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Effect of Fruitlet Thinning on Apple Production and Quality under High Density Plantation

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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, conducted within the Experimental Block of the Division of Fruit Science at SKUAST-K, Shalimar, India, was aimed to thin 5-year-old Fuji Zehn Aztec apple plants. The research was carried out during the years 2020 and 2021and implemented a Randomized Complete Block Design with 11 treatments, including control and various other thinning methods. Chemical and hand thinning were practised at the 12 mm king fruitlet diameter stage. Among the treatments, T_9 (NAA+BA@15+140ppm) demonstrated significant results, with the highest trunk girth increment (0.41 cm), annual shoot extension growth (65.46 cm), leaf area (34.71 cm^2), fruit drop (39.26%), and the least reduction in return bloom (52.22%). Additionally, T_9 resulted in maximum fruit length (79.98 mm), fruit diameter (89.00 mm), fruit weight (224.90 g), fruit volume (197.86 cm^3), Soluble Solid concentration (15.87%), SSC : acidity (40.08), total sugar content (11.07%), anthocyanin content (7.14 mg/100g), ascorbic acid content (6.94 mg/100g), and received the highest

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organoleptic rating score (4.87). However, the highest yield (21.97 kg/tree), yield efficiency (1.50 kg/cm^2), fruit firmness (8.36 kg/cm2), hue angle (68.57°), and acidity (0.59%) were recorded in the control group. Notably, T_1 (Hand thinning @ 2 fruitlets retained per cluster) achieved the highest fruit retention (97.97%) and the maximum leaf-to-fruit ratio (27.50). These findings shed light on the potential benefits and trade-offs associated with different fruitlet thinning methods in high-density apple plantations. Understanding these effects can aid orchard management practices to optimize both production and fruit quality.

Keywords: Apple; hand thinning; chemicals; yield; quality; return bloom.

1. INTRODUCTION

The apple, often addressed as the "King of Temperate Fruits," holds an essential role in the agricultural landscape of Jammu and Kashmir, boasting a notable productivity of 11.43 MT/ha—an achievement that eclipses other apple-producing states in the country [1]. However, this achievement remains considerably below the standards set by horticulturally advanced countries. The region's struggle with low apple productivity is attributable to a range of factors, encompassing aging orchards, sparse planting densities, a lack of high-quality planting material, limited access to irrigation resources, and sharp susceptibility to the vagaries of insect pests and diseases [2]. Moreover, the biennial bearing phenomenon exhibited by commercial apple cultivars negatively affects the region's economic prospects.

In the realm of apple cultivation, “THINNING” emerges as a crucial horticultural practice employed to orchestrate fruit set, optimize fruit quality, and enhance overall yield and includes the judicious removal of emerging fruitlets from apple trees, thereby alleviating competition for vital resources and fostering the well-being of both the tree and the remaining fruits.

The introduction of chemical thinners, specifically 1-Napthaleneacetic acid (NAA) and synthetic cytokinin 6-Benzyladenine (6-BA), has emerged as a game-changer in the endeavor to maximize apple yield [3]. NAA, when applied as a thinner, catalyzes the synthesis of ethylene within fruitlet tissue, triggering fruitlet abscissionand effectively reduces the overall fruit load. Additionally, NAA causes a hormonal shift within the fruit by suppressing auxin synthesis. This suppression of auxin hampers seed development and curtails the fruit's carbohydrate requirements, resulting in fruit abortion—an outcome where some developing fruits fail to reach full maturity and are consequently shed from the tree [4-8].

6-BA, on the other hand, encourages the vigorous growth of shoots within the apple tree, thereby inciting competition for essential resources, including carbohydrates, among the shoots and developing fruits. This increase in the competition can limit the availability of energy and nutrients for the developing fruits. Consequently, some fruits are naturally shed from the tree through fruit abscission—a process that effectively lightens the overall fruit load, allowing the nutrient and resource flow to the remaining fruits [9,10]

Achieving uniformity in yield and consistent fruit production year after year through strategic thinning is indispensable for sustainable apple cultivation. Fuji apple trees, known for their moderate to strong alternate bearing behavior, exemplify the cyclic pattern of biennial bearing, hence yielding a profusion of fruits in "on" years and significantly fewer fruits or none at all in "off" years [11].

Therefore, this investigation was undertaken with the aim of mitigating the influence of crop load on Fuji Zhen Aztec apple trees through chemical and hand thinning techniques. The aim was hence focused to optimize crop load, enrich fruit quality, and stimulate return bloom in the succeeding season.

2. MATERIALS AND METHODOLOGY

The study was conducted to investigate the influence of thinning on both the qualitative and quantitative attributes of the Fuji Zehn Aztec apple cultivar, of uniform girth raised on M9-T337 rootstock and trained over Tall Spindle System Employing a Randomized Complete Block Design over the 1×3m spaced Fuji plants, the experiment incorporated three replications and included the following treatments: T_0 (Control), T_1 (Hand thinning @ 2 fruitlets/cluster), T_2 (Hand thinning @ 3 fruitlets/cluster), T_3 (Napthalene acetic acid @ 15 ppm), T_4 (Napthalene acetic acid @ 20 ppm), T_5 (Benzyl adenine @ 120 ppm), T_6 (Benzyl adenine @ 140 ppm), T_7 (Napthalene acetic acid + Benzyl adenine @ 15 + 120 ppm), T_8 (Napthalene acetic acid + Benzyl adenine @ 20 + 120 ppm), T_9 (Napthalene acetic acid + Benzyl adenine @ 15 + 140 ppm), and T_{10} (Napthalene acetic acid + Benzyl adenine @ 20 + 140 ppm). The apple plants, of the M9-T337 variety, were trained using the Tall Spindle system, with a spacing of 1 × 3m. Thinning was carried out 20 days after full bloom, specifically at the 10-12mm fruitlet diameter stage, on May 5, 2020. Four branches of uniform girth were tagged from each tree for the collection of diverse observations.

This experimental framework allowed for a comprehensive assessment of the impact of thinning on the chosen apple cultivar's characteristics.

3. RESULTS AND DISCUSSION

Thinning significantly affected the growth, phenology, yield and quality attributes in Fuji Zehn Aztec plants.

3.1 Vegetative Growth

Treatment T_9 (NAA+BA @ 15+140 ppm) exhibited the most substantial increments in plant girth (0.41 cm), annual shoot extension growth (65.46 cm), and leaf area (34.71 cm^2). Conversely, treatment T_0 (control) recorded the least growth increments in plant girth (0.18 cm), annual shoot extension growth (57.19 cm), and leaf area (26.20 cm^2). However, all other treatments displayed significant improvements compared to the control group. The remarkable vegetative growth in treatment T_9 can be attributed to an increased supply of photosynthetic assimilates and nutrients, which, in turn, enhance cell division and cell wall plasticity. This observation aligns with findings by Cripps [12], who noted a reduction in vegetative growth in apple trees due to increased crop load, resulting from heightened competition between reproductive and vegetative growth. Beyá-Marshall and Fichet [13] too have reported a negative effect of crop load on the root and shoot growth of olive trees in “on” year. Anthony et al. [14] also reported that apple trees with lower crop loads exhibited significantly greater vegetative growth compared to trees with heavier crop loads.

3.2 Phenology

Treatment T_1 (Hand thinning @ 2 fruitlets/cluster) exhibited the highest fruit retention (97.97%), while the least fruit retention (60.74%) was observed in treatment T_9 (NAA+BA @ 15+140 ppm). Conversely, the maximum fruit drop (39.26%) occurred in treatment T_9, while the minimum drop (2.03%) was recorded in treatment T_1. These variations in fruit retention and drop can be attributed to thinning frequency, where higher thinning frequency results in lower final fruit retention. Additionally, there is a negative correlation between fruit drop and final fruit retention, as observed in the study. Similar findings were reported by Bhatt [15] in plum cv. "Kala Amritsari," where hand thinning resulted in a lower number of fruit abscission events, possibly due to reduced early-stage competition among fruitlets [16]. It has also been reported by Nartvaranant [17] that 50% fruit thinning by hand one month after fruit set enhances per cent of fruit retention throughout the fruit development.

Return bloom was significantly impacted by the different thinning treatments, with treatment T_9 (NAA+BA @ 15+140 ppm) showing the least percent reduction in bloom density (52.22%), and treatment T_0 (control) exhibiting the highest percent reduction (86.29%). These results align with those of Embree et al. [18], who reported that decreasing crop load in the "on" year promotes the formation of blossom clusters in the "off" year. This could be due to the fact that heavy crop loads in the control group act as nutrient drains, inhibiting flower bud formation. Additionally, Serra et al. [19] noted that with increasing crop load, return bloom decreased in Honeycrisp apple.

In this section, the impact of different thinning treatments on yield attributes is discussed:

3.3 Yield Attributes

The various thinning treatments resulted in a significant reduction in both fruit yield and yield efficiency when compared to the control group. Treatment T_0 (control) displayed the highest fruit yield (21.97 kg/tree) and yield efficiency (1.50 kg cm^2), while treatment T_9 (NAA+BA @ 15+140 ppm) recorded the lowest fruit yield (19.42 kg/tree) and yield efficiency (0.96 kg cm^2). All other treatments yielded significantly less than the control. This reduction in yield can be attributed to the abscission of fruitlets induced by the application of NAA and BA. Since yield is primarily determined by fruit number [20], the decrease in fruit number resulting from thinning treatments led to the observed reduction in yield. These findings align with the results of Clever [21], who reported a significant yield reduction in apple cv. "Elstar Elshof" with the application of NAA 10 ppm + BA 100 ppm. Koike and Ono [22] also documented a decrease in yield due to thinning.

3.4 Physico-Chemical Parameters

Treatment T9 (NAA+BA @ 15+140 ppm) yielded the highest values for various physico-chemical parameters, including fruit length (79.98 mm), fruit breadth (89.00 mm), length-to-breadth ratio (0.90), fruit weight (224.90 g), fruit volume (197.86 cm^3), and specific gravity (1.13 g/cm^3). Conversely, treatment T0 (control) showed the lowest values for fruit length (70.52 mm), fruit breadth (81.12 mm), length-to-breadth ratio (0.87), fruit weight (188.35 g), fruit volume (187.50 cm^3), and specific gravity (1.00 g/cm^3). This increase in these parameters can be attributed to reduced fruitlet competition, resulting from the earlier abscission caused by the enhanced thinning action of NAA and BA. As a result, there is a significant increase in nutrient supply during the early fruit development stage, driven by an increased rate of photosynthesis due to reduced crop load, a higher leaf-to-fruit ratio, and greater availability and supply of photosynthesis to the remaining fruitlets [23]. These results are consistent with the findings of Radivojevic et al. [24], who reported that fruit size in apple cv. "Braeburn" was significantly affected by crop load.

The maximum leaf-to-fruit ratio (27.50) was documented under treatment T_1 (Hand thinning @ 2 fruitlets/cluster), while the minimum ratio (11.00) was recorded in treatment T_0 (control). The increase in leaf-to-fruit ratio was attributed to selective manual thinning, resulting in reduced crop load. Similar results were reported by Anthony et al. [14], who observed that increasing the level of hand thinning led to an increase in leaf-to-fruit ratio in apple cv. "WA38."

The maximum leaf-to-fruit ratio (27.50) was documented under treatment T_1 (Hand thinning @ 2 fruitlets/cluster), while the minimum ratio (11.00) was recorded in treatment T_0 (control). The increase in leaf-to-fruit ratio resulted from selective manual thinning, which reduced the crop load. Similar findings were reported by Anthony et al. [14], who observed an increase in leaf-to-fruit ratio with higher levels of hand thinning in apple cv. "WA38."

Table 1. Effect of different thinning treatments on increment in plant girth (cm), annual shoot extension growth (cm) and leaf area (cm^2) of Fuji Zehn Aztec

Treatment code	Treatment	Increment in plant girth (cm)	Annual shoot extension (cm)	Leaf area (cm^2)
T_0	Control	0.18	57.19	26.20
T_1	Hand thinning @ 2 fruitlets/cluster	0.29	62.25	30.34
T_2	Hand thinning @ 3 fruitlets/cluster	0.27	61.78	28.80
T_3	NAA @ 15 ppm	0.31	62.52	31.24
T_4	NAA @ 20 ppm	0.32	63.25	31.69
T_5	BA @ 120 ppm	0.23	59.14	27.24
T_6	BA @ 140 ppm	0.25	59.44	27.60
T_7	NAA + BA @ 15 + 120 ppm	0.38	64.28	33.68
T_8	NAA + BA @ 20 + 120 ppm	0.37	64.16	33.36
T_9	NAA + BA @ 15 + 140 ppm	0.41	65.46	34.71
T_{10}	NAA + BA @ 20 + 140 ppm	0.34	63.34	32.26
	C.D ($p \leq 0.05$)	**0.026**	**0.016**	**0.030**

Table 2. Effect of different thinning treatments on "fruit retention (%), fruit drop (%) and return bloom (%)" in Fuji Zehn Aztec

Treatment code	Treatment	Fruit retention (%)	Fruit drop (%)	Return bloom (%)
T_0	Control	76.00 (8.777)	24.00 (4.997)	86.29
T_1	Hand thinning @ 2 fruitlets/cluster	97.97 (9.948)	2.03 (1.741)	72.78
T_2	Hand thinning @ 3 fruitlets/cluster	94.51 (9.773)	5.49 (2.548)	75.34
T_3	NAA @ 15 ppm	68.72 (8.350)	31.28 (5.682)	68.23
T_4	NAA @ 20 ppm	67.81 (8.295)	32.19 (5.761)	63.11
T_5	BA @ 120 ppm	71.46 (8.512)	28.54 (5.435)	81.54
T_6	BA @ 140 ppm	70.82 (8.475)	29.18 (5.494)	78.67
T_7	NAA + BA @ 15 + 120 ppm	62.51 (7.969)	37.49 (6.204)	55.29
T_8	NAA + BA @ 20 + 120 ppm	63.38 (8.024)	36.62 (6.134)	57.23
T_9	NAA + BA @ 15 + 140 ppm	60.74 (7.857)	39.26 (6.345)	52.22
T_{10}	NAA + BA @ 20 + 140 ppm	65.77 (8.171)	34.23 (5.935)	59.78
	C.D ($p \leq 0.05$)	**0.002**	**0.003**	**0.253**

**Values within parenthesis are square root transformed values and the C.D. values have been obtained by square root transformation.*

Table 3. Effect of different thinning treatments on fruit yield (kg/tree) and yield efficiency (kg/cm^2) in Fuji Zehn Aztec

Treatment code	Treatment	Yield (kg/tree)	Yield efficiency (kg/cm^2)
T_0	Control	21.97	1.50
T_1	Hand thinning @ 2 fruitlets/cluster	20.35	1.29
T_2	Hand thinning @ 3 fruitlets/cluster	20.50	1.41
T_3	NAA @ 15 ppm	20.00	1.20
T_4	NAA @ 20 ppm	19.98	1.15
T_5	BA @ 120 ppm	21.14	1.45
T_6	BA @ 140 ppm	20.90	1.42
T_7	NAA + BA @ 15 + 120 ppm	19.51	1.07
T_8	NAA + BA @ 20 + 120 ppm	19.63	1.08
T_9	NAA + BA @ 15 + 140 ppm	19.42	0.96
T_{10}	NAA + BA @ 20 + 140 ppm	19.81	1.14
	C.D ($p \leq 0.05$)	**0.029**	**0.046**

Table 4a. Effect of different thinning treatments on fruit length (mm), fruit breadth (mm), length: breadth, fruit weight (g), fruit volume (g/cm^3), leaf: fruit, fruit firmness (kg/cm^2) and fruit colour {hue angle (º)} in Fuji Zehn Aztec

Treatment code	Treatment	Fruit length (mm)	Fruit breadth (mm)	Length: breadth	Fruit weight (g)	Fruit volume (cm^3)	Specific gravity (g/cm^3)	Leaf: fruit	Fruit firmness (kg/cm^2)	Fruit colour [Hue angle (º)]
T_0	Control	70.52	81.12	0.87	188.35	187.50	1.00	11.00	8.36	68.57
T_1	Hand thinning @ 2 fruitlets/cluster	75.85	86.14	0.88	205.07	192.13	1.06	27.50	7.25	61.51
T_2	Hand thinning @ 3 fruitlets/cluster	73.91	84.39	0.87	201.00	191.77	1.04	18.30	7.34	64.28
T_3	NAA @ 15 ppm	76.98	87.27	0.88	210.34	194.39	1.08	16.00	7.12	61.13
T_4	NAA @ 20 ppm	77.47	87.66	0.88	217.53	195.95	1.11	16.22	6.86	61.08
T_5	BA @ 120 ppm	72.58	83.37	0.87	192.83	188.62	1.02	15.39	7.64	65.71
T_6	BA @ 140 ppm	72.91	83.60	0.88	195.28	189.98	1.02	15.40	7.57	65.35
T_7	NAA + BA @ 15 + 120 ppm	78.80	88.80	0.89	221.22	196.25	1.12	17.59	6.67	59.22
T_8	NAA + BA @ 20 + 120 ppm	78.18	88.25	0.89	221.16	196.22	1.12	17.35	6.70	59.28
T_9	NAA + BA @ 15 + 140 ppm	79.98	89.00	0.90	224.90	197.86	1.13	18.11	6.14	57.22
T_{10}	NAA + BA @ 20 + 140 ppm	77.98	88.12	0.88	219.02	196.11	1.11	16.72	6.85	60.54
	C.D ($p \leq 0.05$)	**0.056**	**0.096**	**0.001**	**0.080**	**0.123**	**0.002**	**0.019**	**0.028**	**0.071**

Table 4b. Effect of different thinning treatments on SSC (%), fruit acidity (%), SSC: acidity, Total sugars (%), Anthocyanin content (mg/100g pulp), ascorbic acid content (mg/100g pulp) and organoleptic rating in Fuji Zehn Aztec

Treatment code	Treatment	SSC (%)	Fruit acidity(%)	SSC: acidity	Total sugars (%)	Anthocyanin content (mg/100g pulp)	Ascorbic acid content (mg/100g pulp)	Organoleptic rating
T_0	Control	14.21	0.59	24.08	9.02	5.17	4.12	3.02
T_1	Hand thinning @ 2 fruitlets/cluster	14.78	0.55	26.89	10.19	6.34	5.41	3.45
T_2	Hand thinning @ 3 fruitlets/cluster	14.62	0.55	26.67	9.81	5.70	5.06	3.34
T_3	NAA @ 15 ppm	14.85	0.54	27.50	10.25	6.38	5.81	3.56
T_4	NAA @ 20 ppm	14.92	0.53	28.31	10.36	6.45	6.06	3.64
T_5	BA @ 120 ppm	14.45	0.57	25.39	9.24	5.24	4.73	3.19
T_6	BA @ 140 ppm	14.51	0.56	25.93	9.33	5.25	4.92	3.32
T_7	NAA + BA @ 15 + 120 ppm	15.43	0.45	34.38	10.56	6.63	6.57	4.16
T_8	NAA + BA @ 20 + 120 ppm	15.22	0.47	32.54	10.56	6.62	6.46	4.14
T_9	NAA + BA @ 15 + 140 ppm	15.87	0.40	40.08	11.07	7.14	6.94	4.87
	C.D ($p \leq 0.05$)	**0.026**	**0.026**	**2.316**	**0.030**	**0.024**	**0.060**	**0.057**

Treatment T_0 (control) exhibited maximum fruit firmness (8.36 kg/cm^2) and hue angle (68.57°), while treatment T9 (NAA+BA @ 15+140 ppm) showed the least fruit firmness (6.14 kg/cm^2) and hue angle (57.22°). Larger fruits tend to have softer flesh, likely due to larger cell size [25]. The reduction in fruit firmness may result from larger fruit size, which weakens the cell walls and reduces cohesion between cells [26]. These findings align with Link [27], who reported that well-supplied fruits with carbohydrates exhibit better flavor and color, and fruit thinning can increase surface color in red fruit cultivars. Basak [28] also noted that thinning apple trees with NAA improved fruit color in the Gala apple cultivar.

Maximum SSC (15.87%), SSC/acidity ratio (40.08), total sugar content (11.07%), anthocyanin content (7.14 mg/100g), ascorbic acid content (6.94 mg/100g), and organoleptic rating (4.87 pts) were achieved under treatment T_9 (NAA+BA @ 15+140 ppm), while the minimum SSC (14.21%), SSC/acid ratio (24.08), total sugar content (9.02%), anthocyanin content (5.17 mg/100g), ascorbic acid content (4.12 mg/100g), and organoleptic rating (3.02 pts) were recorded in treatment T_0 (control). Similar results have also been reported by Rettke and Dahlenburg [29] in apricots. Mpelasoka et al. [30] also reported an increase in total soluble solids and total sugars with a decrease in crop load of apple cv. "Braeburn." The increase in total soluble solids and total sugars can be attributed to the reduced crop load, leading to an increased leaf-to-fruit ratio, which in turn enhances the synthesis, transport, and accumulation of sugars in the remaining fruits, resulting in higher total soluble solids and sugar content.

The increase in SSC: acidity ratio may be due to an increase in SSC and a decrease in acidity. These results are consistent with the findings of Samra and Shalan [31]. The findings are also in agreement with Rupasinghe et al. [32], who reported that sugar accumulation in apples is required for anthocyanin synthesis, as UDP glycosides are direct substrates for cyanidin 3-glycosides, which are pigments in apple peel and flesh. The increase in ascorbic acid might be due to the lower rate of conversion of ascorbic acid to dehydro-ascorbic acid and the increased SSC. Meitei et al. [33] observed a similar increase in ascorbic acid by using chemical thinners on Peach cultivar Flordasun. These findings are also in line with the results of Naor et al. [34], who found that as crop load increased, the overall sensory evaluation quality decreased in Sauvignon Blanc grapes.

However, the highest titratable acidity (0.59%) was recorded under treatment T_0 (control), and the lowest titratable acidity (0.40%) was noticed under treatment T_9 (NAA+BA @ 15+140 ppm). The reduction in acidity under chemical thinning treatments may be due to the conversion of organic acids into sugar and the dilution effect resulting from increased fruit size, which leads to changes in the quality attributes. These results are consistent with the findings of Roussos et al. [35], who reported a similar decrease in titratable acidity in apricots.

4. CONCLUSION

The study demonstrates that treatment T9 (NAA+BA @ 15+140 ppm), applied twenty days after full bloom, effectively regulated crop load in Fuji Zehn Aztec apple plants, resulting in improved fruit quality and enhanced return bloom. This finding suggests the potential for optimizing apple production through careful thinning practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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