International Journal of Plant & Soil Science

Volume 37, Issue 12, Page 80-90, 2025; Article no.IJPSS.149360
ISSN: 2320-7035

Growth and Quality Response of Phalsa (*Grewia subinaequalis* D.C.) to Varying Pruning Intensities and Foliar Micronutrient Applications

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Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i125875

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/149360

Original Research Article

Received: 01/10/2025
Published: 09/12/2025

ABSTRACT

Aims: To evaluate the effect of different pruning intensities and foliar applications of micronutrients on the vegetative growth, yield, and quality attributes of phalsa (*Grewia subinaequalis* D.C.) under subtropical conditions.
Study Design: Factorial randomized block design with two factors—pruning intensity and foliar micronutrient application.

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Cite as: *Kishan Singh, A. K. Singh, Saurabh Singh, and Saurabh Raj Pandey. 2025. "Growth and Quality Response of Phalsa (Grewia Subinaequalis D.C.) to Varying Pruning Intensities and Foliar Micronutrient Applications". International Journal of Plant & Soil Science 37 (12):80–90. https://doi.org/10.9734/ijpss/2025/v37i125875.*

Place and Duration of Study: Main Experiment Station, Department of Fruit Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India, during the 2018–2019 cropping season.

Methodology: The experiment comprised various pruning intensities (50 cm, 75 cm, and others) combined with foliar sprays of micronutrients including $FeSO_4$ (0.4%), $ZnSO_4$ (0.4%), and Borax (0.2%). Data on vegetative traits (shoot length, number of shoots, leaves per shoot, internodal length), yield parameters (fruit yield per hectare), and quality traits (reducing sugars, non-reducing sugars, total sugars) were recorded using standard procedures. Statistical analysis was performed to determine treatment effects and significance levels.

Results: Pruning at 75 cm resulted in the maximum shoot length (216.19 cm), whereas 50 cm pruning produced the highest number of shoots (49.88), leaves per shoot (80.24), and fruit yield (23.81 q/ha). Among foliar applications, $FeSO_4$ at 0.4% enhanced shoot length (213.86 cm), shoot number (50.00), and leaf count (81.61). $ZnSO_4$ at 0.4% produced the longest internodal length (7.15 cm). Fruit yield was highest with $FeSO_4$ at 0.4% (23.36 q/ha), statistically comparable to Borax at 0.2%. Quality attributes were significantly improved under 50 cm pruning, which recorded the highest reducing sugars (15.24%), non-reducing sugars (3.97%), and total sugars (19.22%).

Conclusion: Moderate pruning at 50 cm combined with foliar application of $FeSO_4$ at 0.4% proved most effective in enhancing vegetative growth, fruit yield, and quality of phalsa. This integrated approach offers a practical and efficient strategy for improving phalsa productivity in subtropical regions.

Keywords: Foliar application; fruit yield; micronutrient spray; phalsa; pruning intensity.

1. INTRODUCTION

Phalsa (*Grewia subinaequalis* D.C.) (2n = 36) is a subtropical, indigenous minor fruit crop of India belonging to the family Tiliaceae (Kaur et al., 2024). Commonly known as star apple, it is primarily cultivated in the states of Haryana, Punjab, and Uttar Pradesh. Native to the Indian subcontinent and Southeast Asia, phalsa is grown commercially in tropical and subtropical regions of India (Kumar et al., 2014).

Phalsa is typically propagated through seeds and can thrive in a wide range of soils, including moderately alkaline conditions. However, optimum growth and fruiting are achieved in well-drained loamy soils. The plant is characterized as a large, scraggly shrub or small tree, reaching heights of 4.5 meters or more (Shesh et al., 2013). It features long, slender, drooping branches, with young branchlets densely covered in hairs. The leaves are alternate, deciduous, and widely spaced—broadly heart-shaped or ovate, pointed at the apex, oblique at the base, and measuring up to 20 cm in length and 16.25 cm in width. The leaf margins are coarsely toothed, and the undersides have a whitish pubescence.

Phalsa flowers are small and yellow, borne in dense cymes in the leaf axils during the onset of spring (February–March). The fruits, which develop on the current season's shoots, are spherical (1–1.6 cm in diameter) and grow in clusters (Randhawa and Dass, 1962). As they mature, the fruits change colour from green to purplish-red and eventually to dark purple. The harvesting period spans from the second fortnight of May to mid-June. The fruit has a pleasantly acidic flavour, somewhat resembling grapes.

Phalsa is valued not only for its refreshing taste but also for its medicinal and nutritional properties. The fruit is rich in antioxidants, anthocyanins, vitamin C, and essential minerals, making it beneficial in combating oxidative stress, inflammation, and microbial infections (Mehmood et al., 2020). Additionally, it has traditional applications in treating ailments such as heat stroke, digestive disorders, and respiratory issues (Sinha et al., 2015).

Despite its nutritional richness and adaptability to harsh agro-climatic conditions, phalsa remains an underutilized crop with limited research attention compared to major fruits. One of the critical factors influencing its productivity and fruit quality is the management of pruning and micronutrient application. Since phalsa bears fruit on current season's growth, pruning plays a crucial role in stimulating new shoot emergence and enhancing yield (Ali et al., 2001; Mahida et al., 2022). Simultaneously, foliar application of micronutrients such as Fe, Zn, and B has shown promise in improving physiological processes, flowering, and fruit development (Jitendra et al., 2017;, Singh et al., 2009).

Therefore, optimizing pruning intensity in conjunction with appropriate foliar micronutrient application could be a sustainable and effective strategy to enhance the growth, yield, and quality of phalsa. However, limited scientific data are available on the interactive effects of these agronomic interventions under subtropical Indian conditions. This study was undertaken to evaluate the impact of different pruning intensities and foliar sprays of selected micronutrients on vegetative growth, fruit yield, and quality attributes of phalsa.

2. MATERIALS AND METHODS

2.1 Experimental Site and Observations

The present investigation was carried out during 2018–2019 at the Main Experiment Station, Department of Fruit Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.), India. The weekly meteorological data including temperature, relative humidity and rainfall recorded during the course of the investigation were obtained from the Meteorological Observatory of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya have been illustrated in Fig 1.

A factorial randomized block design consisting of three replications was employed to assess the effects of pruning intensity and micronutrient spray on phalsa. The experiment consisted of two factors: Factor A, pruning intensity, with three levels—P_1: pruning at 25 cm above ground level, P_2: pruning at 50 cm above ground level, and P_3: pruning at 75 cm above ground level; and Factor B, micronutrient spray, comprising four treatments—M_1: control (water spray), M_2: ferrous sulphate at 0.4%, M_3: borax at 0.2%, and M_4: zinc sulphate at 0.4%. In total, twelve treatment combinations were formulated and are detailed in Table 1.

Randomly selected five plants from each treatment were used for recording observations on growth, yield, and quality parameters. Growth parameters such as shoot length (cm), number of shoots per plant, number of leaves per shoot, and internodal length (cm) were measured and their average values were calculated. Yield was estimated by multiplying the average fruit yield per plant by the number of plants per hectare.

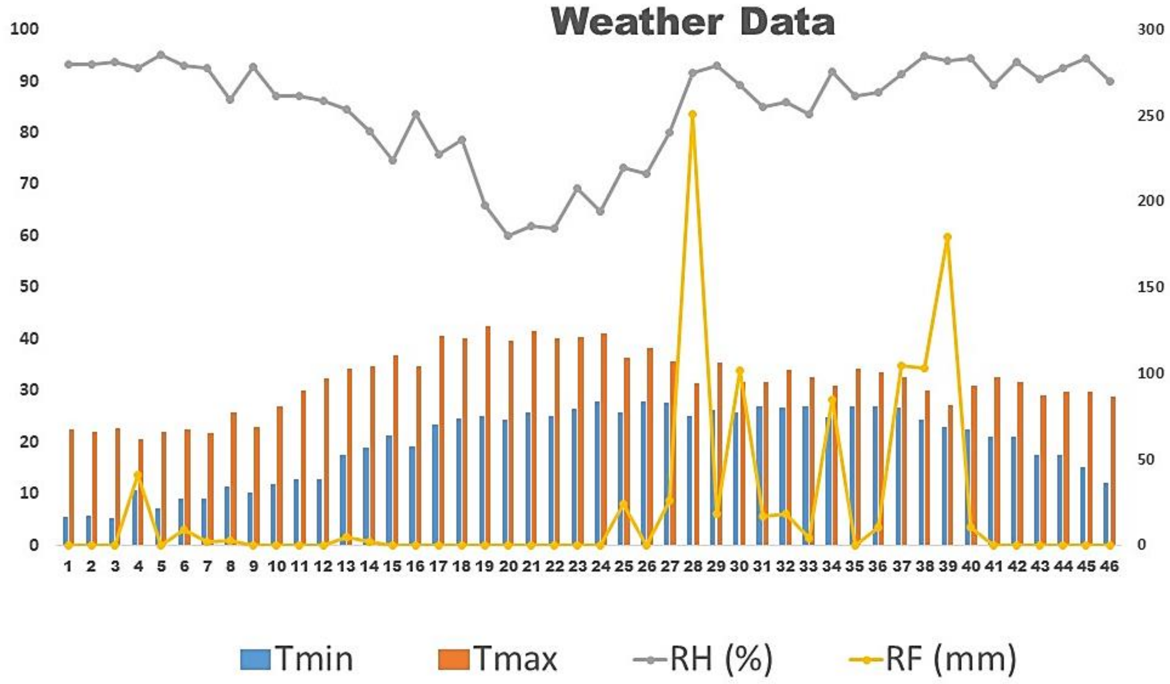

Fig. 1. Average weekly meteorological data during the period of experimentation 2018-19

Table 1. List of treatment combinations

S. No.	Treatment code with details
1.	P_1M_1: 25cm+Water spray
2.	P_1M_2: 25cm + $FeSO_4$ 0.4%
3.	P_1M_3: 25cm + H_3BO_3 0.2%
4.	P_1M_4: 25cm + $ZnSO_4$ 0.4%
5.	P_2M_1: 50cm +Water spray
6.	P_2M_2: 50cm + $FeSO_4$ 0.4%
7.	P_2M_3: 50cm + H_3BO_3 0.2%
8.	P_2M_4: 50cm + $ZnSO_4$ 0.4%
9.	P_3M_1: 75cm +Water spray
10.	P_3M_2: 75cm + $FeSO_4$ 0.4%
11.	P_3M_3: 75cm + $H_3BO_3$0.2%
12.	P_3M_4: 75cm + $ZnSO_4$ 0.4%

P = Pruning level; M = Micronutrient treatment;

For quality analysis, five fully mature fruits were randomly harvested from each treatment. The quality parameters such as reducing sugars, non-reducing sugars, and total sugars were determined using Lane and Eyon method described by Ranganna (Ranganna, 2001).

2.2 Statistical Analysis

The data recorded for various parameters were statistically analyzed using the analysis of variance (ANOVA) method as per Fisher's method (Panse and Sukhatme, 1985). The significance of treatment effects was determined by comparing the calculated F-values with the tabulated values at a 5% level of probability. Standard error of the mean (SEm±) and critical difference (CD at 5%) were calculated to assess the significance between treatment means using the following formula:

$$\text{(i) SEm} \pm = \sqrt{\frac{\text{EMS}}{\text{n}}}$$

Where,

EMS is the mean sum of square of error.

$$\text{n} = \frac{\text{Total number of experimental unit}}{\text{Levels of factor}}$$

$$\text{(ii) C.D.} = \text{t x} \sqrt{\frac{2\ \text{EMS}}{\text{n}}}$$

3. RESULTS AND DISCUSSION

3.1 Effect on Shoot Length

Pruning intensity and foliar application of micronutrients significantly affected shoot length (Table 2). Maximum shoot length (216.19 cm) was recorded with P_3, while the minimum (210.69 cm) was observed at P_1. Among treatments, M_2 at 0.4% produced the longest shoots (213.86 cm), followed closely by M_3 (213.71 cm). The interaction between pruning and micronutrient spray (P × M) was found to be statistically significant, as indicated by the SEm ± of 1.33 and a CD at 5% level of 3.90, demonstrating that the combined effects of both factors played a crucial role in influencing the trait under study. The maximum shoot length (221.33 cm) observed under P_3M_4, aligning with previous reports where proper pruning intensity coupled with appropriate micronutrient application enhanced shoot length in phalsa (Panse and Sukhatme, 1985; Jitendra et al., 2017; Singh and Singh, 2017).

3.2 Effect on Number of Shoots Per Plant

The data presented in Table 3 reveal that both pruning intensity and micronutrient spray, as well as their interaction, significantly influenced the number of shoots per plant in phalsa. The pruning at 50 cm above ground level (P_2) resulted in the highest mean number of shoots per plant (49.88), followed by P_3 with a mean of 48.16, while the lowest number of shoots (46.88) was recorded under P_1. This indicates that moderate pruning (50 cm) is most effective in promoting shoot proliferation, likely due to optimal removal of apical dominance while retaining sufficient carbohydrate reserves in the plant.

Regarding the effect of micronutrient sprays, the maximum average number of shoots (50.00) was observed with the application M_2, followed by M_3 with 48.00, while the minimum (46.89) was recorded in the zinc sulphate treatment (M_4). The control treatment (M_1) resulted in 47.95 shoots per plant. These results suggest that ferrous sulphate plays a vital role in enhancing vegetative growth, possibly due to its role in chlorophyll synthesis and enzymatic activity.

The interaction effect between pruning and micronutrient spray (P × M) was also found to be statistically significant. The highest number of shoots (53.67) was recorded in the combination of P_2M_3, followed by P_2M_2 (52.33). These findings imply that boron and iron, when applied under optimal pruning conditions, synergistically promote axillary bud growth and shoot development. On the other hand, the lowest number of shoots (44.19) was observed in P_2M_1, indicating the limited impact of pruning alone without micronutrient supplementation. The significance of the interaction is supported by the statistical analysis, where the SEm ± for P × M was 1.25, and the critical difference (CD) at 5% was 3.66, confirming the reliability of these observations. Similar interactions between pruning and nutrient management have been

Table 2. Effect of pruning intensity and micro nutrients on Shoot length (cm)

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	211.49	208.33	213.67	211.16
M_2 - ($FeSO_4$ 0.4%)	214.47	213.67	213.44	213.86
M_3- (Borax 0.2%)	212.80	212.00	216.33	213.71
M_4- ($ZnSO_4$ 0.4%)	204.00	209.33	221.33	211.55
Mean	210.69	210.83	216.19	
	P	**M**	**P X M**	
SEm ±	0.67	0.77	1.33	
CD at 5%	1.95	2.25	3.90	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate.

Table 3. Effect of pruning intensity and micro nutrients on Number of shoot per plant

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	76.00	72.64	81.33	76.65
M_2 - ($FeSO_4$ 0.4%)	79.91	84.33	80.60	81.61
M_3- (Borax 0.2%)	82.12	82.53	76.94	80.53
M_4- ($ZnSO_4$ 0.4%)	80.93	80.39	82.10	81.14
Mean	79.74	79.97	80.24	
	P	**M**	**P X M**	
SEm ±	0.97	1.11	1.93	
CD at 5%	NS	3.27	5.66	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate.

Table 4. Effect of pruning intensity and micro nutrients on Number of leaves per shoot

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25 cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	50.33	44.19	49.33	47.95
M_2 - ($FeSO_4$ 0.4%)	47.00	52.33	50.67	50.00
M_3- (Borax 0.2%)	44.33	53.67	46.00	48.00
M_4- ($ZnSO_4$ 0.4%)	44.67	49.33	46.67	46.89
Mean	46.88	49.88	48.16	
	P	**M**	**P X M**	
SEm ±	0.62	0.72	1.25	
CD at 5%	1.83	2.11	3.66	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate.

Table 5. Effect of pruning intensity and micro nutrients on Inter nodal length (cm)

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	6.50	6.90	6.39	6.59
M_2 - ($FeSO_4$ 0.4%)	6.93	7.15	7.23	7.10
M_3- (Borax 0.2%)	7.05	6.59	7.32	6.98
M_4- ($ZnSO_4$ 0.4%)	6.99	7.34	7.12	7.15
Mean	6.86	6.99	7.01	
	P	**M**	**P X M**	
SEm ±	0.09	0.10	0.18	
CD at 5%	NS	0.30	0.53	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate.

Table 6. Effect of pruning intensity and micro nutrients on Fruit yield per hectare

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	18.17	22.64	18.29	19.7
M_2 - ($FeSO_4$ 0.4%)	18.31	29.50	22.27	23.36
M_3- (Borax 0.2%)	21.36	23.62	23.76	22.91
M_4- ($ZnSO_4$ -0.4%)	17.92	19.50	18.92	18.78
Mean	18.94	23.81	20.81	
	P	**M**	**P X M**	
SEm ±	0.26	0.30	0.52	
CD at 5%	0.76	0.87	1.51	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate

Table 7. Effect of pruning intensity and micro nutrients on % reducing sugar content of phalsa fruit

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	12.55	13.82	13.20	13.19
M_2 - ($FeSO_4$ 0.4%)	14.50	14.74	14.53	14.59
M_3- (Borax 0.2%)	15.56	16.23	15.51	15.76
M_4- ($ZnSO_4$ 0.4%)	15.64	16.18	15.63	15.81
Mean	14.56	15.24	14.71	
	P	**M**	**P X M**	
SEm ±	0.07	0.08	0.14	
CD at 5%	0.21	0.24	0.42	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate

reported in phalsa and other fruit crops like guava and ber (Wali et al., 2005; Kumar et al, 2017; Shinde, 2020, Saritha et al., 2021).

3.3 Effect on Number of Leaves Per Shoot

The number of leaves per shoot was significantly influenced by micronutrient treatments, while the effect of pruning intensity alone was statistically non-significant (Table 4). Among the micronutrients, M_2 recorded the highest mean number of leaves per shoot **(**81.61**),** followed closely by zinc sulphate (M_4) and borax M_3 with 81.14 and 80.53, respectively. The lowest number (76.65) was observed in the control treatment (M_1), indicating the positive role of micronutrients in enhancing vegetative growth.

Although the pruning levels did not significantly affect leaf number individually, the interaction between pruning and micronutrient treatments (P × M) was significant. The maximum number of leaves per shoot (84.33) was observed in P_2M_2**,** followed by P_2M_3 and P_3M_4, suggesting that moderate pruning combined with micronutrient application enhances leaf production. Similar findings have been reported in other fruit crops, where foliar nutrition and optimal pruning improved foliage development (Yadav et al., 2020, Singh et al., 2025).

3.4 Effect on Inter-Nodal Length

Among the pruning levels, although internodal length ranged from 6.86 cm to 7.01 cm, the differences were statistically non-significant (Table 5). This suggests that the variation in pruning severity (25 cm to 75 cm) did not independently alter internodal elongation to a significant extent. However, a slight increase in mean internodal length was noted with higher pruning levels, with the longest internodes (7.01 cm) recorded under P_3, possibly due to enhanced shoot vigour resulting from heavier pruning (Kumar et al., 2017).

Micronutrient treatments significantly influenced internodal length. The maximum internodal length (7.15 cm) was observed with M_4, followed closely by M_2 (7.10 cm). M_3 also promoted internodal elongation (6.98 cm), whereas the minimum internodal length (6.59 cm) was recorded in the control (M_1). Zinc and iron play vital roles in cell elongation and division, which likely contributed to increased internodal growth (Singh et al., 2017, Johnson and Mirza, 2020). The interaction effect P_3M_4 showed the maximum length (7.32 cm). The higher internodal length might be attributed to enhanced cell division and elongation, which are influenced by essential micronutrients such as zinc and iron (Johnson and Mirza, 2020; Tao et al., 2024). These nutrients may have indirect role in stimulating the endogenous synthesis or activity of growth hormones like gibberellins, thereby promoting internodal elongation (Iqbal et al., 2011).

Table 8. Effect of pruning intensity and micronutrients on % Non-reducing sugar of phalsa fruit

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	2.43	3.02	2.75	2.73
M_2 - ($FeSO_4$ 0.4%)	3.39	4.20	3.47	3.68
M_3- (Borax 0.2%)	3.37	4.31	3.55	3.74
M_4- ($ZnSO_4$ 0.4%)	3.42	4.37	3.74	3.84
Mean	3.15	3.97	3.37	
	P	**M**	**P X M**	
SEm ±	0.04	0.05	0.09	
CD at 5%	0.13	NS	0.15	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate.

Table 9. Effect of pruning intensity and micronutrients on % Total sugars of phalsa fruit

Micro nutrients	**Pruning levels**			**Mean**
	P_1 (25cm)	**P_2 (50cm)**	**P_3 (75cm)**	
M_1- (Water Spray)	14.92	16.87	15.95	15.91
M_2 - ($FeSO_4$ 0.4%)	17.88	18.94	18.00	18.27
M_3- (Borax 0.2%)	18.93	20.54	19.05	19.50
M_4- ($ZnSO_4$ 0.4%)	19.02	20.55	19.21	19.59
Mean	17.68	19.22	18.05	
	P	**M**	**P X M**	
SEm ±	0.07	0.09	0.15	
CD at 5%	0.22	0.25	0.43	

P = Pruning level; M = Micronutrient treatment; $FeSO_4$ = Ferrous sulphate; $ZnSO_4$ = Zinc sulphate

3.5 Effect on Fruit Yield

The data in Table 6 show that fruit yield per hectare in phalsa was significantly influenced by both micronutrient application and pruning intensity**.** Among the pruning levels, P_2 exhibited highest fruit yield (23.81 q/ha) followed by P_3 (75 cm) with 20.81 t/ha, and the lowest (18.94 q/ha) under P_1 (25 cm). These findings suggest that moderate pruning intensity (50 cm) is most favourable for maximizing fruit yield in phalsa, likely due to an optimal balance between vegetative growth and reproductive development. Pruning removes older and less productive shoots, promoting the emergence of vigorous new shoots with higher fruit-bearing capacity (Abid et al., 2012; Aziz et al., 2018; Chaturvedi et al., 2014; Kumar and Saravanan, 2017).

Micronutrient application also had a significant effect on fruit yield. The highest mean yield (23.36 t/ha) was recorded with M_2**,** followed by M_3 with 22.91 q/ha. In contrast, the control treatment (M_1) and M_4 recorded lower yields, 19.70 and 18.78 q/ha respectively. Iron is a vital component of many enzymes involved in photosynthesis and respiration, which directly contribute to higher assimilate production and ultimately, better yield (22, 23, 28). Boron, on the other hand, plays a crucial role in pollen viability, fertilization, and fruit set, which might explain the improved yields observed with Borax application (23, 29). The most effective treatment combination was P_2M_2**,** which resulted in the maximum fruit yield (29.50 q/ha**)**. This significant interaction effect (P × M) suggests that moderate pruning, when combined with iron supplementation, can synergistically enhance productivity in phalsa (Kumar and Saravanan, 2017).

3.6 Effect on Reducing Sugars

The results presented in Table 7 indicate that both pruning intensity and micronutrient application had a significant effect on the reducing sugars content of phalsa fruits. Among the pruning treatments, the highest reducing sugar content (15.24%) was recorded with P_2, while the lowest (14.56%) was observed with P_1. This suggests that moderate pruning may enhance sugar accumulation by improving light penetration, photosynthetic efficiency, and carbohydrate partitioning towards fruit development.

Regarding the micronutrient treatments, the highest reducing sugar content (15.81%) was observed with M_4, whereas the lowest (13.19%) was recorded in the control treatment (M_1). Zinc is known to enhance enzymatic activity and photosynthetic processes, which likely contributed to the increased sugar synthesis and translocation in the fruit. All micronutrient treatments showed a significantly positive impact compared to the control.

A significant interaction effect (P × M) was also observed. The maximum reducing sugar content (16.23%) was recorded with the P_2M_3, while the lowest (13.05%) was observed in P_1M_1. This indicates that the combined effect of optimal pruning and micronutrient application particularly boron can synergistically improve sugar accumulation in phalsa fruits. Boron plays a crucial role in carbohydrate metabolism and sugar transport within plant tissues, which might explain its superior performance in enhancing reducing sugar content when combined with moderate pruning (Muengkaew et al., 2017). These results are in line with the previous findings (Chaturvedi et al., 2014) in phalsa and (Farid et al., 2020) in custard apple, who also reported increased sugar content in fruits with balanced pruning and appropriate micronutrient application.

3.7 Effect on Non-Reducing Sugars

It is obvious from the Table 8 that pruning intensity significantly influenced on non-reducing sugar. The maximum (3.97%) non- reducing sugars was recorded with P_2 while, the minimum (3.15 %) non-reducing sugar was recorded with P_1. The foliar application of micro nutrients doesn’t affect the non-reducing sugar content of phalsa fruit significantly. The maximum (3.84%) non-reducing sugar was noted under foliar application of $ZnSO_4$ 0.4% (M_4) and minimum (2.73%) non-reducing sugars was recorded with control. The interaction between pruning levels and chemicals on non- reducing sugars was found significant. The maximum (4.37) per cent of non- reducing sugars was noted with P_2M_4 and the minimum values were estimated in P_1M_1 (2.43%). This interaction effect highlights the potential of combining optimal pruning with micronutrient application, particularly zinc, to enhance the biochemical composition of phalsa fruits (Chaturvedi et al., 2014).

3.8 Effect on Total Sugars

An examination of the data presented in Table 9 revealed that total sugar content in phalsa fruits was significantly influenced by both pruning intensity and micronutrient application. Among the pruning levels, the highest total sugar content (19.22%) was recorded with P_2, while the lowest (17.68%) was observed with P_1. This suggests that moderate pruning facilitates better carbohydrate accumulation, likely by enhancing light interception, photosynthetic efficiency, and source–sink balance, thereby promoting sugar synthesis and translocation to the fruits.

Foliar application of micronutrients also had a significant impact on total sugar content. The maximum total sugar percentage (19.59%) was observed with M_4, which was statistically at par with M_3. In contrast, the lowest total sugar content (15.91%) was recorded under the control treatment M_1. Zinc plays a crucial role in the activation of several enzymes involved in carbohydrate metabolism, while boron facilitates sugar transport and cell wall formation, both of which contribute to increased sugar accumulation in fruits (Muengkaew et al., 2017; Farid et al., 2020).

The interaction between pruning intensity and micronutrient treatments was also found to be statistically significant. The highest total sugar content (20.55%) was recorded with the treatment combination P_2M_4, which was statistically at par with P_2M_3. Conversely, the lowest value (14.92%) was observed with P_1M_1. These results indicate that the synergy between optimal pruning and targeted micronutrient application particularly zinc and boron can markedly improve the quality of phalsa fruits by enhancing sugar content (Abid et al., 2012; Kadam et al., 2018).

4. CONCLUSION

The study concludes that the growth, yield, and quality of phalsa can be significantly influenced by the appropriate combination of pruning intensity and foliar application of micronutrients. While 50 cm pruning with a foliar spray of $FeSO_4$ (0.4%) or $ZnSO_4$ (0.4%) produces the highest shoot growth, fruit yield, and sugar content, similar benefits can also be achieved with borax (0.2%) under the same pruning intensity. Among the treatments, 50 cm pruning is recommended as the most effective intensity for optimizing plant performance. Foliar application of $ZnSO_4$ is particularly beneficial for improving total sugar content in fruits under subtropical conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/149360