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Research article

Appraisal of extended cane length and fruit thinning strategies on the performance of growth yield and quality of kiwifruit

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A R T I C L E I N F O

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A B S T R A C T

The kiwifruit has been identified as an enormous fruit for mid-hill horticulture due to its wider adaptability and diversification. The size and quality of kiwifruit were affected by its market. As a result, appropriate canopy management and orchard techniques are key components in its production. Pruning and hand thinning, especially in kiwifruit, have been observed to improve the size and quality of the fruit. Traditional pruning maintained shorter canes with 6–12 nodes and 4 fruits/shoots. However, this study extended cane length and retained loads of 20 nodes/cane and 6 fruits/shoot. Considering the above, a study was conducted to determine the effects of extended cane length and fruit thinning on kiwifruit growth, yield, and fruiting performance. Five pruning levels have been employed: 8, 10, 12, 14, and 16 nodes/cane; 4, 6, and 8 fruits/fruiting shoot. The result revealed that the pruning of up to 12 nodes/cane coupled with thinning up to 6 fruits/fruiting shoot resulted in maximum cane diameter, leaf area, leaf: fruit ratio, advancement in flower initiation, bud break percentage (86.79 %), real fertility index, fruit yield and a proportion of grade “A" fruits. The highest leaf chlorophyll content (67.50), flowers per floral shoot, and productivity were recorded with pruning up to 16 nodes/cane coupled with thinning up to 6 fruits/fruiting shoot. The physico-chemical parameters such as fruit weight, diameter, volume, TSS, TSS: acid ratio, total sugars, and C: N ratio of the leaf and shoot were also found to be highest with pruning up to 12 nodes/cane coupled with thinning up to 6 fruits/fruiting shoot. This treatment also gave the maximum net return on a per-hectare basis, hence it was found to be the most profitable for the farmers.

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1. Introduction

Kiwifruit (*Actinidia deliciosa* Chev.) belonging to the genus *Actinidia* is a deciduous, dioecious, perennial, and warm temperate fruit of the Actinidiaceae family [1]. The kiwifruit vine is characterized by vigorous growth and intense competition for carbohydrates between vegetative and reproductive growth [2]. The kiwifruit is rich in vitamin C and contains an array of nutrients such as dietary fiber, potassium, phosphorus, vitamin E, and folate as well as various bioactive components like anti-oxidants and enzymes [3]. The Kiwifruit is a nodal fruit for mid-hill horticulture, which has a bigger domestic and international market. India first introduced it in the 1960s at Lal Bagh Garden, Bangalore, but its commercial relevance was discovered in the last three decades [1]. After being introduced at NBPGR, Phagli, Shimla, it was a successful crop in 1969 [4]. China, Italy, New Zealand, Iran, Greece, and Chile grow kiwifruit economically. The world produces 4.03 million metric tonnes of kiwifruit on 2.78 lakh acres [5] (see Fig. 1).

Cultural factors like pruning affect kiwifruit vine growth, yield, and quality [6]. Kiwifruit fruit only on the current season's growth from the previous year's node. So, kiwi vine management—training, trimming, and pollination—affects fruit crop size, dry matter content, profitability, and productivity [7]. Competition for carbohydrates, amino acids, minerals, and water occurs between vegetative growth and fruiting and among vine fruits. Maintaining an adequate C: N ratio for vegetative and reproductive growth requires cultural management [8]. Kiwifruit quality and quantity depend on bud load per vine following winter pruning [6]. Cane size affects flower and fruit production per vine [9,10]. Different-grade fruits are also affected by crop load [2].

Manipulation of crop load through fruit thinning has a significant role in plant development and is critical for getting higher fruit yields and superior fruit taste [8]. Fruit thinning is necessary for various fruit crops such as kiwifruit due to their tendency to bear heavily [9]. Hand thinning is practiced by thinning of blossom or small fruitlets to obtain better fruit size and quality [11]. The Allison cultivar is a prolific bearer and is the most promising for cultivation in mid Himalayan region. It bears excessive fruiting which results in small-size fruits with poor quality and ultimately low returns [8,11]. Thus, thinning is an important aspect for better returns to the farmers coupled with higher marketable prices due to good crops of better quality every year. Proper thinning of fruits at the right time has been commonly practiced in many fruit trees to get better fruit size [12].

In most fruit crops carbohydrate supply from photosynthesis may vary through factors such as leaf area, leaf position, light exposure, and leaf age and this can have significant effects on the amount of photosynthates supplied to fruit sinks [13]. Kiwifruit vines produce excessive vegetative growth thus, proper canopy management is essential to reduce vegetative growth and improve the yield of high-quality fruits per vine [14–16]. Although past research has examined certain elements of kiwifruit management, such as pruning procedures or fruit thinning methods, there is a requirement to combine these approaches completely. Studying the relationship between the length of the cane and fruit thinning procedures can offer useful knowledge for improving kiwifruit production systems to achieve sustainable yields and high-quality fruit [14–17]. There is a lack of information on the standardization of pruning technique especially the cane length coupled with fruit thinning in kiwifruit. However, isolated studies have been made to standardize the pruning intensity, fruit thinning, and use of plant growth regulators namely; CPPU for the quality improvement in kiwifruit. Keeping in view the above facts, the study was carried out to elucidate the influence of cane length and fruit thinning on the fruit yield and quality performance of kiwifruit.

2. Materials and methods

2.1. Study area

The experiment was carried out at Dr. Y.S. Parmar University of Horticulture and Forestry Nauni, Solan (HP), which is an elevation of 1260 m above mean sea level (m ASL) with the latitude of 30° 50′ North and longitude of 77°11′30″ East. The location of the experimental field falls under the sub-temperate, sub-humid, and mid-hills agro-climatic zone (Zone-II) of Himachal Pradesh. The average annual rainfall of the area was about 120–130 cm, and major amount of which was received from July to September. Summer

Table 1
Different treatment combinations in the experimental trial.

Code	Treatment details
CP_8FT_4	Pruning up to 8 nodes/cane (CP_8) + Thinning to 4 fruits/fruiting shoot (FT_4)
CP_8FT_6	Pruning up to 8 nodes/cane (CP_8) + Thinning to 6 fruits/fruiting shoot (FT_6)
CP_8FT_8	Pruning up to 8 nodes/cane (CP_8) + Thinning to 8 fruits/fruiting shoot (FT_8)
$CP_{10}FT_4$	Pruning up to 10 nodes/cane (CP_{10}) + Thinning to 4 fruits/fruiting shoot (FT_4)
$CP_{10}FT_6$	Pruning up to 10 nodes/cane (CP_{10}) + Thinning to 6 fruits/fruiting shoot (FT_6)
$CP_{10}FT_8$	Pruning up to 10 nodes/cane (CP_{10}) + Thinning to 8 fruits/fruiting shoot (FT_8)
$CP_{12}FT_4$	Pruning up to 12 nodes/cane (CP_{12}) + Thinning to 4 fruits/fruiting shoot (FT_4)
$CP_{12}FT_6$	Pruning up to 12nodes/cane (CPr_{12}) + Thinning to 6 fruits/fruiting shoot (FT_6)
$CP_{12}FT_8$	Pruning up to 12 nodes/cane (CP_{12}) + Thinning to 8 fruits/fruiting shoot (FT_8)
$CP_{14}FT_4$	Pruning up to 14 nodes/cane (CP_{14}) + Thinning to 4 fruits/fruiting shoot (FT_4)
$CP_{14}FT_6$	Pruning up to 14 nodes/cane (CP_{14}) + Thinning to 6 fruits/fruiting shoot (FT_6)
$CP_{14}FT_8$	Pruning up to 14 nodes/cane (CP_{14}) + Thinning to 8 fruits/fruiting shoot (FT_8)
$CP_{16}FT_4$	Pruning up to 16 nodes/cane (CP_{16}) + Thinning to 4 fruits/fruiting shoot (FT_4)
$CP_{16}FT_6$	Pruning up to 16 nodes/cane (CP_{16}) + Thinning to 6 fruits/fruiting shoot (FT_6)
$CP_{16}FT_8$	Pruning up to 16 nodes/cane (CP_{16}) + Thinning to 8 fruits/fruiting shoot (FT_8)

was moderately hot during May–June, while the winter was severe during December–January. The Physico-chemical properties of orchard soil were determined before the start of the experiment. In general, the physico-chemical properties of the soil were: pH 6.75, electrical conductivity 0.15 dS $m^{-1,}$ and organic carbon 1.30 %. The available N, P, and K content of surface soil were 250.55, 40.00, and 260.35 kg/ha, respectively.

2.2. Experimental design and treatment details

The experiment was carried out on 9-year-old vines of kiwifruit cv. Allison. The vines were maintained under uniform cultural practices and planted at a spacing of 4 m × 6 m. The vines were trained on the T-bar system. The experiment was carried out with Randomized Block Design (Factorial). The dormant pruning was done during the last week of December to the 1st week of January. The variable number of nodes was kept during dormant pruning. Fruit thinning was done during 2nd week of May at the pea-size stage.

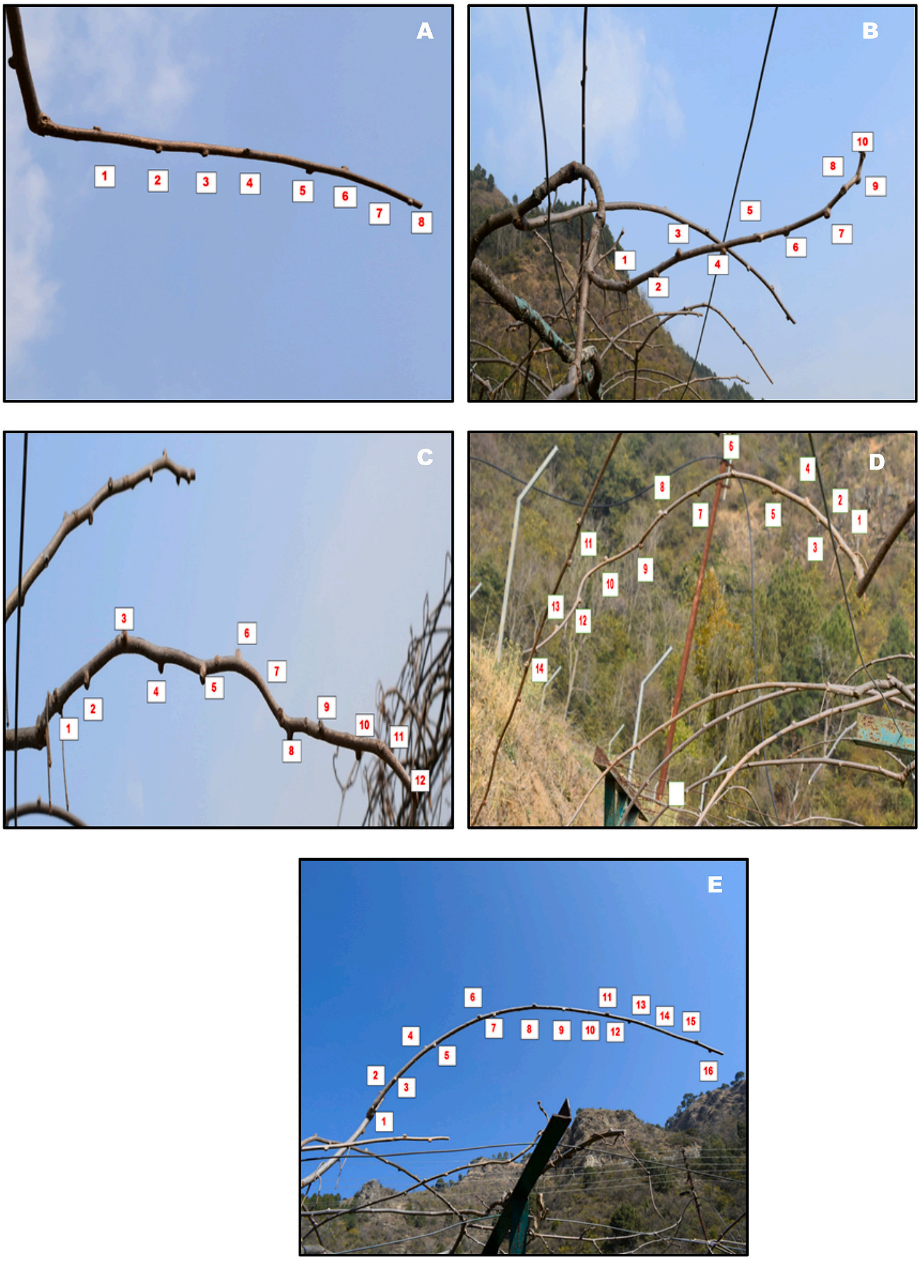

Fig. 1. Different cane pruning levels; A: Pruning up to 8 nodes; B: Pruning up to 10 nodes C: Pruning up to 12 nodes; D: Pruning up to 14 nodes; E: Pruning up to 16 nodes.

The trial consisted of 15 treatments with 5 cane pruning levels and 3 Fruit thinning levels as shown in Table 1. The length of canes is decided according to the number of buds or nodes to be retained depending upon the treatment. After selecting the number of buds, new shoots arise which bear fruits. In Kiwifruit, fruits are borne on the current season shoots which arise from one-year-old cane (Figs. 1 and 2).

2.3. Growth characteristics

Cane diameter (basal diameter) was measured with the help of a Digital Vernier caliper after pruning in winter just above the first basal bud at the first internode. It was expressed in millimeters (mm) per shoot. A sample of ten representative fully-grown leaves from the current season's growth of each vine was collected in the morning hours during 1st week of August. The chlorophyll content of leaves was recorded with a Minolta SPAD-500 Chlorophyll meter. SPAD-502 chlorophyll meter is a simple, portable diagnostic tool that measures the relative chlorophyll contents of leaves with substantial time-saving. For leaf area, twenty fully expanded leaves were collected at random from the middle portion of the shoot in August and leaf area was measured with the help of LI-COR 3100 leaf area meter. The results were expressed as the average leaf area per leaf in square centimeters (cm^2). The leaf area index was calculated as the ratio of the leaf surface (one side only) of a plant to the ground area occupied by the plant (Eq. (1)) [18].

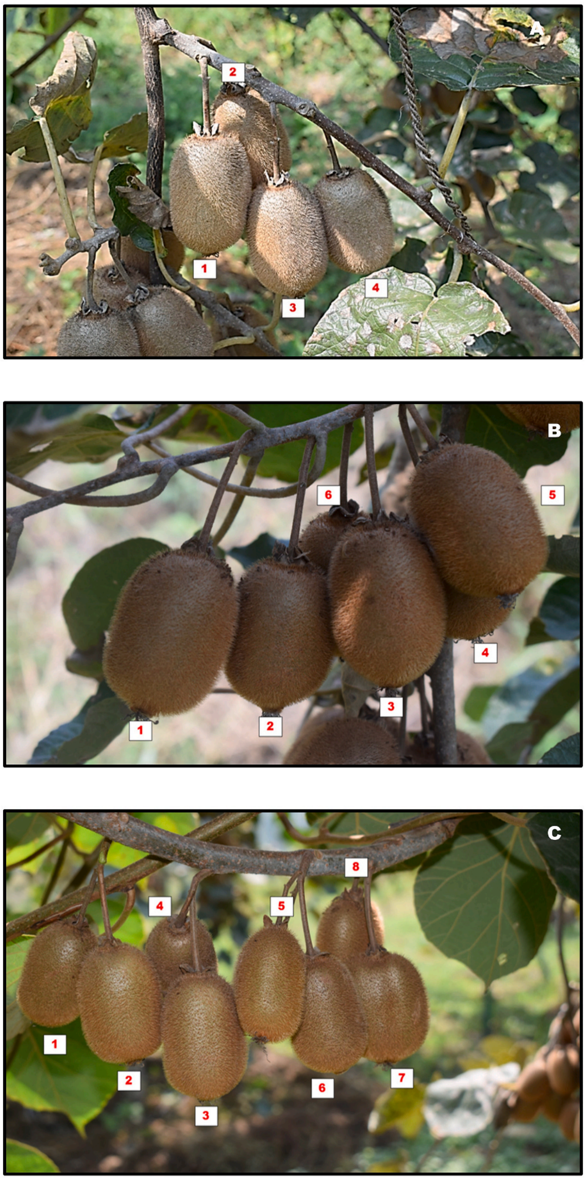

Fig. 2. Different fruit thinning levels A: Thinning to retain 4 fruits, B: Thinning to retain 6 fruits, C: Thinning to retain 8 fruits.

$$\text{Leaf area Index} = \frac{\text{Total leaf area of the plant}}{\text{Ground area occupied by the plant}} \tag{1}$$

The ratio between leaves and fruits per shoot was worked out by dividing the number of leaves per shoot by the number of fruits. The real fertility index of buds was obtained by dividing the number of shoots with inflorescences by the total number of buds of canes in each vine, left after pruning. It was determined according to the method described by Ref. [17] The bud break percentage (BB) was calculated as the number of buds broken per vine to the total number of buds by using a 1 m^2 area per vine as per the method described by Thorp et al. [17] (Eq. (2)).

$$\text{Bud break percentage } (\%) = \frac{\text{Number of bud breaks per vine}}{\text{Total number of buds per vine}} \times 100 \tag{2}$$

2.4. Yield characteristics

The yield of fruits under each treatment was determined based on the weight of crop load removed from each vine at the time of harvest and expressed in kilograms per vine (kg/vine). The productivity was calculated by multiplying the yield per vine with the vine density per hectare. (376 bearing vines/ha).

Graded yield of Fruits harvested from vines was categorized into three grades based on fruit weight. These grades were A grade (>80 g), B grade (50–80 g) and C grade (<50 g). The percent of different-grade fruits per vine was calculated by using the following formula (Eq. (3)):

$$\text{Percent yield of grade 'X'} = \frac{\text{Yield of grade X (kg/vine)}}{\text{Total yield (kg/vine)}} \times 100. \tag{3}$$

where, 'X' = Grade A or B, or C.

The yield efficiency was calculated by dividing the total fruit yield of the individual vine by the trunk cross-sectional area and expressed as kg/cm^2.

2.5. Physico-chemical characteristics of fruit

All the fruits harvested in each treatment and replication were weighed on an electronic balance and average fruit weight was expressed in grams (g). The diameter was measured with the help of a Digital Vernier Caliper and was expressed in centimeters (cm). The fruit volume of all fruits harvested in each treatment and replication was determined by the water displacement method. The average volume was expressed as cubic centimeters per fruit (cm^3/fruit).

The total soluble solids content in fruit was determined by Erma hand refractometer (0-32° Brix). A temperature correction was applied when it was above or below 20 °C [18]. The total soluble solids were expressed as percent. The fruit's titratable acidity and sugar content were assessed using the volumetric approach, as advised by A.O.A.C [18]. TSS: Acid ratio was obtained by dividing the corresponding value of total soluble solids by the titratable acidity content of the fruit juice.

2.6. Carbohydrate and nitrogen ratio

The carbohydrate contents of the leaf and shoot were determined as per the method discussed by Refs. [19,20]. The carbohydrate present in the sample was worked out by the following formula [Eq. (4)].

$$\text{Carbohydrate } (\%) = \frac{\text{Sugar value from graph} \times \text{total volume of extract}}{\text{Aliquot sample used (1ml)} \times \text{weight of samples (mg)}} \times 100 \tag{4}$$

For the nitrogen estimation, The dried sample of leaves weighing 0.1 g was taken in a Kjeldhal flask and digested in 10 ml of concentrated H_2SO_4 in the presence of 1 g digestion accelerator, which was prepared by mixing 2.5 g SeO_2, 100 g K_2SO_4 and 20 g of $CuSO_4 \cdot 5H_2O$ [21]. The digested material was distilled and ammonia liberated was collected in a 4 percent boric acid solution containing bromocresol green and methyl red mixed indicator. The boric acid changed to bluish-green as soon as it came in contact with ammonia. It was titrated against standard hydrochloric acid until the blue color disappeared. Nitrogen percentage was obtained from the following formula (Eq. (5)):

$$\text{Nitrogen } (\%) = \frac{(\text{Titre} - \text{Blank}) \times \text{Normality of HCl} \times 14 \times \text{Final volume of the digested sample}}{\text{Aliquot of the digested sample of sample taken} \times 1000}. \tag{5}$$

The C/N ratio was worked out directly by dividing the carbohydrate (%) by nitrogen (%).

2.7. Statistical analysis

The data obtained from these investigations were appropriately computed, tabulated, and analyzed by applying Randomized Block Design (RBD) Factorial as given by Ref. [22]. The level of significance was tested for different variables at a 5 percent level of significance [23].

Table 2
Effect of cane length and fruit thinning on the growth characteristics of kiwifruit.

Treatments	Cane diameter (mm)				Leaf Chlorophyll (SPAD Value)				Leaf area (cm^2)				Leaf Area Index			
CP	FT															
	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean
CP_{8N}	10.46	10.92	11.86	11.08	48.80	50.60	51.30	50.23	115.47	114.00	116.03	115.17	2.77	2.83	3.14	2.91
CP_{10N}	11.37	12.49	11.97	11.94	52.40	54.90	57.80	55.03	127.40	123.92	121.27	124.20	3.30	2.94	3.57	3.27
CP_{12N}	12.42	13.33	12.72	12.82	62.40	62.30	63.30	62.67	132.20	147.61	130.31	136.71	3.73	3.76	3.24	3.86
CP_{14N}	12.49	12.61	12.62	12.57	62.87	61.43	64.12	64.80	126.27	122.42	123.73	124.14	3.37	3.60	3.53	3.50
CP_{16N}	12.39	12.64	12.66	12.56	62.33	67.50	60.80	63.54	126.30	126.97	125.50	126.26	3.73	3.83	4.23	4.05
Mean	11.83	12.40	12.37		57.76	59.35	59.46		125.53	126.99	123.37		3.45	3.28	3.54	

$CD_{(0.05)}$	Cane diameter (mm)	Leaf Chlorophyll (SPAD Value)	Leaf area (cm^2)	Leaf Area Index
CP	**0.25**	**1.25**	**1.96**	**0.18**
FT	**0.20**	**0.97**	**1.52**	**NS**
CP × FT	**0.44**	**2.17**	**3.39**	**0.31**

Cane Pruning (CP)
CP_{8N}: Pruning up to 8 nodes
CP_{10N}: Pruning up to 10 nodes/cane
CP_{12N}: Pruning up to 12 nodes/cane
CP_{14N}: Pruning up to 14 nodes/cane
CP_{16N}: Pruning up to 16 nodes/cane

Fruit Thinning (FT)
FT_4: Thinning to 4 fruits/fruiting shoot
FT_6: Thinning to 6 fruits/fruiting shoot
FT_8: Thinning to 8 fruits/fruiting shoot

Table 3
Effect of cane length and fruit thinning on the blooming characteristics of kiwifruit.

Treatments	Bud break percentage				Real fertility index				Flowers per floral shoot				Leaf: Fruit ratio			
CP	FT															
	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean
CP_{8N}	44.14	52.49	57.79	51.48	0.43	0.41	0.42	0.42	3.43	3.50	3.47	3.53	1.51	1.61	1.45	1.53
CP_{10N}	61.65	64.47	70.65	65.59	0.51	0.47	0.57	0.52	4.33	4.10	4.57	4.33	1.81	1.91	1.99	1.90
CP_{12N}	72.54	86.79	78.58	79.30	0.54	0.53	0.58	0.55	4.70	5.53	5.30	5.24	1.87	2.03	1.82	1.91
CP_{14N}	71.43	62.32	69.20	67.65	0.36	0.39	0.45	0.40	5.36	5.30	5.35	5.32	1.79	1.74	1.89	1.81
CP_{16N}	72.19	69.88	72.04	71.37	0.39	0.40	0.43	0.41	5.60	5.73	5.63	5.65	1.80	1.40	1.41	1.54
Mean	64.39	67.19	69.65		0.45	0.44	0.49		4.68	4.83	4.87		1.76	1.74	1.71	
$CD_{(0.05)}$																
CP			**5.30**				**0.024**				**0.22**			**0.12**		
FT			**4.10**				**0.019**				**NS**			**NS**		
CP × FT			**9.17**				**0.041**				**0.39**			**0.20**		

Cane Pruning (CP)
CP_{8N}:Pruning up to 8 nodes
CP_{10N}: Pruning up to 10 nodes/cane
CP_{12N}: Pruning up to 12 nodes/cane
CP_{14N}: Pruning up to 14 nodes/cane
CP_{16N}: Pruning up to 16 nodes/cane

Fruit Thinning (FT)
FT_4: Thinning to 4 fruits/fruiting shoot
FT_6: Thinning to 6 fruits/fruiting shoot
FT_8: Thinning to 8 fruits/fruiting shoot

3. Results

3.1. Effect of cane length and fruit thinning on growth characteristics

The interaction between extended cane length and fruit thinning had a notable impact on various parameters, including cane diameter, leaf chlorophyll content, leaf area, and leaf area index. Table 1 highlights that pruning canes to 12 nodes/cane resulted in the highest cane diameter (12.82 mm). Cane diameter ranged from 12.40 mm (thinning to 6 fruits/shoot) to 11.83 mm (4 fruits/shoot). The interplay of cane length and fruit thinning also influenced kiwifruit cane diameter, with the largest (13.33 mm) and smallest (10.46 mm) diameters observed with pruning to 12 nodes/cane and thinning to 6 fruits/fruiting branches.

Examining Table 2 data further, leaf chlorophyll content, measured by SPAD value, was significantly influenced by both cane length and fruit thinning in kiwifruit. The maximum chlorophyll value (64.80) occurred with canes pruning to 14 nodes/cane, while the minimum (50.23) was observed with pruning to 8 nodes/cane. Among different fruit thinning levels, the highest (59.46) leaf chlorophyll content was associated with thinning to 8 fruits/shoot, while the lowest (57.96) occurred with thinning to 4 fruits/shoot. The combined effect revealed that the highest (67.50) leaf chlorophyll content resulted from pruning to 16 nodes/cane and thinning to 6 fruits/shoot, whereas the lowest (48.80) was observed with pruning to 8 nodes/cane and retaining 4 fruits/shoot.

Leaf area and Leaf area Index in kiwifruit vines were significantly impacted by varying cane length and fruit thinning (Table 2). The highest leaf area (136.71 cm^2) resulted from pruning canes to 12 nodes/cane, while the lowest (115.47 cm^2) was observed with 8 nodes/cane. In fruit thinning, the highest leaf area (126.99 cm^2) occurred with the retention of 6 fruits/shoot, statistically comparable (125.53 cm^2) to thinning with 4 fruits/shoot, and the lowest (123.37 cm^2) was noted with thinning to 8 fruits/shoot. The interaction effect revealed the highest leaf area (147.61 cm^2) with pruning to 12 nodes/cane and thinning to 6 fruits/fruiting shoots, while the lowest (114.00 cm^2) was with pruning to 8 nodes/cane and thinning to 6 fruits/shoot. The leaf area index in kiwifruit, impacted by cane length and fruit thinning, is detailed in Table 2. The highest leaf area index (4.05) came from pruning to 16 nodes/cane, while the lowest (2.91) was from pruning to 8 nodes/cane. Though thinning effects were not significant, the highest leaf area index (3.54) occurred with thinning to 8 fruits/shoot and the lowest (3.45) with thinning to 4 fruits/shoot. The interaction effect (CP × FT) on the leaf area index was significant, reaching the highest (4.23) with pruning to 16 nodes/cane + thinning to 8 fruits/fruiting shoots and the lowest (2.77) with pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoots.

3.2. Effect of cane length and fruit thinning on flowering characteristics

Table 3 reveals that different nodes and fruit thinning significantly influenced bud break percentage, real fertility index, flowers per floral shoot, and Leaf: Fruit Ratio in kiwifruit. The highest bud break percentage (79.30) resulted from pruning to 12 nodes/cane, contrasting with the lowest (51.48) from pruning to 8 nodes/cane. Thinning effects showed the highest (69.65) bud break percentage with thinning to 8 fruits/shoot and the lowest (64.39) with thinning to 4 fruits/shoot. Interaction effects were significant, with the highest (86.79) bud break percentage from pruning to 12 nodes/cane + thinning to 6 fruits/fruiting shoot, and the lowest (44.14) from pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot. Table 3 also presents data on the kiwifruit Real Fertility Index influenced by cane length and fruit thinning. The highest Real Fertility Index (0.55) resulted from pruning to 12 nodes/cane, while the lowest (0.40) came from pruning to 14 nodes/cane. Thinning up to 8 fruits/shoot produced the highest actual fertility index (0.49) while thinning up to 6 fruits/shoot yielded the lowest (0.44). Interaction effects revealed the highest (0.58) Real Fertility Index from pruning to 12 nodes/cane + thinning to 8 fruits/fruiting shoot and the lowest (0.36) from pruning to 14 nodes/cane + thinning to 4 fruits/

Table 4
Effect of Cane Length and fruit thinning on the yield characteristics of kiwifruit.

Treatments	Yield per vine (kg vine-^{1})				Productivity (MT ha^{-1})				Yield efficiency (kg cm^{-2}/TCSA)			
CP	FT											
	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean
CP_{8N}	27.67	38.67	38.33	34.89	10.07	14.08	13.95	12.70	1.16	1.52	1.56	1.41
CP_{10N}	37.67	47.67	41.33	42.22	13.71	17.35	15.04	15.37	1.56	1.94	1.61	1.70
CP_{12N}	44.67	52.33	44.33	47.11	16.26	19.05	16.14	17.15	1.82	1.93	1.63	1.80
CP_{14N}	53.33	49.33	46.33	49.67	19.41	17.96	16.87	18.08	2.24	2.12	1.95	2.10
CP_{16N}	53.67	58.33	52.67	54.89	19.54	21.23	19.17	19.98	2.19	2.09	1.96	2.08
Mean	43.40	49.27	44.60		15.80	17.93	16.23		1.79	1.92	1.74	

$CD_{(0.05)}$		**$CD_{(0.05)}$**	**$CD_{(0.05)}$**
Cane Pruning(CP)	**3.76**	**1.37**	**0.18**
Fruit Thinning(FT)	**2.92**	**1.06**	**0.14**
CP × FT	**6.52**	**2.38**	**0.31**

Cane Pruning (CP)
CP_{8N}:Pruning up to 8 nodes
CP_{10N}:Pruning up to 10 nodes/cane
CP_{12N}:Pruning up to 12 nodes/cane
CP_{14N}:Pruning up to 14 nodes/cane
CP_{16N}:Pruning up to 16 nodes/cane

Fruit Thinning (FT)
FT_4:Thinning to 4 fruits/fruiting shoot
FT_6:Thinning to 6 fruits/fruiting shoot
FT_8:Thinning to 8 fruits/fruiting shoot

fruiting shoot.

Table 3 outlines the impact of cane length and fruit thinning on flowers per floral shoot and leaf: fruit ratio in kiwifruit. Pruning to 16 nodes/cane yielded the most flowers per floral shoot (5.65) while pruning to 8 nodes/cane resulted in the lowest (3.53). Thinning to 8 fruits/shoot produced the highest (4.87) flowers per floral shoot while thinning to 4 fruits/shoot recorded the lowest (4.68). Significant interaction effects were observed, with the highest (5.73) flowers per floral shoot from pruning to 16 nodes/cane + thinning to 6 fruits/fruiting shoot and the lowest (3.43) from pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot. Regarding the leaf: fruit ratio, pruning to 12 nodes/cane resulted in the highest ratio (1.91), while pruning to 8 nodes/cane produced the lowest (1.53). Thinning effects were non-significant, with the highest ratio (1.76) from thinning to 4 fruits/shoot and the lowest (1.71) from thinning to 8 fruits/shoot. Significant interaction effects showed the highest (2.03) leaf: fruit ratio from pruning to 12 nodes/cane + thinning to 6 fruits/fruiting shoot and the lowest (1.40) from pruning to 16 nodes/cane + thinning to 6 fruits/fruiting shoot.

3.3. Yield characteristics

Table 4 and Fig. 3 present the fruit production outcomes influenced by cane length and fruit thinning in kiwifruit. The highest fruit yield (54.89 kg/vine) came from pruning to 16 nodes/cane, while the lowest (34.89 kg/vine) resulted from pruning to 8 nodes/cane. Similarly, the highest (49.27 kg/vine) and lowest (43.40 kg/vine) fruit yields under thinning occurred with thinning to 6 and 4 fruits/shoot, respectively. Significant interaction effects were noted, with the highest fruit output (58.33 kg/vine) from pruning to 16 nodes/cane + thinning to 6 fruits/fruiting shoot and the lowest (27.67 kg/vine) from pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot. Productivity metrics mirrored the vine yield results, with the best (19.98 MT/ha) productivity from pruning to 16 nodes/cane and the lowest (12.70 MT/ha) from pruning to 8 nodes/cane. Under thinning, the highest (17.93 MT/ha) and lowest (15.80 MT/ha) productivity occurred with thinning to 6 and 4 fruits/shoot, respectively. Interaction effects showcased the maximum (21.23 MT/ha) productivity from pruning to 16 nodes/cane + thinning to 6 fruits/fruiting shoot and the lowest (10.07 MT/ha) from pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot.

The proportion of grade ‘A’ fruits per vine significantly varied with graded yield. The highest percentage (60 %) of grade ‘A’ fruits resulted from pruning to 12 nodes/cane + thinning to 6 fruits/fruiting shoot, while the combination of pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot yielded the lowest (28.33 %). Table 4 shows statistics on yield efficiency influenced by cane length and fruit thinning. Most efficient pruning up to 14 nodes/cane yielded 2.10 kg cm^{-2}/TCSA. The lowest yield efficiency (1.41 kg cm^{-2}/TCSA) was attained with 8-node pruning. Similarly, thinning up to 6 fruits/shoot produced the highest yield efficiency (1.92 kg cm^{-2}/TCSA), whereas thinning up to 4 fruits/shoot produced the lowest (1.74 kg cm^{-2}/TCSA). The interaction effect on kiwifruit yield efficiency was also substantial. The highest yield efficiency (2.24 kg cm^{-2}/TCSA) was achieved with 14 node pruning and 4 fruit thinning. Lowest (1.16 kg cm^{-2}/TCSA) with $CP_8 + FT_4$ treatment combination. The results in the present study indicated that pruning severities subjected to different bud loads revealed variations in fruit yield and yield efficiency.

3.4. Physico-chemical characteristics

Table 5 presents data on kiwifruit attributes influenced by cane length and fruit thinning. The heaviest fruit (76.48 g) resulted from pruning to 12 nodes/cane, while the lowest fruit weight (71.02 g) came from 8 nodes/cane trimming. Thinning up to 6 fruits/shoot produced the highest (74.76 g) and lowest (72.08 g) fruit weights. Considerable interaction effects were noted, with the maximum weight (81.23 g) from pruning to 12 nodes/cane and thinning to 6 fruits/fruiting shoot, and the lowest (68.31 g) from pruning to 8 nodes/cane and thinning to 4 fruits/fruiting shoot.

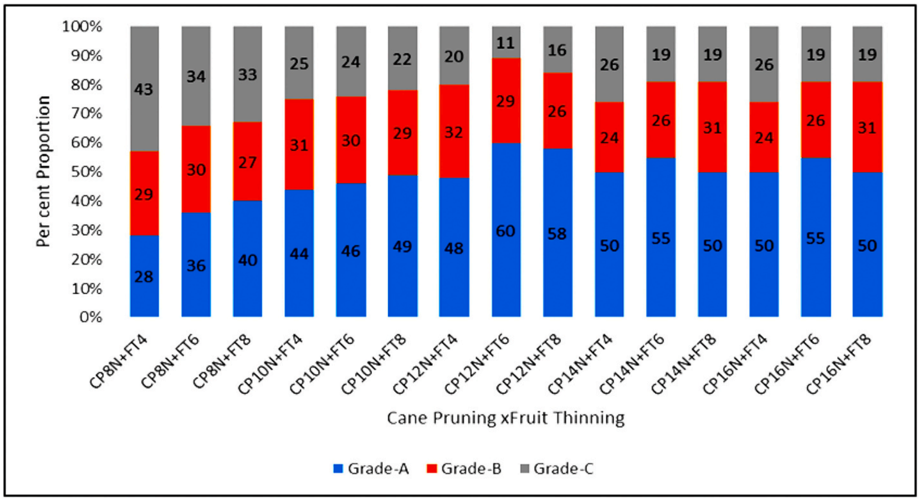

Fig. 3. Effect of cane length and fruit thinning on the graded yield of kiwifruit.

Table 5
Effect of cane length and fruit thinning on the physical fruit characteristics of kiwifruit.

Treatments	Fruit Weight (g)				Fruit diameter (cm)				Fruit Volume (cm^3)			
CP	FT											
	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean
CP_{8N}	68.31	71.29	73.48	71.02	4.03	4.15	4.00	4.06	57.67	64.67	86.67	69.67
CP_{10N}	70.46	72.32	73.69	72.16	4.32	4.21	4.15	4.23	62.67	81.67	92.67	79.00
CP_{12N}	74.00	81.23	74.22	76.48	4.24	4.76	4.62	4.54	92.67	96.33	93.67	94.22
CP_{14N}	72.15	73.08	72.52	72.59	4.38	4.61	4.08	4.36	71.67	84.33	82.33	79.44
CP_{16N}	75.50	75.87	73.30	74.89	4.74	4.15	4.01	4.30	93.67	94.33	85.67	91.22
Mean	72.08	74.76	73.44		4.34	4.38	4.17		75.67	84.27	88.20	

$CD_{(0.05)}$		**$CD_{(0.05)}$**	**$CD_{(0.05)}$**
CP	**2.00**	**0.18**	**2.63**
FT	**1.55**	**0.14**	**2.04**
CP × FT	**3.47**	**0.31**	**4.56**

Cane Pruning (CP)
CP_{8N}:Pruning up to 8 nodes
CP_{10N}:Pruning up to 10 nodes/cane
CP_{12N}:Pruning up to 12 nodes/cane
CP_{14N}:Pruning up to 14 nodes/cane
CP_{16N}:Pruning up to 16 nodes/cane

Fruit Thinning (FT)
FT_4:Thinning to 4 fruits/fruiting shoot
FT_6:Thinning to 6 fruits/fruiting shoot
FT_8:Thinning to 8 fruits/fruiting shoot

Fruit diameter data revealed the highest (4.54 cm) with pruning to 12 nodes/cane and the lowest (4.06 cm) with pruning to 8 nodes/cane. Thinning effects showed the highest (4.38 cm) and lowest (4.17 cm) fruit diameters with thinning to 6 and 8 fruits/shoot, respectively. Interaction effects were significant, with the highest (4.76 cm) fruit diameter from pruning to 12 nodes/cane + thinning to 6 fruits/fruiting shoot and the lowest (4.03 cm) from pruning to 8 nodes/cane + thinning to 4 fruits/fruiting shoot. For fruit volume (cm^3), the highest (94.22 cm^3) resulted from pruning to 12 nodes/cane, and the lowest (69.67 cm^3) from pruning to 8 nodes/cane. Thinning effects showed the highest (88.20 cm^3) and lowest (75.67 cm^3) fruit volumes with thinning to 8 and 4 fruits/shoot, respectively. Significant interaction effects were noted, with the highest (96.67 cm^3) fruit volume from pruning to 12 nodes/cane + thinning to 6 fruits/fruiting shoot, and the lowest (57.67 cm^3) from pruning to 8 nodes/cane + thinning to 8 fruits/fruiting shoot.

In terms of Total Soluble Solids (TSS), pruning up to 12 nodes/cane resulted in the highest TSS (16.47 %), while pruning up to 8 nodes/cane yielded the lowest (13.57 %). Thinning also influenced TSS, with the highest (15.35 %) observed when thinning up to 6 fruits/shoot and the lowest (15.23 %) when thinning up to 8 fruits/shoot. Significant interaction effects were found, with the highest TSS (16.83 %) recorded with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot and the lowest (13.57 %) with pruning up to 8 nodes/cane + thinning up to 4 fruits/fruiting shoot. Regarding titratable acidity, pruning up to 8 nodes/cane resulted in the highest acidity (1.39 %), while pruning up to 10 nodes/cane led to the lowest (1.25 %). Thinning also played a role, with the highest acidity (1.37 %) observed when thinning up to 4 fruits/shoot and the lowest (1.30 %) with thinning up to 8 fruits/shoot. Interaction effects were significant, with the highest acidity (1.48 %) recorded with pruning up to 8 nodes/cane + thinning up to 4 fruits/fruiting shoot and the lowest (1.18 %) with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot (Table 6). The TSS: acid ratio was influenced by pruning up to 12 nodes/cane (highest ratio of 12.84) and pruning up to 8 nodes/cane (lowest ratio of 10.26). Thinning also affected the ratio, with the highest (11.80) when thinning up to 6 fruits/shoot and the lowest (11.25) when thinning up to 4 fruits/shoot. Significant interaction effects were found, with the highest ratio (14.33) recorded with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot and the lowest (9.17) with pruning up to 8 nodes/cane + thinning up to 4 fruits/fruiting shoot. In terms of total sugar content, pruning up to 12 nodes/cane resulted in the highest content (7.42), while pruning up to 8 nodes/cane led to the lowest (5.69). Thinning effects were observed, with the highest content (6.42) when thinning up to 6 fruits/shoot and the lowest (6.15) when thinning up to 8 fruits/shoot. Interaction effects were significant, with the highest total sugar content (7.94) recorded with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot and the lowest (5.38) with pruning up to 8 nodes/cane + thinning up to 4 fruits/fruiting shoot.

Fig. 4 illustrates the impact of variable cane length and fruit thinning on ascorbic acid in kiwifruit. The highest ascorbic acid content was observed with pruning up to 12 nodes/cane, while the lowest was recorded with pruning up to 8 nodes/cane. Similarly, the highest ascorbic acid content under thinning occurred with thinning up to 6 fruits/shoot, and the lowest with thinning up to 4 fruits/shoot. Significant interaction effects were noted, with the highest ascorbic acid (82.40 mg/g fruit) recorded with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot and the lowest (59.15 mg/g fruit) with pruning up to 8 nodes/cane + thinning up to 4 fruits/fruiting shoot.

3.5. C: N ratio of leaf

Fig. 5 illustrates the impact of cane length and fruit thinning on the C: N ratio of kiwifruit leaves and shoots. The highest leaf C:N ratio occurred with pruning up to 12 nodes/cane, while the lowest was observed with pruning up to 8 nodes/cane. Under thinning, the highest leaf C:N ratio was noted with thinning up to 8 fruits/shoot, and the lowest was recorded with thinning up to 4 fruits/shoot. Similarly, for shoots, the highest C:N ratio occurred with pruning up to 12 nodes/cane, while the lowest was recorded with pruning up

Table 6
Effect of cane length and fruit thinning on the chemical characteristics of kiwifruit.

Treatments	Total soluble solids (°Brix)				Titratable acidity (%)				TSS: acid ratio				Total sugars (%)			
CP	FT															
	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean	FT_4	FT_6	FT_8	Mean
CP_{8N}	13.57	14.30	14.43	13.57	1.48	1.44	1.23	1.39	9.17	9.90	11.70	10.26	5.38	5.92	5.78	5.69
CP_{10N}	14.43	15.47	15.40	14.43	1.23	1.28	1.24	1.25	11.77	12.10	12.39	12.09	5.92	5.75	5.86	5.84
CP_{12N}	16.47	16.83	16.03	16.47	1.25	1.18	1.46	1.29	13.18	14.33	11.01	12.84	7.38	7.94	6.95	7.42
CP_{14N}	16.30	15.87	15.57	16.30	1.41	1.39	1.27	1.36	11.56	11.44	12.28	11.76	6.38	6.66	6.01	6.35
CP_{16N}	15.43	14.30	14.73	15.43	1.46	1.28	1.28	1.34	10.57	11.21	11.56	11.11	5.97	5.84	6.13	5.98
Mean	15.24	15.35	15.23	15.24	1.37	1.31	1.30		11.25	11.80	11.79		6.20	6.42	6.15	
$CD_{(0.05)}$																
CP		**0.45**			**0.05**		**0.51**			**0.21**						
FT		**NS**			**0.04**		**0.39**			**0.16**						
CP × FT		**0.78**			**0.09**		**0.88**			**0.36**						

Cane Pruning (CP)
CP_{8N}:Pruning up to 8 nodes
CP_{10N}:Pruning up to 10 nodes/cane
CP_{12N}:Pruning up to 12 nodes/cane
CP_{14N}:Pruning up to 14 nodes/cane
CP_{16N}:Pruning up to 16 nodes/cane

Fruit Thinning (FT)
FT_4:Thinning to 4 fruits/fruiting shoot
FT_6:Thinning to 6 fruits/fruiting shoot
FT_8:Thinning to 8 fruits/fruiting shoot

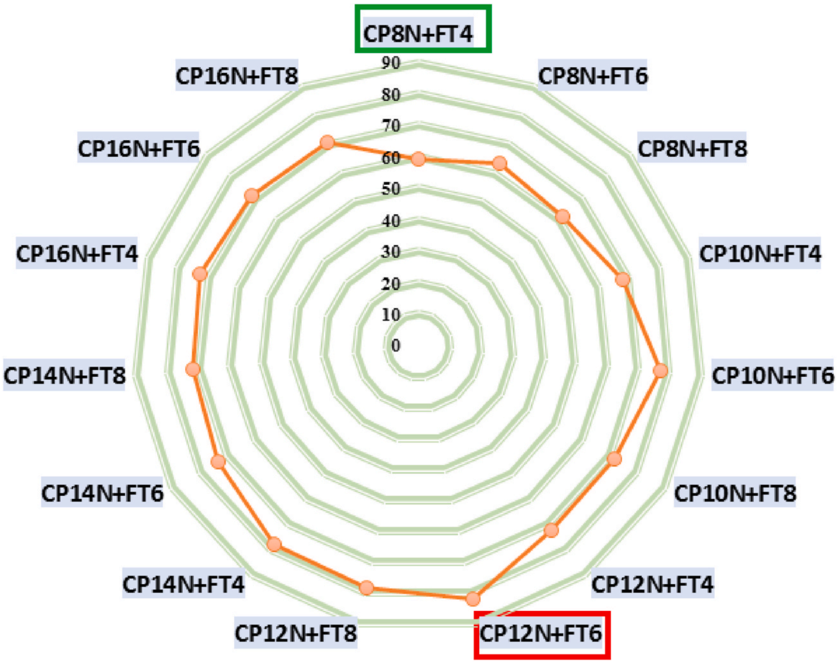

Fig. 4. Effect of cane length and fruit thinning on the ascorbic acid content (mg/g fresh weight) of kiwifruit.

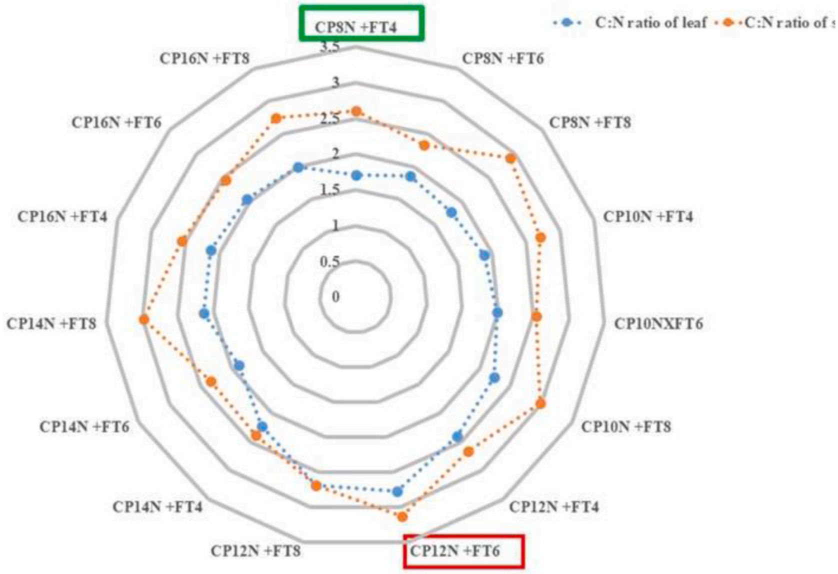

Fig. 5. Effect of cane length and fruit thinning on the leaf and shoot C: N ratios of kiwifruit.

to 14 nodes/cane. Under thinning, the highest C:N ratio of shoots was observed with thinning up to 8 fruits/shoot, and the lowest was recorded with thinning up to 6 fruits/shoot. Interaction effects showed the highest shoot C: N ratio with pruning up to 12 nodes/cane + thinning up to 6 fruits/fruiting shoot and the lowest with pruning up to 8 nodes/cane + thinning up to 6 fruits/fruiting shoot.

3.6. Economic analysis

Fig. 6 illustrates the impact of cane length and fruit thinning on the B: C (Benefit to Cost) ratio of kiwifruit. The data indicates that the highest net return was achieved with the treatment of pruning up to 12 nodes/cane coupled with thinning up to 6 fruits/shoot, resulting in a B: C ratio of 9.78:1. Conversely, the lowest net return (Rs 99,42,08) was obtained with the treatment of pruning up to 8

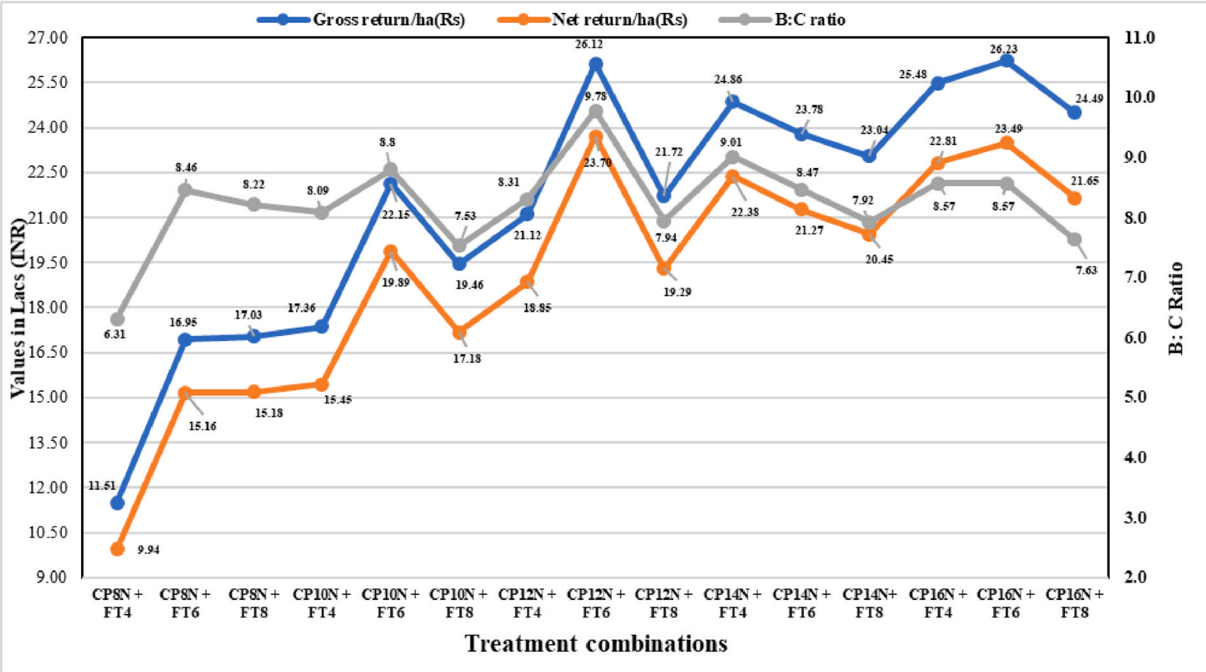

Fig. 6. Effect of cane length and fruit thinning on the B: C ratio of kiwifruit.

nodes/cane coupled with thinning up to 4 fruits/shoot, yielding a B: C ratio of 6.31:1.

4. Discussion

The key to kiwifruit production is canopy control and orchard practices, which determine fruit size and quality. The previous pruning method used shorter canes with particular node and fruit combinations. This study examines if lengthening cane length and changing fruit thinning levels can improve growth, yield, and fruiting. Kiwifruit responds differently to pruning levels, specifically the number of nodes per cane, according to the study. Pruning up to 12 nodes per cane and thinning up to 6 fruits per fruiting stalk yielded various benefits like the highest cane diameter, leaf area, leaf: fruit ratio, flower initiation, bud break %, true fertility index, fruit yield, and grade “A" fruit proportion. This study also emphasizes the importance of physico-chemical parameters in fruit quality. The treatment of trimming up to 12 nodes per cane and thinning up to 6 fruits per fruiting shoot improved fruit weight, diameter, volume, total soluble solids (TSS), TSS: acid ratio, total sugars, and leaf and shoot C: N ratios. This predicts vast improvements in kiwifruit’s physical and chemical properties. The pruning of up to 16 nodes per cane and thinning of up to 6 fruits per fruiting shoot improves leaf chlorophyll, flowers per floral shoot, and yield. This therapy may boost photosynthetic activity and flower development. The study shows how pruning and thinning tactics affect kiwifruit farmers’ profitability, which is significant. The most profitable per-hectare treatment was trimming up to 12 nodes per cane and thinning up to 6 fruits per fruiting branch. This canopy management strategy can improve fruit quality and farmer profitability. The increase in cane diameter with pruning to 12 nodes/cane and thinning to 6 fruits/fruiting shoot, as evidenced by the highest cane diameter (13.33 mm), may be attributed to enhanced carbohydrate availability and reserves compared to shorter canes. Larger cane diameters resulting from thinning contribute to improved light interception and leaf size, facilitating the production of more photo-assimilates. The higher leaf chlorophyll content in the CP $\times$ FT combination may be due to the seasonal changes in the photosynthetic capacity of the leaves of kiwifruit vines. They reported an increase in photosynthetic capacity during 3–5 months after the leaf emergence, which was closely related to the concomitant changes in leaf N and chlorophyll contents in kiwifruit. Higher chlorophyll content in the leaves might be due to the higher vegetation density and absorption of the optimum amount of nutrients from the soils [24].

Increased pruning and thinning in kiwifruit vines lead to a rise in leaf area, influenced by sunlight and photosynthesis effects on canopy leaves. The study aligns with Thorp et al. [17], showing lower bud break percentage and fewer flowers per floral shoot on shorter canes compared to longer canes. Longer shoots, likely developing at the proximal end of the canes, benefit from better access to stored carbohydrates, while shorter shoots are distributed toward distal portions of the canes Efficiency per mixed bud was highest with 12-node-long canes. Consistent with [25,26], the percentage of sprouted buds increased with longer cane lengths.

The real Fertility Index increased with bud load, possibly due to less fertility in the first few nodes at the base of the shoot in some kiwifruit cultivars. The percentage of total sprouting and non-sprouted buds varied with cane length, consistent with different sprouting percentages in canes with varying bud counts. Marodin et al. [26] also reported 46 % sprouted buds with long canes in kiwifruit.

Increased bud load and pruning intensity led to higher leaf-fruit ratios, with long shoots exhibiting higher ratios than short or medium shoots [27]. The highest ratio in 12-bud pruning and the lowest in 6-bud pruning suggest enhanced annual shoot growth in longer canes, crucial for maintaining an adequate leaf: fruit ratio [26]. This balance ensures sufficient sunlight exposure for normal fruit development and quality, allowing efficient assimilate translocation within the plant. Vine yield increased with higher bud loads, notably with canes having 12 and 18 nodes (longer canes), aligning with Inglese and Gullo [25]. Thorp et al. [17] found consistently high yields with large canes and high crop loads. Similar trends were reported by Refs. [27,28] in grapes, where long pruning resulted in higher yields per vine than short pruning. Yield decrease with increased thinning intensity improved fruit size and quality [29]. The increase in yield might be attributed to larger fruit size and weight [30]. The highest yield of A-grade fruits with hand thinning to 6 fruits/shoot. The disparity in productivity among treatments may be attributed to increased bud load per vine, potentially enhancing final productivity. Marodin et al. [26] noted that with more than 20 buds per cane, leaves' number and size were insufficient to meet the carbohydrate demand of fruits. Maintaining 10 buds favored increased fruit weight without reducing productivity, aligning with Miller et al. [31]. Leader pruning resulting in more open canopies led to increased fruit yield [32]. Canopy management systems favoring the development and retention of high-quality wood types, coupled with minimal summer pruning, were associated with higher productivity and yields [33].

An increase in yield efficiency might be due to better sunshine and carbohydrate balance in long canes [30–33]. The loss in yield efficiency of short canes resulted from the reduction in fruit mass and number produced per winter bud [34]. The increase in fruit weight may be attributed to larger diameter canes and leader-pruned vines having more available carbohydrates [35]. Cooper and Marshall [35] emphasized the significance of leaf number/fruit ratio in influencing fruit weight, suggesting its greater impact compared to crop load. Hand thinning, which enhances fruit size, is likely due to the increased availability of photosynthates, nutrients, and water for remaining fruits post-thinning. Jindal et al. [36] noted that reduced fruit competition, stemming from a significant reduction in fruit number, leads to a higher leaf-to-fruit ratio and increased fruit weight. Akbas and Ozcan [37] reported a relative increase in fruit weight with higher thinning levels, aligning with the idea that changes in photosynthetic product utilization contribute to this effect. Additionally, a 1/6 F/L ratio was associated with the highest fruit diameter, possibly due to increased leaf number per fruit resulting from thinning. Similar observations were made by Karakus and Kalyoncu [38], and Pescie and Strik [39], supporting the connection between hand thinning, increased leaf-to-fruit ratio, and enhanced fruit size.

Higher total soluble solids (TSS) resulting from increased pruning severity may be linked to an elevated leaf-to-fruit ratio, promoting carbohydrate and metabolite synthesis. TSS tends to increase with thinning, as observed by Chandel et al. [40] attributed to enhanced organic metabolite transfer from leaves to fruits. Furthermore, the TSS: acid ratio rises after thinning, likely due to increased sugar content and decreased titratable acidity, consistent with findings from Babita and Rana [41]. The increase in sugar content with pruning severity may be attributed to starch conversion, enhancing photosynthetic efficiency, and metabolite transfer to developing fruits. Hand thinning was found to increase sugar concentration [42], while Ibrahim et al. [43] demonstrated a rise in sugar levels with pruning severity. Additionally, to Ref. [6], higher sugar levels in fruits from medium-vigor canes after storage.

Elevated ascorbic acid levels post-hand thinning may result from an increased leaf-to-fruit ratio and photosynthetic rate, consistent with [44,45]. The C: N ratio increase with pruning severity may be related to cane length, impacting bud break and soluble sugar accumulation. Longer canes exhibit higher carbohydrate and nitrogen content, affecting shoot growth, leaf area, and light penetration [44]. Optimal cane pruning and fruit thinning contribute to increased economic returns, emphasizing the positive impact of maintaining a balanced leaf-to-fruit ratio and effective carbohydrate distribution. Achieving higher yields with specific pruning and thinning practices, such as retaining 6 fruits/fruiting shoots, results in better prices and higher net returns.

5. Conclusion

In conclusion, the findings of this investigation highlight the significant impact of pruning and thinning practices on the overall performance and yield of the studied crop. Specifically, the combination of pruning up to 12 nodes per cane and thinning up to 6 fruits per fruiting shoot (CP12 N + FT6) emerged as the optimal treatment. This approach led to notable improvements in cane diameter, leaf area, leaf: fruit ratio, flower initiation, bud break percentage, real fertility index, and fruit yield. Moreover, it resulted in a considerable proportion of grade "A" fruits (60 %) and demonstrated superior quality parameters, including the highest leaf chlorophyll content, flowers per floral shoot, and overall productivity (21.23 MT/ha). Physico-chemical attributes, such as fruit weight, diameter, volume, TSS, TSS: acid ratio, total sugars, and C: N ratio of the leaf and shoot, also reached their peak with the CP12 N + FT6 treatment. In addition to its agronomic benefits, this approach exhibited the highest net return on a per-hectare basis, making it the most financially viable option for farmers. In summary, the combination of pruning up to 12 nodes per cane and retaining 6 fruits per fruiting shoot not only maximizes growth, yield, and fruit quality but also proves to be economically advantageous, positioning it as a recommended and profitable practice for cultivation.

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Data availability

Available data is provided in the publication and any other information will be provided on request.

CRediT authorship contribution statement

Vikrant Patiyal: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Vishal S. Rana:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Neerja Rana:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abeer Hashem:** Writing – review & editing, Writing – original draft, Visualization, Funding acquisition, Conceptualization. **Elsayed Fathi Abd_Allah:** Writing – review & editing, Writing – original draft, Visualization, Funding acquisition. **Sunny Sharma:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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