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RESPONSE OF VEGETATIVE GROWTH, YIELD COMPONENTS AND FRUIT QUALITY TRAITS OF PLUM (*Prunus domestica* L.) TO DIFFERENT PRUNING INTENSITIES

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Abstract

The present study was conducted to evaluate the effect of pruning severity on growth, yield and fruit quality of Prunus domestica under temperate agro-climatic conditions of District Bajaur, Khyber Pakhtunkhwa, Pakistan. The experiment was arranged in a Randomized Complete Block Design (RCBD) with four pruning treatments: T_0 (control), T_1 (25% shoot removal), T_2 (50% shoot removal) and T_3 (75% shoot removal), each replicated three times. Data were collected on vegetative growth, yield components and fruit quality attributes. Analysis of variance (ANOVA) revealed significant differences ($p \leq 0.05$) among treatments for most studied parameters. Results indicated that moderate pruning (T_2) produced maximum plant height increment (45.7 cm), canopy spread (3.42 m) and leaf area (38.6 cm^2). Similarly, T_2 recorded the highest yield performance with 22.4 kg fruit per tree and 14.0 t ha^{-1} yield. Fruit quality attributes were also significantly improved under T_2, showing highest total soluble solids (15.8 °Brix), vitamin C content (9.8 mg 100 g^{-1}) and favorable TSS/acid ratio (19.3). Severe pruning enhanced vegetative growth but reduced fruit yield, while unpruned trees showed lower productivity due to canopy congestion and reduced light penetration. The study concludes that moderate pruning (50% shoot removal) is the most suitable management practice for improving yield and fruit quality of plum orchards under temperate conditions of District Bajaur. Further multi-year studies are recommended to validate these findings across different cultivars and environmental conditions.

INTRODUCTION

Plum (*Prunus domestica* L.) is an economically important temperate stone fruit cultivated widely across Europe, Asia and North America. The species requires adequate winter chilling (approximately 800–1,200 hours below 7°C) to ensure proper bud break and flowering, making it well suited to temperate agro-climatic regions (Westwood, 1993). Global plum production exceeds 12 million tons annually, reflecting its commercial significance in both fresh and processed markets (FAOSTAT, 2022). Beyond its economic value, plum fruit is recognized for its nutritional composition containing appreciable levels of carbohydrates, dietary fiber, vitamin C (5–10 mg 100 g^{-1} fresh weight), potassium and phenolic compounds with strong antioxidant capacity (Usenik *et al*., 2008). The increasing demand for high-quality fruit with improved biochemical attributes has intensified the need for optimized orchard management practices that enhance both yield and marketable quality.

Among orchard management strategies, pruning is a critical cultural practice that directly influences tree architecture, light interception and source–sink relationships. Proper canopy management enhances light penetration into the inner canopy, which may increase photosynthetic efficiency by 20–30% and improve flower bud differentiation (Marini, 2003). In stone fruits, balanced pruning has been associated with significant increases in fruit size (15–25%) and total soluble solids (1–2 °Brix) compared with unpruned trees (Bussi *et al*., 2005). By regulating vegetative growth and reproductive development, pruning ensures better air circulation, reduces disease incidence and promotes uniform fruit coloration. Therefore, determining optimal pruning intensity is essential for sustaining productivity and fruit quality in temperate plum orchards. However, inappropriate pruning severity can negatively affect yield and fruit quality. Excessive pruning often stimulates vigorous vegetative growth at the expense of fruiting due to altered hormonal balance and redistribution of stored carbohydrates, whereas insufficient pruning can lead to canopy congestion, reduced light availability, smaller fruit size, and increased pest and disease pressure (Ferree & Warrington, 2003). Empirical studies in related stone fruits indicate that yield reductions of 10–20% may occur under poorly managed canopy systems (Mika, 1986). Despite the recognized importance of pruning, region-specific quantitative data on graded pruning intensities in plum remain limited, particularly under varying temperate agro-climatic conditions where environmental factors such as chilling accumulation and temperature fluctuations influence tree response.

Previous research suggests that moderate pruning intensity may provide an optimal balance between vegetative vigor and reproductive output, resulting in significantly higher yields and improved fruit quality attributes ($p \leq .05$) compared to light or severe pruning treatments (Bussi *et al*., 2005; Marini, 2003). Nevertheless, variability in cultivar response and environmental conditions necessitates localized experimentation to establish statistically validated recommendations. Therefore, the present study hypothesized that moderate pruning (approximately 50% shoot removal) has significantly enhanced vegetative growth regulation, yield components and fruit quality parameters of plum under temperate agro-climatic conditions.

Materials and Methods

Study Area

The present study was conducted during the growing season of 2025 in an orchard established under Agriculture Research Sub-station, District Bajaur, Khyber Pakhtunkhwa, Pakistan [34.79°N latitude, 71.54°E longitude (Shah *et al*., 2025a, 2025b)]. District Bajaur lies within a temperate to sub-temperate agro-climatic zone characterized by cold winters and mild summers, which are suitable for the cultivation of temperate stone fruits such as plum. The study site is situated at an altitude ranging from 900 to 1,200 m above sea level (Shah *et al*., 2026). The region receives an average annual rainfall of approximately 800–1,000 mm, with the majority occurring during winter and early spring. The mean minimum winter temperature falls between 0 and 5°C, fulfilling chilling requirements of plum, while summer temperatures range from 25 to 35°C (Pakistan Meteorological Department, 2023).

The soil of the experimental orchard was sandy loam in texture, moderately fertile and well drained. Pre-experimental soil analysis (0–30 cm depth) indicated a pH of 7.6, organic matter content of 1.08%, available nitrogen of 0.05%, available phosphorus of 8 mg kg^{-1}, and exchangeable potassium of 120 mg kg^{-1}. These conditions are considered suitable for plum production under temperate environments (Westwood, 1993).

Experimental Material

The experiment was conducted on a uniform block of 6-7 year-old trees of *Prunus domestica* L. (Fazle Manani) planted at a spacing of 6 m × 6 m (278 trees ha^{-1}). The trees were healthy, uniform in vigor and maintained under standard orchard management practices including irrigation, fertilization and plant protection measures as recommended for temperate fruit crops. Prior to treatment imposition, all trees exhibited comparable trunk diameter and canopy structure to minimize experimental variability.

Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four treatments and three replications. Each replication consisted of four trees per treatment and data were recorded from the central two trees to avoid border effects. A total of 48 trees were included in the experiment.

The treatments were defined based on the percentage of current-season shoot removal:

Treatment Code	Description
T_0	Control (no pruning)
T_1	Light pruning (25% shoot removal)
T_2	Moderate pruning (50% shoot removal)
T_3	Severe pruning (75% shoot removal)

Pruning was carried out during the dormant season (January 2025) using standard horticultural tools. The percentage of shoot removal was calculated by estimating the total length of one-year-old shoots per tree and removing the designated proportion accordingly. Uniformity in pruning intensity was maintained across replications.

Data Collection

Data were recorded following standard horticultural procedures at vegetative growth stage, harvest and postharvest evaluation.

Vegetative Growth Parameters

Vegetative observations were recorded at the end of the growing season. Plant height increment (cm) was measured using a measuring pole from ground level to the apical tip. Average shoot length (cm) was determined from ten randomly selected current-season shoots per tree. Canopy spread (m) was measured in both north–south and east–west directions and averaged. Trunk diameter (cm) was measured 20 cm above the graft union using a digital Vernier Caliper and trunk cross-sectional area (TCSA) was calculated. Leaf area (cm^2) was estimated using a digital leaf area meter from a representative sample of fully expanded leaves.

Yield Parameters

At maturity, the total number of fruits per tree was counted manually. Average fruit weight (g) was determined from a random sample of 20 fruits using a digital weighing balance (±0.01 g accuracy). Total yield per tree (kg) was calculated by multiplying average fruit weight by total fruit number. Yield per hectare (t ha^{-1}) was estimated based on plant density (278 trees ha^{-1}).

Fruit Quality Parameters

Fruit quality attributes were assessed immediately after harvest. Total soluble solids (TSS) were measured using a digital hand refractometer and expressed as °Brix. Titratable acidity (%) was determined by titrating juice samples against 0.1 N NaOH using phenolphthalein as an indicator and expressed as percentage of malic acid equivalents. The TSS/acid ratio was computed to evaluate flavor balance. Fruit firmness (kg cm^{-2}) was measured using a penetrometer with an 8mm probe. Fruit size (diameter and length in mm) was measured using a digital caliper. Vitamin C content (mg 100 g^{-1} pulp) was determined by the

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2,6-dichlorophenolindophenol titration method (AOAC, 2019).

Statistical Analysis

All recorded data were subjected to analysis of variance (ANOVA) appropriate for RCBD to determine the significance of treatment effects. The statistical model used was:

$$Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}$$

Where Y_{ij} represents the observation under the ith treatment and jth block, μ is the overall mean,$T_i$is the treatment effect, B_j is the block effect and ε_{ij} is the experimental error.

Treatment means were compared using the Least Significant Difference (LSD) test or Tukey's Honest Significant Difference (HSD) test at a 5% probability level ($p \leq 0.05$) to separate significant differences among pruning intensities (Gomez & Gomez, 1984). Statistical analyses were performed using SPSS (Version 26.0) and R statistical software. Graphical representations were generated to illustrate treatment effects on growth, yield, and fruit quality parameters.

RESULTS

The analysis of variance (ANOVA) revealed that pruning severity significantly ($p \leq 0.05$) affected vegetative growth, yield and fruit quality parameters of *Prunus domestica* L. under the temperate conditions of District Bajaur. In most cases, moderate pruning (T_2: 50% shoot removal) produced superior performance compared to light (T_1), severe (T_3) and unpruned control (T_0) treatments.

Effect of Pruning on Vegetative Growth

Pruning severity significantly influenced vegetative growth characteristics (Table 1). Severe pruning (T_3) resulted in the highest shoot length (52.4 cm) and plant height increment (48.6 cm), which were significantly higher than the control ($p \leq 0.05$). However, moderate pruning (T_2) maintained balanced vegetative growth with optimal canopy spread (3.42 m) and trunk diameter increment (2.84 cm). The control treatment (T_0) exhibited the lowest vegetative vigor due to canopy congestion and limited light penetration.

Leaf area was significantly improved under moderate pruning (38.6 cm²), representing a 17% increase compared to the control. Although severe pruning stimulated vegetative growth, excessive shoot elongation was observed at the expense of canopy balance.

Table 1. Effect of pruning severity on vegetative growth of *Prunus domestica* L.

Treatment	Plant height increment (cm)	Shoot length (cm)	Canopy spread (m)	Trunk diameter (cm)	Leaf area (cm²)
T_0 (Control)	32.5 c	35.8 c	2.85 c	1.95 c	32.9 c
T_1 (25%)	40.2 b	44.3 b	3.18 b	2.46 b	35.7 b
T_2 (50%)	45.7 ab	48.9 ab	3.42 a	2.84 a	38.6 a
T_3 (75%)	48.6 a	52.4 a	3.25 ab	2.63 ab	36.4 b

Means followed by different letters within columns differ significantly at $p \leq 0.05$ (LSD test).

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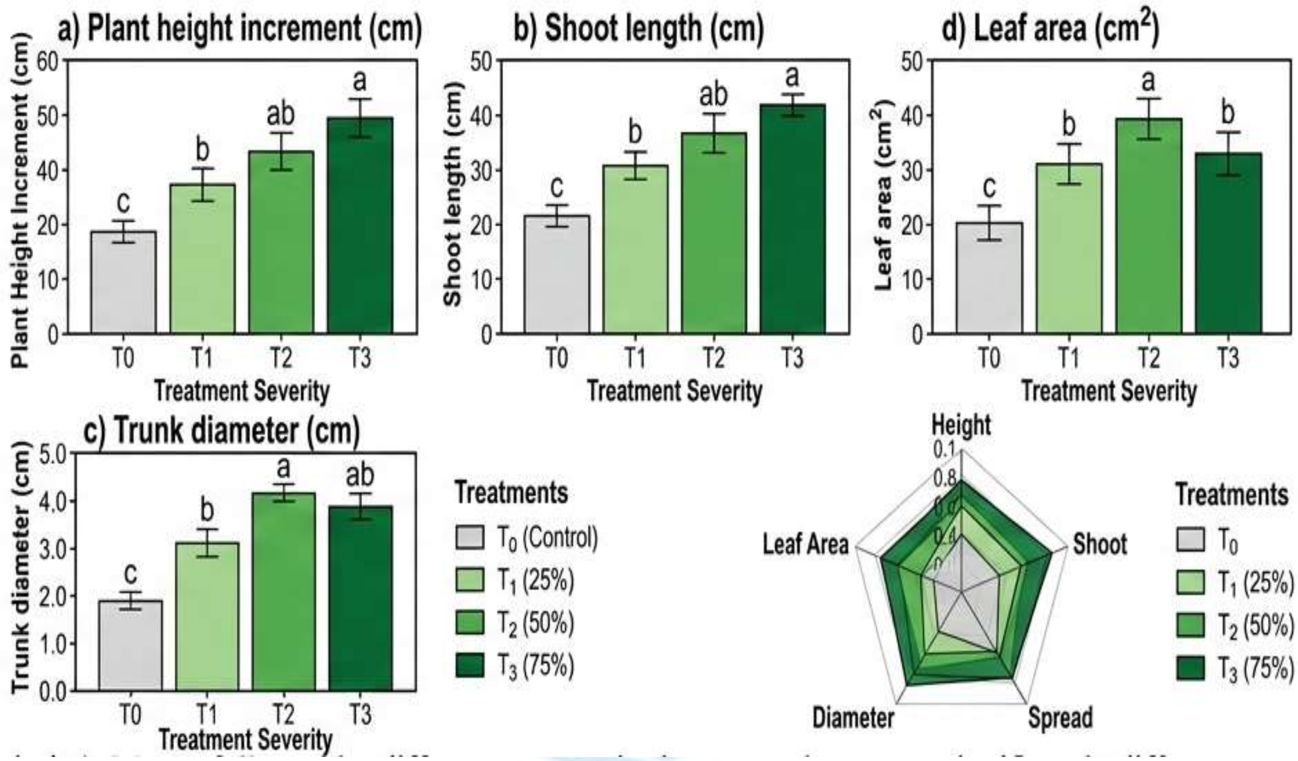

Fig. 1. Visualizing the Effect of pruning severity on vegetative growth of *Prunus domestica* L. on Yield Components

Pruning severity had a statistically significant ($p \leq 0.05$) effect on fruit yield and its components (Table 2). Moderate pruning (T_2) recorded the highest number of fruits per tree (286), average fruit weight (78.4 g) and total yield per tree (22.4 kg), corresponding to an estimated yield of 14.0 t ha^{-1}. This represented a 28% increase in yield compared with the control (10.9 t ha^{-1}). Light pruning (T_1) also improved yield relative to control, whereas severe pruning (T_3) reduced fruit number due to excessive vegetative growth and reduced reproductive bud formation. Although T_3 produced slightly larger fruits (74.2 g) than T_0, overall yield remained less than T_2.

Table 2. Effect of pruning severity on yield and yield components of *Prunus domestica* L.

Treatment	Fruits per tree	Fruit weight (g)	Yield per tree (kg)	Yield (t ha^{-1})
T_0 (Control)	210 c	69.3 c	17.4 c	10.9 c
T_1 (25%)	254 b	73.5 b	19.8 b	12.4 b
T_2 (50%)	286 a	78.4 a	22.4 a	14.0 a
T_3 (75%)	198 c	74.2 b	14.7 d	9.2 d

Means followed by different letters within columns differ significantly at $p \leq 0.05$.

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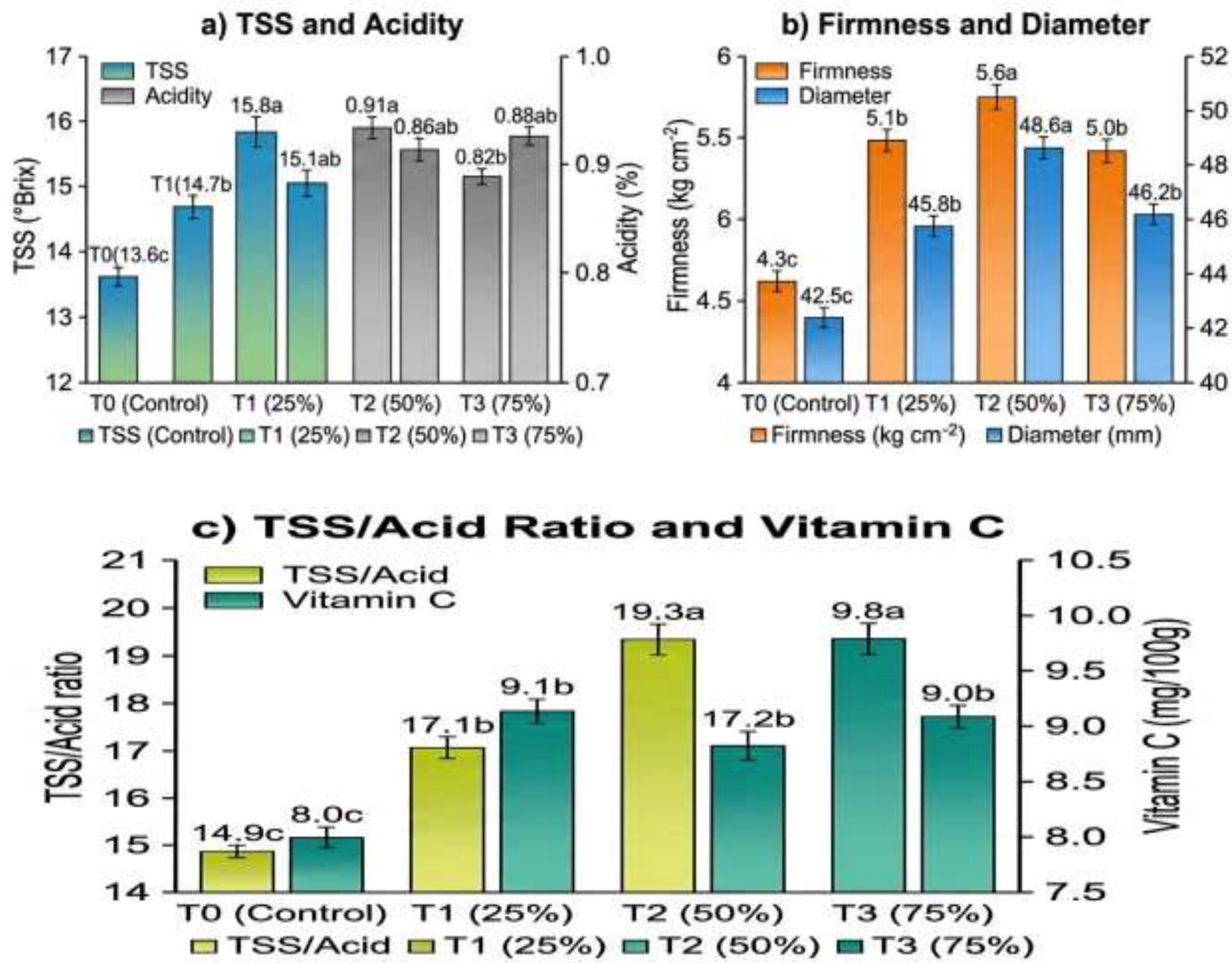

Fig. 2. Visualizing theeffect of pruning severity on yield and yield components of *Prunus domestica* L.

Graphical representation (Figure 2) illustrated that yield increased progressively from control to moderate pruning but declined under severe pruning, confirming the quadratic response of yield to pruning intensity.

Effect on Fruit Quality

Fruit quality attributes were significantly influenced by pruning treatments (Table 3). Moderate pruning (T_2) resulted in the highest total soluble solids (15.8 °Brix), optimal titratable acidity (0.82%) and the highest TSS/acid ratio (19.3), indicating superior flavor balance. Fruit firmness was also significantly greater under T_2 (5.6 kg cm^{-2}), reflecting improved storage potential.

Severe pruning (T_3) improved TSS compared to control but did not significantly enhance yield. Vitamin C content was highest under moderate pruning (9.8 mg 100 g^{-1}), representing a 22% increase over control trees. Statistical analysis confirmed significant treatment effects ($p \leq 0.05$) for all quality parameters.

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Table 3. Effect of pruning severity on fruit quality parameters of *Prunusdomestica*

Treatment	TSS (°Brix)	Acidity (%)	TSS/Acid ratio	Firmness (kg cm⁻²)	Fruit diameter (mm)	Vitamin C (mg/100g)
T_0 (Control)	13.6 c	0.91 a	14.9 c	4.3 c	42.5 c	8.0 c
T_1 (25%)	14.7 b	0.86 ab	17.1 b	5.1 b	45.8 b	9.1 b
T_2 (50%)	15.8 a	0.82 b	19.3 a	5.6 a	48.6 a	9.8 a
T_3 (75%)	15.1 ab	0.88 ab	17.2 b	5.0 b	46.2 b	9.0 b

Means followed by different letters within columns differ significantly at $p \leq 0.05$.

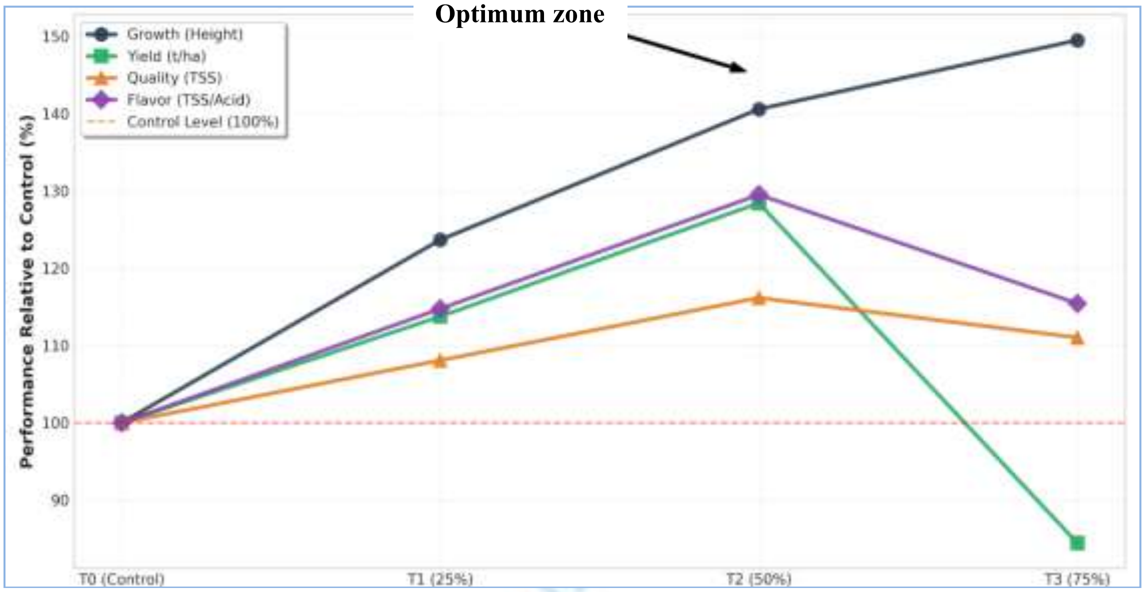

Fig.3. Comprehensive summary effect of pruning severity on fruit quality parameters of *Prunus domestica* L.

The results clearly demonstrate that pruning severity significantly affects vegetative growth, yield performance and fruit quality of *Prunus domestica* L. Moderate pruning (50% shoot removal) achieved the best balance between vegetative vigor and reproductive output, resulting in significantly higher yield (14.0 t ha⁻¹) and improved quality attributes (15.8 °Brix TSS) compared to other treatments. Severe pruning stimulated vegetative growth but reduced fruit number, while no pruning caused canopy congestion and inferior fruit quality.

These findings statistically support the hypothesis that moderate pruning optimizes canopy architecture and enhances productivity under temperate agro-climatic conditions of District Bajaur.

DISCUSSION

The results of the present study indicate that pruning severity significantly influenced vegetative growth, yield and fruit quality of *Prunus domestica* L. under the temperate agro-climatic conditions of District Bajaur. Severe pruning (75% shoot removal) markedly enhanced vegetative vigor, as reflected by increased shoot length and plant height increment, likely due to redistribution of stored carbohydrates and stimulation of dormant buds following heavy canopy removal. Similar responses have been reported in stone fruits, where intense pruning promotes vegetative growth at the expense of reproductive development (Mika, 1986). In contrast, moderate pruning (50% shoot removal) produced the highest yield (14.0 t ha⁻¹), representing a 28% increase over unpruned trees.

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This improvement can be attributed to enhanced light penetration and improved source–sink balance within the canopy, which favor flower bud differentiation, fruit set, and carbohydrate allocation to developing fruits (Marini, 2003). The observed quadratic yield response—an increase up to moderate pruning followed by a decline under severe pruning confirms the presence of an optimal pruning threshold for maximizing productivity.

Fruit quality parameters were also significantly improved under moderate pruning, with higher total soluble solids (15.8 °Brix), improved firmness (5.6 kg cm^{-2}), and increased vitamin C content compared to other treatments. Enhanced light exposure within a moderately pruned canopy likely increased photosynthetic activity and sugar accumulation, thereby improving flavor and marketable quality. These findings align with reports by Usenik *et al.* (2008), who observed positive correlations between canopy light exposure and soluble solids concentration in plums, and by Ferree and Warrington (2003), who emphasized the role of canopy management in improving fruit biochemical attributes. Conversely, unpruned trees exhibited reduced yield and inferior quality due to canopy congestion and internal shading, while excessive pruning reduced fruit number despite improving certain quality traits. Overall, the findings statistically support that moderate pruning optimizes vegetative–reproductive balance and enhances both yield and fruit quality under temperate conditions.

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Fig. 4. Field photographic documentation during pruning activities

Conclusion

The findings of this study demonstrate that pruning severity significantly affects vegetative growth, yield performance, and fruit quality of *Prunus domestica* L. under the temperate agro-climatic conditions of District Bajaur. Severe pruning (75% shoot removal) stimulated excessive vegetative growth, whereas unpruned trees exhibited canopy congestion, reduced light penetration, and comparatively lower productivity. In contrast, moderate pruning (50% shoot removal) achieved an optimal balance between vegetative vigor and reproductive development, resulting in the highest fruit yield (14.0 t ha^{-1}), improved fruit size, elevated total soluble solids (15.8 °Brix), enhanced firmness, and higher vitamin C content.

Statistical analysis confirmed that moderate pruning significantly ($p \leq 0.05$) outperformed both light and severe pruning treatments across most growth, yield, and quality parameters. Therefore, under temperate conditions similar to

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those of District Bajaur, 50% shoot removal during dormant pruning is recommended as an effective canopy management strategy to maximize productivity and fruit quality in *Prunus domestica* L. Further multi-season trials are suggested to validate these findings across different cultivars and environmental conditions for broader regional recommendations.

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