ 6–7 mm berry size

The observations on growth parameters were taken by selecting the five random canes per vine in each replication. The internodal length of fruiting shoot was measured in between the fourth and fifth nodes from the base was measured using a 30 cm scale on five randomly selected fruiting shoots per vine expressed in centimetres (cm). Observations were recorded at 45 and 90 days after forward pruning (DAFP) for all parameters. The internodal girth of the fruiting shoot was recorded using vernier calipers between the fourth and fifth nodes from the base on five randomly selected fruiting shoots from each vine expressed in milimetres (mm). The SPAD 502 was used to determine leaf chlorophyll content by measuring the absorbance of the leaf in two wavelength regions. For the determination, the fifth node from the base of five physiologically matured leaves on each vine was selected and the mean value was recorded. This is a non-destructive method for estimating leaf chlorophyll content. The values were expressed in SCMR (SPAD Chlorophyll Meter Reading). The LAI-2200C Plant canopy analyzer was used to measure the Leaf Area Index (LAI) through a non-destructive, accuracy and efficient method. Prior

to data collection, the sensor was calibrated and measurements were taken under uniform canopy conditions. An initial above canopy reading was recorded in an open area to assess incident light. Subsequently, four below canopy readings were taken at ground level from all sides of the plant, while avoiding direct sunlight. The instrument automatically calculated LAI based on light attenuation. To ensure consistency, all readings were taken at the same time of day. Leaf area was initially measured using the linear method and expressed in cm^2. The same leaves were then oven-dried at 60 °C until a constant weight was obtained and their dry weight was recorded in milligrams (mg). Specific Leaf Area (SLA) was calculated by dividing the area by the corresponding leaf weight and results were expressed in cm^2/ mg.

$$SLA = \frac{\text{Leaf area } (cm^2)}{\text{Leaf dry weight (mg)}}$$

Statistical analysis

All data for the growth parameters were tabulated and statistical analysis, specifically ANOVA (Analysis of Variance) was conducted using a Factorial Randomized Block Design. The results were analyzed at 5 per cent level of significance using Cochran and Cox's (1957) method of analysis of variance. A critical difference of 5 per cent level was established, when the 'F' test for comparing treatment means was found to be significant.

Table 2 : Internodal length (cm) of fruiting shoot at 45 and 90 days after forward pruning as influenced by bunch thinning, foliar application of growth regulators and micronutrients in grapes cv. Manik Chaman

Treatment	Internodal length (cm) of fruiting shoot at 45 DAFP			Internodal length (cm) of fruiting shoot at 90 DAFP		
	2024	2025	Pooled	2024	2025	Pooled
Bunch thinning (C)						
C_1-35 bunches/vine	5.30	5.69	5.50	5.95	6.36	6.16
C_2-Control	4.92	5.36	5.14	5.62	5.79	5.71
S.Em ±	0.08	0.07	0.06	0.10	0.12	0.08
CD at 5 %	0.25	0.23	0.18	0.30	0.33	0.25
Module (M)						
M_1-Module 1	5.07	5.46	5.27	5.72	5.79	5.76
M_2-Module 2	5.16	5.60	5.38	5.80	6.10	5.95
M_3-Module 3	5.63	5.92	5.78	6.18	6.63	6.41
M_4-Module 4	4.58	5.11	4.85	5.46	5.78	5.62
S.Em ±	0.12	0.10	0.08	0.14	0.15	0.12
CD at 5 %	0.36	0.32	0.25	0.43	0.45	0.35
Interactions (C × M)						
C_1M_1	5.24	5.55	5.40	5.94	6.06	6.00
C_1M_2	5.39	5.72	5.56	5.91	6.29	6.11
C_1M_3	5.91	6.16	6.03	6.50	7.04	6.77
C_1M_4	4.66	5.34	5.00	5.44	6.05	5.74
C_2M_1	4.90	5.37	5.14	5.50	5.52	5.51
C_2M_2	4.92	5.49	5.20	5.66	5.90	5.78
C_2M_3	5.36	5.69	5.53	5.86	6.23	6.04
C_2M_4	4.50	4.88	4.69	5.48	5.51	5.49
S.Em ±	0.17	0.15	0.12	0.20	0.21	0.17
CD at 5 %	NS	NS	NS	NS	NS	NS

NS :Non significant

DAFP: Days after forward pruning

M_1-Module 1: GA_3 at100ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+Boric acid at 1g/L)+CPPU (2 ppm)+BRs (0.5 and 1.0 ppm)

M_2-Module 2: GA_3 at120ppm+micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+ $MnSO_4$ at 2 g/L+ Boric acid at 1g/L)+CPPU (2 ppm)+BR (0.5 and 1.0 ppm)

M_3-Module 3: GA_3 at150ppm+micronutrients spray($ZnSO_4$ at3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm)

M_4-Module 4: GA_3 at100 ppm

Table 3 : Internodal girth (mm) of fruiting shoot at 45 and 90 days after forward pruning as influenced by bunch thinning, foliar application of growth regulators and micronutrients in grapes cv. Manik Chaman

Treatment	Internodal girth (mm) of fruiting shoot at 45 DAFP			Internodal girth (mm) of fruiting shoot at 90 DAFP		
	2024	2025	Pooled	2024	2025	Pooled
Bunch thinning (C)						
C_1-35 bunches/vine	6.01	6.37	6.19	6.65	6.81	6.73
C_2-Control	5.62	5.71	5.66	6.17	6.09	6.13
S.Em ±	0.09	0.10	0.07	0.09	0.07	0.06
CD at 5 %	0.27	0.29	0.21	0.27	0.25	0.19
Module (M)						
M_1-Module 1	5.69	5.97	5.83	6.36	6.34	6.35
M_2-Module 2	5.95	6.00	5.98	6.46	6.57	6.52
M_3-Module 3	6.20	6.36	6.28	6.76	6.93	6.84
M_4-Module 4	5.42	5.81	5.61	6.07	5.96	6.02
S.Em ±	0.12	0.14	0.10	0.12	0.13	0.09
CD at 5 %	0.38	0.41	0.30	0.37	0.39	0.27
Interactions (C × M)						
C_1M_1	5.91	6.23	6.07	6.52	6.73	6.62
C_1M_2	6.24	6.39	6.31	6.66	6.91	6.79
C_1M_3	6.47	6.75	6.61	7.14	7.31	7.23
C_1M_4	5.44	6.09	5.77	6.29	6.28	6.28
C_2M_1	5.47	5.71	5.59	6.20	5.95	6.07
C_2M_2	5.66	5.62	5.64	6.25	6.24	6.24
C_2M_3	5.94	5.97	5.95	6.37	6.54	6.46
C_2M_4	5.40	5.53	5.46	5.86	5.65	5.75
S.Em ±	0.18	0.19	0.14	0.17	0.18	0.12
CD at 5 %	NS	NS	NS	NS	NS	NS

NS :Non significant

DAFP: Days after forward pruning

M_1-Module 1: GA_3 at 100 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+Boric acid at 1g/L)+CPPU (2 ppm)+BRs (0.5 and 1.0 ppm)

M_2-Module 2: GA_3 at 120 ppm+micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+ $MnSO_4$ at 2 g/L+ Boric acid at 1g/L)+CPPU (2 ppm)+BR (0.5 and 1.0 ppm)

M_3-Module 3: GA_3 at 150 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm)

M_4-Module 4: GA_3 at100 ppm

Table 4 : Chlorophyll content (SPAD values) at 45 and 90 days after forward pruning as influenced by bunch thinning, foliar application of growth regulators and micronutrients in grapes cv. Manik Chaman

Treatment	Chlorophyll content (SPAD values) at 45 DAFP			Chlorophyll content (SPAD values) at 90 DAFP		
	2024	2025	Pooled	2024	2025	Pooled
Bunch thinning (C)						
C_1-35 bunches/vine	35.44	37.63	36.54	39.40	39.71	39.56
C_2-Control	33.83	36.28	35.06	36.78	37.07	36.93
S.Em ±	0.44	0.41	0.31	0.61	0.58	0.50
CD at 5 %	1.34	1.25	0.96	1.86	1.77	1.52
Module (M)						
M_1-Module 1	34.45	35.99	35.22	37.56	37.22	37.39
M_2-Module 2	34.77	37.11	35.94	38.08	38.95	38.52
M_3-Module 3	36.12	39.07	37.59	40.30	42.31	41.31
M_4-Module 4	33.21	34.67	34.44	36.43	35.08	35.75
S.Em ±	0.62	0.58	0.45	0.87	0.83	0.71
CD at 5 %	1.89	1.77	1.35	2.64	2.51	2.15
Interactions (C × M)						
C_1M_1	35.45	36.49	35.97	38.39	38.54	38.47

C_1M_2	35.41	37.40	36.41	39.35	39.56	39.46
C_1M_3	37.42	40.34	38.88	42.71	45.21	43.96
C_1M_4	33.50	36.29	34.89	37.15	35.52	36.34
C_2M_1	33.44	35.48	34.46	36.72	35.89	36.31
C_2M_2	34.13	36.81	35.47	36.81	38.34	37.58
C_2M_3	34.82	37.79	36.30	37.89	39.41	38.65
C_2M_4	32.93	35.05	33.99	35.70	34.64	35.17
S.Em ±	0.88	0.82	0.63	1.23	1.17	1.00
CD at 5 %	NS	NS	NS	NS	NS	NS

NS :Non significant
DAFP: Days after forward pruning

M_1-Module 1: GA_3 at 100 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+Boric acid at 1g/L)+CPPU (2 ppm)+BRs (0.5 and 1.0 ppm)
M_2-Module 2: GA_3 at 120 ppm+micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+ $MnSO_4$ at 2 g/L+ Boric acid at 1g/L)+CPPU (2 ppm)+BR (0.5 and 1.0 ppm)
M_3-Module 3: GA_3 at 150 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm)
M_4-Module 4: GA_3 at100 ppm

Table 5 : Leaf area index (LAI) at 45 and 90 days after forward pruning as influenced by bunch thinning, foliar application of growth regulators and micronutrients in grapes cv. Manik Chaman

Treatment	Leaf area index at 45 DAFP			Leaf area index at 90 DAFP		
	2024	**2025**	**Pooled**	**2024**	**2025**	**Pooled**
Bunch thinning (C)						
C1-35 bunches/vine	1.75	1.97	1.86	3.14	3.36	3.25
C2-Control	1.47	1.49	1.48	2.70	2.79	2.74
S.Em ±	0.07	0.08	0.06	0.08	0.09	0.08
CD at 5 %	0.19	0.20	0.17	0.24	0.27	0.24
Module (M)						
M_1-Module 1	1.49	1.63	1.56	2.73	2.98	2.86
M_2-Module 2	1.51	1.72	1.61	2.97	3.12	3.04
M_3-Module 3	2.04	1.97	2.01	3.36	3.51	3.44
M_4-Module 4	1.40	1.59	1.50	2.62	2.69	2.66
S.Em ±	0.08	0.09	0.08	0.11	0.12	0.11
CD at 5 %	0.25	0.29	0.24	0.34	0.36	0.34
Interactions (C × M)						
C_1M_1	1.58	1.86	1.72	2.97	3.20	3.09
C_1M_2	1.62	1.92	1.77	3.18	3.42	3.30
C_1M_3	2.33	2.35	2.34	3.49	3.53	3.51
C_1M_4	1.48	1.76	1.62	2.73	2.89	2.81
C_2M_1	1.41	1.40	1.40	2.49	2.76	2.63
C_2M_2	1.40	1.51	1.45	2.75	2.82	2.79
C_2M_3	1.75	1.60	1.67	3.03	3.10	3.06
C_2M_4	1.32	1.43	1.37	2.51	2.49	2.50
S.Em ±	0.12	0.13	0.11	0.16	0.17	0.16
CD at 5 %	NS	NS	NS	NS	NS	NS

NS :Non significant
DAFP: Days after forward pruning

M_1-Module 1: GA_3 at 100 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+Boric acid at 1g/L)+CPPU (2 ppm)+BRs (0.5 and 1.0 ppm)
M_2-Module 2: GA_3 at 120 ppm+micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+ $MnSO_4$ at 2 g/L+ Boric acid at 1g/L)+CPPU (2 ppm)+BR (0.5 and 1.0 ppm)
M_3-Module 3: GA_3 at 150 ppm+micronutrients spray($ZnSO_4$ at3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm)
M_4-Module 4: GA_3 at 100 ppm

Table 6 : Specific leaf area (SLA) at 45 and 90 days after forward pruning as influenced by bunch thinning, foliar application of growth regulators and micronutrients in grapes cv. Manik Chaman

Treatment	Specific leaf area (cm^2/g) at 45 DAFP			Specific leaf area (cm^2/g) at 90 DAFP		
	2024	2025	Pooled	2024	2025	Pooled
Bunch thinning (C)						
C_1-35 bunches/vine	131.55	147.47	139.51	125.78	141.42	133.60
C_2-Control	145.19	158.83	152.01	143.47	151.75	154.61
S.Em ±	3.41	3.57	2.14	2.37	1.79	1.31
CD at 5 %	10.33	10.84	6.50	7.18	2.39	3.99
Module (M)						
M_1-Module 1	141.24	159.92	150.58	139.91	157.17	146.54
M_2-Module 2	135.52	146.71	141.12	126.83	137.33	132.08
M_3-Module 3	123.63	137.36	130.49	122.44	125.00	123.72
M_4-Module 4	153.09	168.60	160.85	154.32	181.83	168.08
S.Em ±	4.82	5.06	3.03	3.35	1.11	1.86
CD at 5 %	14.61	15.33	9.19	10.15	3.38	5.64
Interactions (C × M)						
C_1M_1	132.37	148.29	140.33	128.41	145.00	139.21
C_1M_2	127.82	144.72	136.27	118.07	135.33	126.70
C_1M_3	117.44	137.23	127.33	115.56	117.67	116.61
C_1M_4	148.59	159.64	154.11	141.08	162.67	151.87
C_2M_1	150.11	171.55	160.83	157.41	174.33	165.87
C_2M_2	143.22	148.71	145.96	135.59	139.33	137.46
C_2M_3	129.82	137.49	133.65	129.31	132.33	130.82
C_2M_4	157.59	177.56	167.58	167.56	201.00	184.28
S.Em ±	6.81	7.15	4.29	4.73	1.58	2.63
CD at 5 %	NS	NS	NS	NS	4.78	7.97

NS :Non significant
DAFP: Days after forward pruning

M_1-Module 1: GA_3 at 100 ppm+micronutrients spray($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+Boric acid at 1g/L)+CPPU (2 ppm)+BRs (0.5 and 1.0 ppm)
M_2-Module 2: GA_3 at120 ppm+micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+ $MnSO_4$ at 2 g/L+ Boric acid at 1g/L)+CPPU (2 ppm)+BR (0.5 and 1.0 ppm)
M_3-Module 3: GA_3 at150 ppm+micronutrients spray($ZnSO_4$ at3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm)
M_4-Module 4: GA_3 at100 ppm

Results and Discussion

The pooled data on bunch thinning treatments showed a significant difference with respect to internodal length and girth of fruiting shoot (Table 2 and 3). Among the bunch thinning treatments, vines retained with 35 bunches (C_1) recorded the highest internodal length (5.50 & 6.16 cm) and girth (6.19 & 6.73 mm) of fruiting shoot compared to the control (5.14 & 5.71 cm) and (5.66 & 6.13 mm) at 45 and 90 DAFP, respectively. In the present investigation, the maximum internodal length and girth of fruiting shoot was observed in 35 bunches per vine. This might be due to reduced competition among the bunches for photosynthates and metabolites. This allowed for enhanced physiological activity and improved vine vigour. This effect was pronounced during the peak vegetative growth phase, when a greater proportion of photosynthates was allocated to the shoots, it promotes increase in length and girth of the fruiting shoot. However, the control treatment experienced higher competition for assimilates, resulting in restricted shoot growth. Somkuwar *et al*. (2020) opined that decrease in bunch load as a positive effect on internodal length and girth of fruiting shoots due to reduced competition between the bunches in grapes cv. Thompson Seedless. These observations are also consistent with the findings of Siddanna (2024) in Thompson Seedless grapes and Somkuwar *et al*. (2014) in Jambo Seedless. In terms of module treatments, significant difference in internodal length and girth of fruiting shoots was observed. Module 3 (which comprises of GA_3 at 150 ppm + micronutrients spray ($ZnSO_4$ at 3g/L+$FeSO_4$ at 2g/L+$MnSO_4$ at 2g/L+ Boric acid at 1 g/L) + CPPU (2 ppm) + BRs (0.5 and 1.0 ppm) was recorded the highest internodal length (5.78 & 6.41 cm) and girth (6.28 & 6.84 mm), followed by Module 2 (5.38 & 5.95

cm cm) and (5.98 & 6.52 mm), while the lowest internodal length (4. 85 & 5.62 cm) and girth (5.61 & 6.02 mm) was observed in Module 4 at 45 and 90 DAFP, respectively. The increase in internodal length and girth was due to the higher levels of gibberellins (particularly additional application at prebloom stage), CPPU, brassinosteroids and micronutrients. This response is likely due to enhanced cell division and elongation triggered by gibberellic acid, which loosen the cell wall by activating the modify enzymes such as expansis and cellulases (Richard, 2006). Brassinosteroids and CPPU also support stem elongation by regulating cell growth and boosting carbohydrate availability through the up regulation of extracellular invertase activity. The present results are in confirmation with the findings of Bhat *et al* (2011). Manganese involved in nitrogen metabolism which activates the nitrate reducing and amino acid synthesising enzymes and helps in increasing the protein and chlorophyll formation, these factors attributed to increased vegetative growth of the plant. Similar findings have been reported by Shah *et al.* (2016) in Flame Seedless.

The data on bunch thinning treatments showed a significant variation in chlorophyll content and LAI (Table 4 & 5). Among the bunch thinning treatments, vines retained with 35 bunches (C_1) reported a significantly highest chlorophyll content (36.54 & 39.56) and LAI (1.86 at 45 DAFP and 3.25 at 90 DAFP) compared to the control C_2 (35.06 & 36.93) and (1.47 and 2.74) at 45 and 90 DAFP, respectively. Bunch regulation showed a positive correlation with chlorophyll content and leaf area index. Treatments with fewer bunch per vine recorded higher chlorophyll content and leaf area index, while these parameters declined as the number of bunches per vine increased. This may be due to the vine's resource allocation pattern, where a reduced number of bunches allows the availability of sufficient carbohydrates for vegetative growth, it enhances the crop's photosynthetic efficiency. During the bunch development stage, developing bunches act as strong sinks, drawing substantial resources from the vine, while leaves serve as the primary source of photosynthates. When fewer bunches are maintained, the overall resource demand decreases, allowing more allocation towards leaf development and resulting in increased chlorophyll content and leaf area index. This larger leaf area enhances the vine's photosynthetic efficiency, enabling greater production and storage of carbohydrates, which are later mobilized to support fruit growth. Since, shoot growth and fruit production compete for limited resources, effective leaf area becomes critical in ensuring sufficient carbohydrate supply for both vegetative growth and fruit development. Santhoshkumar *et al*. (2025) studied that bunch regulation with 35 bunches per vine increased the chlorophyll content and leaf area index compare to the control in Thompson Seedless. These findings are in agreement with the observations of Omar and Aboryia (2000) in Ruby Seedless. Among the different modules, Module 3 recorded the maximum chlorophyll content (37.59 & 41.31) and LAI (2.01 and 3.44), followed by Module 2 (35.94 & 38.52) and (1.61 and 3.04), while the lowest chlorophyll content (34.44 & 35.75) and LAI (1.50 and 2.66) value was observed in Module 4 at 45 and 90 DAFP, respectively. In terms of module treatments, higher amount of gibberellic acid, CPPU and brassinosteroids in combination with micronutrients enhanced the chlorophyll content and LAI. This may be due to enhanced chlorophyll biosynthesis in leaves by promoting the cell division and elongation. Anand (2021) reported that application of GA_3 along with brassinosteriods increased the chlorophyll content in grapes cv. 2A clone. Additionally, micronutrients particularly iron plays a crucial role in chlorophyll biosynthesis as it is a key component of enzymes like ferrochelatase and δ-aminolevulinic acid synthase, which were responsible for formation of chlorophyll precursors. It also facilitates electron transport during photosynthesis, indirectly supporting chlorophyll stability and function. These results are in accordance with the findings of Yogeesha (2005) in grapes.

The pooled data showed that bunch thinning treatments resulted a significant effect on specific leaf area at 45 and 90 DAFP (Table 6). The maximum SLA was noted in C_2 (152.01 cm²/g & 154.61 cm²/g) and the vines retained with 35 bunches (C_1) recorded a lower SLA (139.15 cm²/g & 133.60 cm²/g) at 45 and 90 DAFP, respectively. It was observed that vines retained with 35 bunches per vine recorded the lowest specific leaf area (SLA). The unregulated bunch load *i.e* control produced leaves that were larger but thinner due to poor dry matter accumulation. The lower SLA under the 35 bunchs/vine treatment attributed to higher accumulation of dry matter, as the regulated bunch load promoted better translocation of assimilates and photosynthates. Similar findings were reported by Brandon *et al*. (2012) who stated that low SLA species generally have higher dry matter content, thicker cell walls and greater leaf and root longevity. These results are further supported by Chougule (2004) in Thompson Seedless and Fageria *et al*. (2006) in grapes. The data pertaining to SLA showed significant difference with respect to different module treatments. The Module 4 (M_4) showed the highest SLA values (160.85 cm²/g at 45 DAFP & 168.08 cm²/g at 90 DAFP), followed by

Module 1 (150.58 & 152.54 cm²/g respectively), while lowest SLA was recorded in Module 3 (130.49 & 123.72 cm²/g). The interaction effects between bunch thinning and module treatments were non-significant at 45 DAFP, where as it is significant at 90 DAFP. The interaction between control and module 4 (C_2M_4) treatment was recorded the highest SLA (184.28 cm²/g), followed by C_2M_1 (165.87 cm²/g), while 35 bunches per vine and module 3 (C_1M_3) showed the lowest SLA (126.70 cm²/g). The module treatment significantly influenced SLA. This might be due to higher dry matter accumulation in leaves resulted by combined application of growth regulators and micronutrients. This effect is likely due to improved physiological efficiency and enhanced source-sink relationship. The treatment also promoted better translocation of assimilates and photosynthates. As a result, overall plant growth and productivity was enhanced. Similar findings were reported by Omar and Aboryia (2000) in Thompson Seedless and Khilari *et al*. (2020) in Sahebi grapes. The interaction effects between bunch thinning and module treatments were non-significant at 45 DAFP, however it is significant at 90 DAFP with respect to SLA and SLW. The combined effect of bunch load and module treatments attributed to higher accumulation of dry matter, promoting better translocation of assimilates and photosynthates. These results are in line with observations made by Brandon *et al*. (2012), Omar and Aboryia (2000) in Thompson Seedless, Al-Atrushy *et al*. (2019) in grapevine.

Conclusion

The results of the study concluded that different cluster thinning and higher concentration of GA_3, growth regulators (CPPU & BRs) and micronutrients showed a notable effect on the growth and physiological parameters. The retention of 35 bunches per vine and the application of GA_3 at 150 ppm combined with a micronutrient spray ($ZnSO_4$ at 3 g/L, $FeSO_4$ at 2 g/L, $MnSO_4$ at 2 g/L and boric acid at 1 g/L), CPPU (2 ppm) and BRs (0.5 and 1.0 ppm) at different growth stages, led to enhanced physiological and growth traits.

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