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Impact of Crop Load on Growth, Flowering and Fruiting in Apple cv. Gala Redlum

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Authors' contributions

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

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ABSTRACT

This study assesses the influence of varying crop loads on growth, return bloom and fruiting traits with a focus on trunk cross-sectional area (TCSA)in High-Density Apple Cultivar Gala Redlum, Study was conducted at the experimental field of the Division of Fruit Science, SKUAST-Kashmir, during 2021-2022.The experiment, organized in a randomized complete block design (RCBD) with three replications, utilized 4-year-old "Gala Redlum" plants. The trees were hand-thinned to 4, 6, 8, 10 fruits per cm2 of TCSA, with a control group undergoing no thinning. Results indicated that the highest values for annual shoot length (36.40 cm), return bloom (111.50 flower clusters/tree), fruit length (68.49 mm), fruit diameter (75.07 mm), and fruit weight (191.62 g) in the C2 treatment (4 fruits per cm2 of TCSA). Following closely, the C3 treatment (6 fruits per cm2 of TCSA) exhibited substantial values for the aforementioned parameters. Furthermore, the S2 treatment (10-12 cm2 TCSA) recorded maximum annual shoot length (30.63 cm), return bloom (64.13 flower clusters/tree), fruit length (61.74 mm), fruit diameter (69.18 mm), and fruit weight (168.16 g). Notably, the combined treatment C2xS2 yielded the highest return bloom (114.00 flower clusters/tree) and fruit characteristics (fruit length, diameter, and weight).

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Keywords: Gala Redlum; hand thinning; trunk cross sectional area; return bloom; yield.

1. INTRODUCTION

The cultivated apple (*Malus x domestica* Borkh.) holds the distinction of being the premier table fruit globally, often referred to as the "King of temperate fruits." Originating in the temperate region of western Asia, between the Black Sea and Caspian Sea, the cultivated apple belongs to the Rosaceae family and is an interspecific hybrid complex of allopolyploid origin, with *Malus sieversii* identified as a progenitor species. A vital temperate fruit in the northwestern Himalayan region, apple cultivation is significant in over 90 countries worldwide, covering 4,717,384 ha and producing 79,139,368 MT annually [1]. In India, it spans 309,000 ha, with Jammu and Kashmir leading in production [2].

Despite being the primary fruit of the Kashmir valley, the productivity of apples in Jammu and Kashmir, at 11 MT/ha, falls short of international benchmarks. Transitioning from low to high-density orcharding, particularly with the introduction of exotic varieties, poses challenges in achieving desired size and quality if not thinned properly. High-density orcharding, coupled with excessive crop load, contributes to biennial bearing, leading to economic losses through reduced fruit size and sporadic yields especially in early years. The reliance on chemical thinning has been prominent, but the need for environmentally acceptable alternatives prompts a focus on precision crop load management, integrating precision pruning, chemical, and hand thinning.

The prevailing industry norm involves chemical thinning during bloom and post-bloom, followed by hand thinning. However, the weather-dependent response to chemical thinning, coupled with varying cultivar sensitivity, underscores the need for environmentally friendly approaches. Crop manipulation methods, such as mechanical thinning, hand flower thinning, and bud extinction during winter, have been explored [3]. The study aims to assess the impact of different crop loads on growth, yield, and physical parameters concerning trunk cross-sectional area in high-density apple cultivar Gala Redlum, considering the significance of effective thinning practices for optimizing fruit quality, marketable size, and addressing alternate bearing. Keeping in view the importance and economic value of thinning the investigation therefore was carried out to study the effect of different crop loads on growth, yield and physical parameters vis-à-vis trunk cross-sectional area in high density apple cv. Gala Redlum.

2. MATERIALS AND METHODS

The experiment was conducted on four-year-old Gala Redlum apple trees grafted onto M-9 rootstock at the experimental farm of the Division of Fruit Science, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar campus, during year 2021-22. Adhering to recommended package practices, including fertilizer application, fertigation, and irrigation, the trial aimed to assess the impact of two key factors: hand thinning and (TCSA). RCBD with three replications was employed for the factorial experiment. The factorial design incorporated various combinations of hand thinning and TCSA as distinct treatment factors. The meticulous application of recommended horticultural practices ensured the experiment's precision and reliability. The experiment involved crop loads of 4, 6, 8, 10 fruits per cm^2 of TCSA, labeled as C2, C3, C4 and C5 respectively, with a non-thinned control group as C1.The orchard trees were categorized into two groups labeled as S1 (8-10 cm^2 TCSA) and S2 (10-12 cm^2 TCSA) based on trunk cross-sectional area measurements. The Trunk Cross-sectional Area was determined as per Westwood [4]:

Trunk Cross sectional Area (TCSA) in cm^2=[Trunk girth of scion (cm)]^2/3.14.

Return Bloom was assessed during the month of April in the subsequent year, with a comprehensive evaluation of return bloom was conducted by quantifying the total number of flower clusters per tree at full bloom. This meticulous count provides valuable insights into the regenerative capacity of the apple trees, indicating the potential for subsequent flowering and fruiting. Plant Height (m) was measured from base to terminal growth point. Annual shoot length (cm) was determined by recording the growth of the current season of the four selected branches on four sides and the mean increment growth was calculated. Fruit length of fifteen fruits per tree was measured with the help of a digital verniercalliper and average fruit length was expressed in millimetres (mm). Fruit diameter of fifteen fruits per tree was measured with the help of a digital vernier calliper and average diameter was expressed in millimetres (mm). Length: Diameter ratio was calculated by dividing length by respective diameter of fruit sample. Fruit weight from different treatments was weighed individually on a sensitive monopan balance and the average fruit weight was recorded in grams (g) per fruit. The assessment of all the key parameters in the study is grounded in scientific rigor.

3. RESULTS AND DISCUSSION

3.1 Plant Height (m)

The impact of crop load on plant height in apple cultivar Gala Redlum was assessed and presented in Table 1. Notably, the results indicate that crop load does not exert a significant influence on plant height (Table 1). However, plant height does exhibit a significant correlation withTCSA. The highest plant height (3.27 m) was observed in S2 (10-12 cm^2 TCSA), while the lowest (2.86 m) was recorded in S1 (8-10 cm^2 TCSA).

The table further, illustrates that the interaction effect of crop load and CSA on plant height was non-significant. These findings align with the research conducted by Serra [5], who similarly reported that plant height remained unaffected by variations in crop load.

The examination of plant height (in meters) further revealed a significant association with trunk cross-sectional area (TCSA). Specifically, the maximum plant height was observed under S2 (10-12 cm^2 TCSA), whereas the minimum was recorded under S1 (8-10 cm^{2}TCSA). This correlation suggests that an increase in plant height corresponds to an increase in trunk cross-sectional area (TCSA). The rationale behind this phenomenon may be attributed to the direct relationship between TCSA and the transport of nutrients from the root to various parts of the plant. Additionally, TCSA influences the distribution of food materials from the production site to the utilization site, thereby impacting vegetative growth [6]. These outcomes align with the findings of Srivastava et al. [7] who reported a positive correlation between plant height and TCSA.

While crop load does not appear to significantly affect plant height in the studied apple cultivar Gala Redlum, trunk cross-sectional area emerges as a crucial factor influencing plant height. The positive correlation between plant height and TCSA underscores the importance of nutrient transport and food material distribution in shaping vegetative growth.

3.2 Annual Shoot Length (cm):

Table 2 presents the findings on annual shoot length, indicating that both crop load and trunk cross-sectional area significantly influence this parameter. The highest annual shoot length, measuring 36.40 cm, was observed in C2 (4 fruits per cm^2 of TCSA), followed by C3 (6 fruits per cm^2 of TCSA) with an annual shoot length of 32.98 cm. Conversely, the control group (no thinning) exhibited the minimum annual shoot length at 23.49 cm. Additionally, annual shoot length was significantly affected by different trunk cross-sectional areas, with S2 (10-12 cm^2 TCSA) producing the maximum annual shoot length at 30.63 cm, and S1 (8-10 cm^{2}TCSA) resulting in the minimum at 30.10 cm.

Table 1. Effect of crop load on plant height (m) in apple cv. Gala Redlum

Crop Load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	**S2 (10-12 cm^{2}TCSA)**	
C1 (No thinning)	2.82	3.27	3.04
C2 (4 fruits per cm^2 of TCSA)	2.91	3.34	3.12
C3 (6 fruits per cm^2 of TCSA)	2.95	3.28	3.11
C4 (8 fruits per cm^2 of TCSA)	2.81	3.26	3.03
C5 (10 fruits per cm^2 of TCSA)	2.85	3.21	3.01
Mean	2.86	3.27	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.1239
Crop load (C) = N.S (S×C) = N.S

Table 2. Effect of crop load on annual shoot length (cm) in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	**S2 (10-12 cm^2 TCSA)**	
C_1 (No thinning)	23.15	23.84	23.49
C_2 (4 fruits per cm^2 of TCSA)	36.15	36.66	36.40
C_3 (6 fruits per cm^2 of TCSA)	32.86	33.11	32.98
C_4 (8 fruits per cm^2 of TCSA)	31.32	31.53	31.42
C_5 (10 fruits per cm^2 of TCSA)	27.04	28.03	27.54
Mean	30.10	30.63	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.017
Crop load (C) = 0.027 (S×C) = 0.038

It is evident that the interaction effect of crop load and TCSA) on annual shoot length was significant. The C2xS2 treatment combination yielded the maximum annual shoot length at 36.66 cm, followed by C2xS1 with an annual shoot length of 36.15 cm. In contrast, the minimum annual shoot length of 23.15 cm was recorded in the C1xS1 treatment combination.

The observed increase in annual shoot length with an increase in trunk cross-sectional area (TCSA) is consistent with the idea that TCSA is directly linked to nutrient transport from the root to different parts of the plant, as well as the distribution of food materials from the site of production to the site of utilization [6]. This relationship ultimately influences annual shoot length. These results align with the findings of Srivastava et al. [8], supporting the notion that annual shoot length tends to increase with an augmentation of TCSA.

The study underscores the significant roles played by both crop load and trunk cross-sectional area in shaping annual shoot length in the studied apple cultivar. The interaction effect further emphasizes the need for a nuanced understanding of these factors for effective orchard management practices, aligning with the broader goal of optimizing tree growth and productivity.

3.3 Return Bloom (Number of flower clusters per tree)

Table 3 presents the significant impact of both crop load and trunk cross-sectional area on return bloom. The data reveals that C2 (4 fruits per cm^2 of TCSA) exhibits the highest return bloom, recording 111.50 flower clusters per tree, followed closely by C3 (6 fruits per cm^2 of TCSA) with 88.16 flower clusters per tree. In contrast, the control group (no thinning) shows the lowest return bloom at 12.16 flower clusters per tree. Furthermore, return bloom is significantly influenced by varying trunk cross-sectional areas, with S2 (10-12 cm^2 TCSA) yielding the maximum at 64.13 flower clusters per tree, and S1 (8-10 cm^2 TCSA) resulting in the minimum at 60.66 flower clusters per tree.

The analysis of the interaction effect between crop load and TCSA on return bloom indicates a non-significant impact. However, specific treatment combinations do exhibit distinct effects. The C2xS2 treatment combination records the highest return bloom 114.00 flower clusters per tree, followed by C2xS1 with 109.00 flower clusters per tree. Conversely, the minimum return bloom of 10.33 flower clusters per tree is observed in the C1xS1 treatment combination.

The observed increase in return bloom with an increase in TCSA can be attributed to the direct relationship between TCSA and the transport of nutrients from the root to various parts of the plant. Additionally, TCSA influences the distribution of food materials from the production site to the utilization site [6]. This, in turn, ultimately impacts return bloom. These findings underscore the importance of understanding the physiological mechanisms associated with trunk cross-sectional area in influencing the flowering patterns of apple trees.

The results highlight the significant roles of both crop load and trunk cross-sectional area in shaping return bloom in the studied apple cultivar. The intricate relationship between these factors emphasizes the need for a holistic understanding of orchard management practices to optimize flowering and, consequently, fruit production.

3.4 Fruit Length (mm)

Table 4 presents the significant impact of both crop load and trunk cross-sectional area on fruit length in the studied apple cultivar. The data reveals that C2 (4 fruits per cm^2 of TCSA) exhibits the maximum fruit length, recording 68.49 mm, followed closely by C3 (6 fruits per cm^2 of TCSA) with a fruit length of 65.37 mm. In contrast, the control group (no thinning) shows the minimum fruit length at 52.31 mm. Additionally, there is a significant difference in fruit length across different trunk cross-sectional areas, with S2 (10-12 cm^2 TCSA) producing the maximum fruit length at 61.74 mm, and S1 (8-10 cm^2 TCSA) resulting in the minimum at 59.88 mm.

The significant impact of both crop load and trunk cross-sectional area on fruit length, highlights the importance of these factors in determining the size and morphology of the fruit. The observed variation in fruit length can be attributed to the direct impact of crop load on the resources available for fruit development, as well as the role of trunk cross-sectional area in nutrient transport and distribution within the tree.

Results of the interaction studies regarding different crop loads and trunk cross-sectional areas (TCSA) with respect to fruit length were found to be significant. The data indicates that the C2xS2 treatment combination resulted in the maximum fruit length (69.12 mm). This was followed closely by the C2xS1 treatment combination with a fruit length of 67.87 mm. In contrast, the minimum fruit length of 50.31 mm was recorded in the C1xS1 treatment combination.

Understanding the interaction effects between crop load and trunk cross-sectional area is essential for devising effective orchard management strategies aimed at achieving desirable fruit characteristics. The identified treatment combinations with optimal fruit length can guide future cultivation practices for maximizing fruit quality and overall orchard yield.

3.5 Fruit Diameter (mm)

Results from Table 5 demonstrate the significant impact of both crop load and trunk cross-sectional area (TCSA) on fruit diameter in the studied apple cultivar. The maximum fruit diameter of 75.07 mm was observed in C2 (4 fruits per cm^2 of TCSA), followed by 72.13 mm in C3 (6 fruits per cm^2 of TCSA), while the minimum diameter of 60.98 mm was recorded in the control group (no thinning). Similarly, different trunk cross-sectional areas significantly influenced fruit diameter, with S2 (10-12 cm^2 TCSA) yielding the maximum diameter of 69.18 mm and S1 (8-10 cm2 TCSA) resulting in the minimum at 67.62 mm.

Importantly, the interaction effect of crop load and trunk cross-sectional area on fruit diameter was found to be significant. The C2xS2 treatment combination resulted in the maximum fruit diameter of 75.70 mm, followed by 74.45 mm in the C2xS1 treatment combination. Conversely, the minimum fruit diameter of 59.31 mm was recorded in the C1xS1 treatment combination. These results emphasize the need to consider both crop load and trunk cross-sectional area in orchard management to optimize fruit diameter. The identified treatment combinations with optimal fruit diameter can guide cultivation practices for enhancing fruit quality and overall orchard yield.

3.6 Length: Diameter Ratio

The data presented in Table 6 on the length-to-diameter ratio of fruits, indicates the significant influence of both crop load and (TCSA). The maximum length-to-diameter ratio (0.912) was observed in C2 (4 fruits per cm^2 of TCSA), while the minimum ratio (0.858) was recorded in the control group (no thinning). Additionally, different trunk cross-sectional areas significantly affected the length-to-diameter ratio, with S2 (10-12 cm^2 TCSA) showing the maximum ratio of 0.891, and S1 (8-10 cm^2 TCSA) resulting in the minimum at 0.883.

The interaction studies reveal significant effects of different crop loads and TCSA on the length-to-diameter ratio. The C2xS2 treatment combination displayed the maximum ratio (0.913), followed by 0.912 in the C2xS1 treatment combination. In contrast, the minimum ratio (0.848) was recorded in the C1xS1 treatment combination.

These findings highlight the importance of considering both crop load and trunk cross-sectional area in orchard management to optimize the length-to-diameter ratio of fruits. The identified treatment combinations with optimal ratios can guide cultivation practices for enhancing fruit quality and overall orchard yield.

3.7 Fruit Weight (g)

Significant impact of both crop load and trunk cross-sectional area was observed on fruit weight in the studied apple cultivar. Maximum fruit weight (191.62 g) was observed in C2 (4 fruits per cm2 of TCSA), followed by 180.78 g in C3 (6 fruits per cm^2 of TCSA), while the minimum weight (137.14 g) was recorded in the control group (no thinning). Different trunk cross-sectional areas also significantly influenced fruit weight, with S2 (10-12 cm^2 TCSA) yielding the maximum weight of 168.16 g, and S1 (8-10 cm^2 TCSA) resulting in the minimum at 165.78 g.

Table 3. Effect of crop load on return bloom (number of flower clusters per tree) in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	S2 (10-12 cm^2 TCSA)	
C_1 (No thinning)	10.33	14.00	12.16
C_2 (4 fruits per cm^2 of TCSA)	109.00	114.00	111.50
C_3 (6 fruits per cm^2 of TCSA)	87.33	89.00	88.16
C_4 (8 fruits per cm^2 of TCSA)	72.00	75.66	73.83
C_5 (10 fruits per cm^2 of TCSA)	24.66	28.00	26.33
Mean	60.66	64.13	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.98
Crop load (C) = 1.56 (S×C) = N.S

Table 4. Effect of crop load on fruit length (mm) in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	S2 (10-12 cm^2 TCSA)	
C_1 (No thinning)	50.31	54.31	52.31
C_2 (4 fruits per cm^2 of TCSA)	67.87	69.12	68.49
C_3 (6 fruits per cm^2 of TCSA)	64.36	66.39	65.37
C_4 (8 fruits per cm^2 of TCSA)	62.54	63.48	63.01
C_5 (10 fruits per cm^2 of TCSA)	54.31	55.42	54.86
Mean	59.88	61.74	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.327
Crop load (C) = 0.516 (S×C) = 0.730

Table 5. Effect of crop load on fruit diameter (mm) in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	S2 (10-12 cm^2 TCSA)	
C_1 (No thinning)	59.31	62.64	60.98
C_2 (4 fruits per cm^2 of TCSA)	74.45	75.70	75.07
C_3 (6 fruits per cm^2 of TCSA)	71.12	73.15	72.13
C_4 (8 fruits per cm^2 of TCSA)	69.57	70.27	69.92
C_5 (10 fruits per cm^2 of TCSA)	63.66	64.14	63.90
Mean	67.62	69.18	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.134
Crop load (C) = 0.212 (S×C) = 0.299

Table 6. Effect of crop load on Length: Diameter ratio in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	**S2 (10-12 cm^2 TCSA)**	
C_1 (No thinning)	0.848	0.867	0.858
C_2 (4 fruits per cm^2 of TCSA)	0.912	0.913	0.912
C_3 (6 fruits per cm^2 of TCSA)	0.905	0.908	0.906
C_4 (8 fruits per cm^2 of TCSA)	0.899	0.903	0.901
C_5 (10 fruits per cm^2 of TCSA)	0.853	0.864	0.859
Mean	0.883	0.891	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.005
Crop load (C) = 0.008 (S×C) = 0.011

Table 7. Effect of crop load on fruit weight ratio in apple cv. Gala Redlum

Crop load	TCSA		Mean
	S1 (8-10 cm^2 TCSA)	**S2 (10-12 cm^2 TCSA)**	
C_1 (No thinning)	136.09	138.19	137.14
C_2 (4 fruits per cm^2 of TCSA)	190.36	192.89	191.62
C_3 (6 fruits per cm^2 of TCSA)	179.07	182.49	180.78
C_4 (8 fruits per cm^2 of TCSA)	171.33	172.19	171.76
C_5 (10 fruits per cm^2 of TCSA)	152.08	155.05	153.56
Mean	165.78	168.16	

C.D (p≤0.05)
Trunk cross sectional area (S) = 0.48
Crop load (C) = 0.76 (S×C) = 1.08

The interaction effect of crop load and trunk cross-sectional area on fruit weight was found to be significant. The C2xS2 treatment combination resulted in the maximum fruit weight (192.89 g), followed by 190.36 g in the C2xS1 treatment combination. In contrast, the minimum fruit weight (136.09 g) was recorded in the C1xS1 treatment combination.

Thinning, as evidenced by the increase in fruit size and weight, is attributed to factors such as a reduced number of fruits per tree, an increased leaf to fruit ratio, enhanced availability of photosynthates, and decreased nutritional competition among developing fruits. This leads to greater translocation of assimilates to the remaining fruits, resulting in increased size and weight. These findings align with prior research, including Henriod et al. [9], Link [10], Knight [11], Koike and Ono [12], and Serra [5], who similarly reported the positive impact of thinning on fruit size and weight.

4. CONCLUSION

In conclusion, the study underscores the significance of thinning, particularly in high-density orchards, for achieving both quality yield in the current year and satisfactory return bloom in the following year for the "Gala Redlum" apple cultivar. Moreover, the data suggests that maintaining an optimal fruit quality and consistent bloom is achievable at a crop load threshold of around 4 fruits per cm^2 of TCSA followed by 6 fruits per cm^2 of TCSA.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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