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Effect of Fruit Thinning on the Yield and Quality of Red Delicious Apples

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ABSTRACT

Fruit thinning is an important orchard management practice that improves fruit quality by regulating crop load. This study investigated the effects of different hand-thinning levels on the yield and quality of Red Delicious apple (*Malus domestica Borkh.*) in Wardak Province, Afghanistan. Five treatments were evaluated, including one, two, three, and four fruits per spur, and a control with five fruits per spur, using a randomized complete block design with six replications. Fruit weight, length, diameter, firmness, color, total soluble solids (TSS), titratable acidity (TA), sugar-to-acid ratio, pH, total yield, and non-marketable yield were measured. Fruit thinning significantly increased fruit weight, length, diameter, firmness, TSS, sugar-to-acid ratio, and fruit color, while reducing total yield and non-marketable yield. The highest values for most quality attributes were obtained when one fruit per spur was retained; however, this treatment substantially reduced total yield. In contrast, the control treatment produced the highest yield but lower fruit quality. Fruit thinning had no significant effect on fruit length-to-diameter ratio, titratable acidity, or pH. The results indicate a clear trade-off between fruit quality and yield under different crop loads. Among the tested treatments, retaining two fruits per spur provided the most favorable balance between improved fruit quality and acceptable yield. Therefore, hand thinning to two fruits per spur is recommended as an effective crop load management strategy for optimizing both yield and fruit quality in commercial Red Delicious apple orchards.

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INTRODUCTION

Fruit thinning is the process of removing excess flowers or fruits from the fruit tree to improve growth and achieve the desired quality of the remaining fruits. This process directly affects both the quantity and quality of the yield. The main goal of thinning is to eliminate smaller or excess fruits from the fruit trees, thereby increasing the size and quality of the remaining fruits (Dennis, 2000; Racskó, 2006; Samuolienė et al., 2016; Verma et al., 2023; Wang et al., 2025; Yuri et al., 2011). Excessive fruit on the fruit tree reduces the size and quality of the apples, which can be managed effectively through thinning (Kwon et al., 2019; Wertheim, 2000)

Apple thinning can be carried out at different times, such as during full bloom or fruit thinning (typically 30 to 40 days after full bloom), when the fruit diameter generally ranges from 3 to 18 millimeters (Kaçal et al., 2019). Early thinning, especially before the completion of cell division, is essential for producing high-quality fruits and higher yields (Sidhu et al., 2022; Solomakhin & Blanke, 2010).

Fruit firmness depends on both the number and size of cells in the cortex. A lower number of larger cells results in softer fruits, while a higher number of smaller cells leads to firmer fruits. Therefore, early thinning during the initial or peak stages of cell division results in a greater increase in cell numbers compared to late thinning, ultimately leading to firmer fruits (Bound, 2023).

Hand thinning or chemical thinning helps maintain the physiological balance between vegetative growth and fruit production, thereby increasing both the quantity and quality of the fruit (Breen et al., 2015; Ilie et al., 2016). Apple fruit trees frequently produce a large number of flowers that develop into fruit, so producers should aim to reduce the number of fruits on the tree to increase individual fruit weight (Sidhu et al., 2022; Treder, 2008).

In apple fruit trees, hand thinning can be performed with precision and is considered reliable; however, it is labor-intensive and requires skilled, experienced workers (Schmidt et al., 2011; Sidhu et al., 2022). The scientific name of apple is (*Malus domestica Borkh*). It belongs to the Rosaceae family. It is cultivated in most of the cold regions of Afghanistan (Meland, 2009 Scalisi et al., 2024). The Red Delicious apple tree originated in 1872 in the garden of Jesse Hiatt in Iowa, USA. Today, this is a very important apple variety in the United States and is also known as "Red Delicious" in other countries as well (Noiton & Alspach, 1996).

This is a standard fruit tree, moderately vigorous, with an upright growth habit and slightly spreading, somewhat open branches. It bears fruit moderately early and produces yields regularly. The spur-type tree grows upward and requires branch-spreading tools(Atkinson, 2004). The Red Delicious apple, especially the spur-type, is not self-pollinating and requires a pollinator for fruit set. The Red Delicious variety requires a medium to high chilling hours. Its chilling requirement ranges from 600 to 800 hours, while for some others it may be as high as 1200 to 1300 hours (Akbari et al., 2016; Sassa et al., 1996).

The climatic and natural conditions in Afghanistan are quite favorable for apple cultivation and production. A few years ago, Kabul apples were very famous, but unfortunately, many of those orchards have been largely destroyed (Akbari et al., 2016; Shirzad & Samadi, 2018). In some areas of Afghanistan, such as Wardak, Kabul, Logar, Ghazni, Bamyan, Baghlan, Ghor, Takhar, and Badakhshan, apples are grown commercially, and people have paid more attention to establishing apple orchards. In these areas they are a major source of income for farmers. Apples are still consumed only in fresh form in the country(Wardak et al., 2024).

Apples are one of the most important fruits in the world. They are rich in vitamins, especially Vitamin C, and help improve health by supporting the immune system and digestion. Apples are widely grown in many countries and are used in various foods and drinks. They are a major source of income for farmers. They are used in a variety of processed forms, such as canned goods, jams, juices, pies, and many others (Boyer & Liu, 2004).

The objective of this study is to determine the effects of fruit thinning on Red Delicious apple quantity and quality. The significance of this study is that apples are a major commercial crop in Afghanistan, yet the lack of scientific fruit thinning results in poor fruit quality. Proper thinning improves fruit size, color, taste, and firmness. It also promotes scientific orchard management and strengthens the export potential of Afghan apples, contributing to the national Economy.

METHODS AND MATERIALS

This study was conducted using a Randomized Complete Block Design (RCBD) with five treatments and six replications. Six healthy and uniform Red Delicious apple trees were randomly selected as experimental units. Each tree represented one replication. Five fruit-thinning treatments were evaluated: one fruit per spur (T1), two fruits per spur (T2), three fruits per spur (T3), four fruits per spur (T4), and a control treatment (T5) with five fruits per spur and no thinning.

On each selected tree, ten similar branches were chosen and labeled. Two branches were assigned to each treatment, resulting in five treatments per tree. Hand thinning was carried out after fruit set by removing excess fruits and retaining the specified number per spur, as specified by the treatment. The treatments were randomly allocated to the selected branches within each tree. Data on fruit yield and quality characteristics were collected from the treated branches and analyzed statistically according to the procedures appropriate for the RCBD

Experimental site

This research was conducted in 2024 at a private apple orchard in Sadokhil village, Daimirdad district, Wardak province, at a latitude of 34.232914° and a longitude of 68.468712°. The apple fruit trees in this study were planted with a spacing of 4×5 meters and were 16 years old. They were grown in sandy loam soil with a depth of 3 meters, which is considered fertile and suitable for cultivation. The orchard was irrigated using a flood irrigation system. Additionally, alfalfa (Lucerne) was grown as an intercrop in the orchard, and the area around each tree was plowed to a diameter of 180 cm.

Fruit Thinning

Fruit thinning in the experimental trees was done 40 days after full flowering, on June 1, when the fruit size was between that of a cherry and a walnut.

Land Preparation

In early spring, the area around the experimental trees and the entire orchard was cultivated, and weeds were removed. In this orchard, Lucerne was cultivated as an intercrop.

Application of Fertilizer

Around each tree, 28 kg of animal manure was applied and mixed into the soil with a plow. The first application of 800 grams of nitrogen fertilizer per tree was done immediately after thinning. The second urea fertilizer application (400 g per tree) was applied during August–September.

Harvesting

The apples were harvested on October 12, 2024; all the fruits from the orchard were harvested at once using manual hand picking.

Data Collection

Measurements were taken; fruit length and diameter were measured in millimeters using a digital Tolsen digital Vernier caliper, weight was measured in grams using a digital scale, total yield of the tree, non-marketable yield was measured in kilograms using a digital scale, and fruit color was assessed using an apple color chart. The samples were then sent to the Horticulture Department laboratory at the Faculty of Agriculture, Kabul University, for analysis of sugar content, firmness, pH, and acidity.

The fruit quality assessment included measurement of fruit color, firmness, total soluble solids (TSS), and titratable acidity (TA).

Fruit color was assessed using a color chart that rates fruit color from 1 to 5. Fruit firmness of the fleshy part was measured in kilograms using a Fruit Pressure Tester (FT-327) with an 11 mm plunger with a pressure range of 0–13 kg. A hand refractometer was used to determine the Total Soluble Solids (TSS) of fruits and expressed in degrees Brix (°Brix). For Titratable Acidity (TA) analysis in the laboratory: A 0.1N sodium hydroxide solution was prepared and placed in a burette. Five (5) milliliters of the actual fruit juice were taken and diluted with distilled water to a final volume of 50 milliliters. From the prepared 50 mL diluted solution, 10 mL was transferred to a flask, and 2–3 drops of the phenolphthalein solution were added. The sodium hydroxide solution was then added drop by drop until the color changed to pink; the titer volume was recorded and used to calculate the acidity.

Data Analysis

The data collected from various parameters in the experiment were compiled and analyzed statistically using the analysis of variance (ANOVA) technique. The analysis was performed using the computer software Statistical Tools for Agricultural Research (STAR). Differences between pairs of means were compared using the Least Significant Difference (LSD) method.

FINDINGS

Fruit thinning significantly increased fruit weight, length, diameter, flesh firmness, total soluble solids content, the ratio of soluble solids to acidity, and fruit color. Fruit thinning also reduced total yield and the amount of unmarketable produce, thereby improving overall fruit quality. However, fruit thinning had no significant effect on the fruit length/diameter ratio, titratable acidity, and pH.

Effect of Fruit Thinning on Fruit Weight

In fruit trees, reducing the number of fruits per spur increases individual fruit weight, whereas increasing the number of fruits decreases fruit weight. The effect of fruit thinning on fruit weight shows that different thinning levels had a significant impact on fruit weight. The maximum weight of the fruit was 213.76 g in the first treatment, and the minimum weight was 120.67 g in the control.

***Table 1**. Effect of Fruit Thinning on Fruit Weight of Red Delicious Apple*

Treatment	fruit weight Average (gr)
T1 (One fruit/spur)	213.76 a
T2 (Two fruits/spur)	163.36 b
T3 (Three fruits/spur)	151.76 b
T4 (Four fruits/spur)	139.31 bc
T5(Control)	120.67 c
F-test	**
SEm±	11.24
LSD	23.4483
CV (%)	12.34

Treatments with the same letter(s) are not significantly different

LSD = Least Significant Difference.

CV= Coefficient of Variation

** = Significant at 99% confidence.

Effect of Fruit Thinning on Fruit length

Fruit length was influenced by the reduction in the number of fruits per spur. As the number of fruits per spur decreased, the length of the fruit increased. The longest fruit length was observed when one or two fruits were left per spur. The average fruit lengths in the first and second treatments were significantly higher than those in the third, fourth, and fifth (control) treatments. The maximum length of the fruit was 75.46 mm in the first treatment, and the minimum length of the fruit was 57.80 mm in the control.

***Table 2**. Effect of Fruit Thinning on Fruit Length of Red Delicious Apple*

Treatment	Fruit (length/diameter) ratio (mm)
T1 (One fruit / spur)	75.46 a
T2 (Two fruits / spur)	68.56 ab
T3 (Three fruits / spur)	65.08 bc
T4 (Four fruits / spur)	58.08 c
T5(Control)	57.80 c
F-test	**
SEm±	3.38
LSD	9.6286
CV (%)	9.02

Treatments with the same letter(s) are not significantly different

LSD= Least Significant Difference.
CV= Coefficient of Variation
** = Significant at 99% confidence.

Effect of Fruit Thinning on Fruit Diameter

Fruit diameter was influenced by the reduction in the number of fruits per spur. As the number of fruits per spur decreased, the diameter of the fruit increased. Conversely, as the number of fruits per spur increased, the fruit diameter decreased. The largest fruit diameter was recorded in the treatment where only one fruit was left per spur. The maximum diameter of the fruit was 76.42 mm in the first treatment, and the minimum diameter of the fruit was 59.20 mm in the control.

Table 3. *Effect of Fruit Thinning on Fruit Diameter of Red Delicious Apple*

Treatment	fruit diameter Average (mm)
T1 (One fruit/spur)	76.42 a
T2 (Two fruits/spur)	71.06 b
T3 (Three fruits/spur)	68.34 bc
T4 (Four fruits/spur)	64.93 cd
T5(Control)	59.27 d
F-test	**
SEm±	2.05
LSD	5.8399
CV (%)	5.23

Note: Treatments with the same letter(s) are not significantly different.
LSD = Least Significant Difference.
CV= Coefficient of Variation
** = Significant at 99% confidence.

Effect of Fruit Thinning on the Ratio of Fruit Length to Diameter

Fruit thinning had no significant effect on the ratio of fruit length to diameter. This means that changes in the number of fruits per spur, whether increased or decreased, affected both fruit length and diameter proportionally, and their ratio remained statistically unchanged. As thinning increased fruit length, the diameter increased correspondingly, resulting in proportional, consistent growth in both dimensions. The maximum length /diameter ratio of the fruit was 0.9893 mm when one fruit per spur was left, and the minimum length /diameter ratio of the fruit was 0.9785 mm when five fruits per spur were left.

Table 4. *Effect of Fruit Thinning on Fruit Length, Diameter, and Their Ratio in 'Red Delicious' Apple*

Treatment	fruit length Average (mm)	fruit diameter Average (mm)	Fruit (length/diameter) ratio (mm)
T1 (One fruit/spur)	75.46 a	76.42 a	0.9893
T2 (Two fruits/spur)	68.56 ab	71.06 b	0.9648
T3 (Three fruits/spur)	65.08 bc	68.34 bc	0.9525
T4 (Four fruits/spur)	58.08 c	64.93 cd	0.8920
T5(Control or five fruit/spur)	57.80 c	59.27 d	0.9785
F-test	**	**	Ns
SEm±	3.38	2.05	0.484
LSD	9.6286	5.8399	
CV (%)	9.02	5.23	8.77

Treatments with the same letter(s) are not significantly different.

LSD= Last Significant Deference.
CV= Coefficient of Variation
Ns = No significant difference, ** = Significant at 99% confidence.

Effect of Fruit Thinning on Total Yield per Hectare

The effect of fruit thinning on total yield per Hectare shows that different levels of thinning have had a significant impact on total yield per Hectare. In fruit trees, as the number of fruits per spur increases, total yield per hectare also increases. Also, when the number of fruits per spur decreases, total yield per hectare also decreases. In this trial, the highest total yield per hectare was obtained from fruit trees where five fruits were left per spur. The maximum total yield was 13.27 metric ton/hectare in the control treatment, and the minimum total yield was 8.34 metric ton/hectare in the one fruit per spur treatment.

***Table 5**. Effect of Fruit Thinning on Total Yield per hectare (MT/ H) of Red Delicious Apples*

Treatment	Total yield per hectare (Metric Ton / hectare)
T1 (One fruit/spur)	8.34 c
T2 (Two fruits/spur)	10.29 b
T3 (Three fruits/spur)	11.84 ab
T4 (Four fruits/spur)	12.82 a
T5(Control)	13.27 a
F-test	**
SEm±	1.76
LSD	1.8327
CV (%)	13.45

Treatments with the same letter(s) are not significantly different.
LSD= Least Significant Difference
CV= Coefficient of Variation
** = Significant at 99% confidence

Effect of Fruit Thinning on Quantity of Non-Marketable Yield per Hectare

The effect of fruit thinning on the amount of non-marketable yield shows that different fruit thinning levels significantly impacted the portion of the fruit tree's yield that was not suitable for market.

***Table 6**. Effect of Fruit Thinning on Non-Marketable Yield per hectare (MT/ h) of 'Red Delicious' Apples*

Treatment	Non-marketable yield per hectare (Metric ton /hectare)
T1 (One fruit/spur)	0.27 c
T2 (Two fruits/spur)	0.39 c
T3 (Three fruits/spur)	1.05 b
T4 (Four fruits/spur)	1.43 a
T5(Control)	1.65 a
F-test	**
SEm±	0.1100
LSD	0.2295
CV (%)	19.89

Treatments with the same letter(s) are not significantly different.
LSD = Last Significant Deference .

CV= Coefficient of Variation

** = Significant at 99% confidence.

The maximum non-marketable yield was 1.65 metric ton/hectare in the control treatment, and the minimum non-marketable yield was 0.27 metric ton/hectare, with one fruit per spur. This shows that fruit trees with more fruits per spur produced more non-marketable fruit. Apple Fruit trees with one fruit per spur had the lowest non-marketable yield (Table 6).

Effect of Fruit Thinning on Fruit Firmness

The effect of fruit thinning on fruit firmness shows that different thinning levels had a significant impact on fruit firmness (Table 3). The highest flesh firmness was recorded in the first treatment. However, since leaving only one fruit per spur significantly reduces total yield and can result in economic losses for the grower, the second treatment is recommended to avoid substantial yield reduction.

Table 7. *Effect of fruit thinning on the firmness (kg/cm²) of the fleshy part of Red Delicious apple fruit*

Treatment	Fruit firmness Average (kg/cm² of fruit surface)
T1 (One fruit/spur)	8.45 a
T2 (Two fruits/spur)	8.04 ab
T3 (Three fruits/spur)	7.82 b
T4 (Four fruits/spur)	7.54 b
T5(Control)	7.72 b
F-test	*
SEm±	0.2519
LSD	0.5255
CV (%)	5.51

Treatments with the same letter(s) are not significantly different.

LSD= Least Significant Difference

CV= Coefficient of Variation

*= Significant at 95% confidence

Effect of Fruit Thinning on Fruit Sugar Content

In fruit trees, reducing the number of fruits per spur has led to an increase in the fruit's sugar content (total soluble solids). In this study, the highest sugar content was obtained from fruit trees with one or two fruits per spur. The maximum total soluble solids (TSS) of fruit was 11.63° Brix when one fruit per spur, and the minimum total soluble solids (TSS) of fruit was 10.25° Brix in the control.

Table 8*. Effect of fruit soluble solid content (Brix of Red Delicious apple fruit*

Treatment	fruit sugar content Average in Brix (°Brix)
T1 (One fruit/spur)	11.63 a
T2 (Two fruits/spur)	10.92 ab
T3 (Three fruits/spur)	10.68 b
T4 (Four fruits/spur)	10.78 b
T5(Control)	10.25 b
F-test	*
SEm±	0.3568
LSD	0.7443
CV (%)	5.69

Treatments with the same letter(s) are not significantly different.

LSD=Least Significant Difference.

CV= Coefficient of Variation

*= Significant at 95% confidence

Effect of Fruit Thinning on Fruit Acidity

In this research, the number of fruits per spur did not show a significant difference in fruit titratable acidity (TA)across treatments. In the first treatment (one fruit per spur), fruit acidity was 0.7, and in the fifth treatment (control), the acidity was 0.983.

***Table 9**. Effect of fruit thinning on fruit acidity of Red Delicious apple fruit*

Treatment	fruit acidity Average (TA)
T1 (One fruit/spur)	0.700
T2 (Two fruits/spur)	0.700
T3 (Three fruits/spur)	0.733
T4 (Four fruits/spur)	0.800
T5(Control)	0.983
F-test	Ns
SEm±	0.1049
LSD	
CV (%)	23.19

Treatments with the same letter(s) are not significantly different.

LSD= Last Significant Difference.

CV= Coefficient of Variation

Ns = No significant difference.

Effect of Fruit Thinning on the Ratio of Sugar Content to Acidity in Fruit

The effect of fruit thinning on the ratio of sugar to acidity (which determines fruit taste) shows that different thinning levels have a significant impact on this ratio. When acidity increases in fruit, sugar content in the fruit decreases, and as acidity decreases, sugar content increases. Therefore, thinning treatments also influence this ratio. The maximum total soluble solids per acidity ratio of fruit was 16.98 when one fruit per spur, and the minimum total soluble solids per acidity ratio of fruit was 11.12 in the control.

***Table 10**. Effect of fruit thinning on sugar-to-acid ratio of Red Delicious apple fruit*

Treatment	Sugar/acidity ratio of fruit
T1 (One fruit/spur)	16.98 a
T2 (Two fruits/spur)	16.22 a
T3 (Three fruits/spur)	14.90 a
T4 (Four fruits/spur)	14.10 ab
T5(Control)	11.12 b
F-test	*
SEm±	1.71
LSD	3.5621
CV (%)	20.17

Treatments with the same letter(s) are not significantly different.

LSD= Least Significant Difference.

CV= Coefficient of Variation

*= Significant at 95% confidence

Effect of Fruit Thinning on Fruit pH

The effect of fruit thinning on fruit pH indicates that different fruit thinning levels do not have a statistically significant effect on pH according to statistical analysis. In one fruit per spur, the fruit pH was 2.78, and in the control, the pH was 2.32 (Table 11).

***Table 11**. Effect of fruit thinning on pH Level of Red Delicious apple fruit*

Treatment	Fruit pH level
T1 (One fruit/spur)	2.78
T2 (Two fruits/spur)	2.55
T3 (Three fruits/spur)	2.35
T4 (Four fruits/spur)	2.20
T5(Control)	2.32
F-test	Ns
SEm±	0.2006
LSD	
CV (%)	14.24

Treatments with the same letter(s) are not significantly different.
LSD= Last Significant Difference.
CV= Coefficient of Variation
Ns = No significant difference.

Effect of Fruit Thinning on Fruit Color

As the number of fruits per spur increased, the fruit color intensity decreased. Conversely, as the number of fruits per spur decreased, the fruit color improved. The effect of fruit thinning on fruit color was significant across different levels of fruit thinning, as shown in Table 3. The maximum fruit color score was 4.75 degrees when one fruit per spur was retained, and the minimum fruit color score was 3.51 degrees in the control treatment. The Highest fruit color intensity was recorded in the first treatment, where one fruit per spur was retained (Table 12).

***Table 12**. Effect of fruit thinning on Color of Red Delicious apple fruit*

Treatment	Fruit color rated on a scale of (1 - 5) *
T1 (One fruit/spur)	4.75 a
T2 (Two fruits/spur)	4.12 b
T3 (Three fruits/spur)	4.00 b c
T4 (Four fruits/spur)	3.58 cd
T5(Control)	3.51 d
F-test	**
SEm±	0.2285
LSD	0.4767
CV (%)	9.92

*The color of the fruit has been measured using a scale from 1-5 based on a fruit color chart.
Treatments with the same letter(s) are not significantly different.
LSD= Least Significant Difference.
CV= Coefficient of Variation** = Significant at 99% confidence.

DISCUSSION

In fruit trees, reducing the number of fruits per spur leads to an increase in individual fruit weight, whereas increasing the number of fruits results in a decrease in fruit weight. The improvement in fruit weight and size is associated with cell size in the fruit. The larger fruit size observed in this study may be attributed to greater cell enlargement, and early thinning can potentially increase fruit size. In this study, the highest fruit weight was observed in fruit trees with only one fruit per spur. Our findings are consistent with those of Costa et al. (2013), who stated that as crop load increases, fruit weight decreases. Similarly, the results align with those of Win et al. (2023), who noted that fruit weight increased with more intensive mechanical thinning.

Fruit thinning reduced the number of fruits per tree, increasing individual fruit length. The greatest fruit length (75.46 mm) was recorded in the first treatment, where only one fruit was retained per spur. These findings confirm that early and careful fruit thinning can enhance fruit growth by allowing more nutrients and resources to be allocated to each fruit. Win et al. (2022) These findings are consistent with those of Bound (2023) and Meland (2009) , who also reported that fruit thinning increases fruit length.

Fruit thinning reduced the number of fruits per tree, increasing individual fruit weight. The greatest fruit length (75.46 mm) was recorded in the first treatment, where only one fruit was retained per spur.

The results of the study indicate that reducing the number of fruits per tree increases fruit diameter, with the largest diameter (76.42 mm) observed in the first treatment, in which only one fruit was retained per spur. Flower thinning increased the yield of fruit with a diameter greater than 70 mm, especially if thinning was done at the end of flowering Wociór (2012). The results align with those of Bound (2023)and Meland (2009), who reported that thinning enhances fruit size.

Fruit thinning had no significant effect on the ratio of fruit length to diameter. This means that changes in the number of fruits per spur, whether increased or decreased, affected both fruit length and diameter proportionally, and their ratio remained statistically unchanged. Our findings are consistent with those of Milić et al. (2013), who reported that thinning did not affect the L/D ratio in Camspur apple but increased the L/D ratio only in Sandidge fruits. Our results align Bound (2023), who noted that increasing crop load had no significant effect on the fruit L/D ratio of Delicious apples hand-thinned. These findings align with those of Win et al. (2022), who also reported that the Effect of Bloom Thinning on the fruit length-to-diameter (L/D) ratio was not significantly different among treatments.

As the number of fruits per spur increases, total yield increases; conversely, as the number of fruits per spur decreases, total yield decreases. Total yield is directly related to the total number of fruits and their cumulative weight per tree. These findings correspond with Win et al. (2022), who suggested that fruit trees with a higher number of fruits on the trunk had higher yields than those with fewer fruits. The total yield increases with the increase in the number of Fruits per trunk; similarly, the total yield per hectare also increases.

Basak (2006) As the number of fruits per spur increased, the amount of non-marketable fruit also increased noticeably, and as the number of fruits per spur decreased, the amount of non-marketable fruit also decreased. Our research findings are similar to those of Basak (2006), who stated that fruit thinning increases marketable yield and reduces non-marketable yield.

Our research findings show that fruit thinning increases fruit firmness in trees. Our findings are consistent with those of Bound (2023) and Garriz et al. (2000), who reported that, in the Fuji, Delicious, Braeburn, and Pink Lady varieties, increasing the number of fruits resulted in reduced firmness. Similarly, our results align with the findings of Link (2000), who suggested that increased crop load in a tree leads to a decrease in fruit firmness, possibly due to a limited carbohydrate supply that restricts cell wall development.

the number of fruits per spur increases, the sugar content or total soluble solids of the fruit decreases. Our findings align with those of Bound (2023) and Koike et al. (2003), who stated that increasing crop load in trees leads to a reduction in sugar content. Our results also agree with Koen et al. (1988), who reported a 14% increase in sugar content in hand-thinned Fuji apples compared to Unthinned fruit trees.

The number of fruits per spur did not show a significant difference in fruit titratable acidity (TA) across treatments. these findings are consistent with the results of Win et al. (2022), who stated that different crop load levels in trees do not significantly affect fruit acidity. They are also relatively similar to the findings of Win et al. (2023), who reported no significant differences in fruit acidity among control (manual), chemical, low mechanical, and low mechanical + chemical thinning treatments. However, they did observe differences in acidity when comparing these with high mechanical and high mechanical + chemical thinning treatments.

Fruit thinning increases the ratio of soluble solids to acidity in the fruit. Wen acidity increases in fruit, sugar content in the fruit decreases, and as acidity decreases, sugar content in the fruit increases. The results align with Win et al. (2023), who stated that as acidity increases, sugar content in the fruit decreases, and as acidity decreases, sugar content increases. Therefore, thinning treatments also influence this ratio. They found that in the high mechanical + chemical thinning treatment, the sugar-to-acidity ratio was higher, resulting in better-tasting fruit.

The effect of fruit thinning on fruit pH indicates that different fruit thinning levels do not have a statistically significant effect on pH according to statistical analysis. Our findings are consistent with those of Ouma & Matta (2003),They suggested that different chemical thinners did not have a significant effect on the pH of the apple varieties Braeburn, Jon-A-Red, and Empire. Our research findings are similar to those of Matta & Ouma (2007), who stated that thinning in Empire apples does not affect the fruit's pH.

In this study, the best and most intense fruit color was observed in fruit trees where only one fruit per spur was retained. The findings of this research align with those of Sidhu et al. (2022), who reported that in Scilate varieties, the conversion of starch into sugars is slower when the fruit tree bears heavy fruit loads. This slower conversion delays chlorophyll breakdown, resulting in greener fruit color and delayed ripening. Therefore, early and heavier thinning promotes earlier ripening and better coloration. Similarly, Serra et al. (2016) suggested that heavy crop load negatively affects ripening, whereas lighter fruit load promotes ripening. Additionally, Robinson & Lopez (2009) stated that higher crop loads reduce the development of fruit color.

CONCLUSION

Fruit thinning significantly affected the yield and quality of 'Red Delicious' apple. Reducing the number of fruits per spur improved fruit weight, size, firmness, total soluble solids, sugar-to-acidity ratio, fruit color, and marketable yield, while decreasing the proportion of non-marketable fruits. However, fruit thinning had no significant effect on fruit length-to-diameter ratio, titratable acidity, or fruit pH. Retaining one fruit per spur produced the highest fruit quality but resulted in the lowest yield per hectare, whereas the control treatment produced the highest yield but lower fruit quality. These results demonstrate a clear trade-off between fruit quality and yield under different crop load levels. Considering both yield and fruit quality, retaining two fruits per spur was the most suitable treatment, providing a favorable balance between productivity and marketable fruit quality. Therefore, this practice can be recommended for commercial production of 'Red Delicious' apple under conditions similar to those of the study area. Since the experiment was conducted during a single growing season at a single location and with only one cultivar, further studies across multiple years, locations, cultivars, and thinning methods are needed to validate and expand these findings.

Authors Contributions

- Nasir Ahmad Ziarmal conducted the field study and collected the raw data.
- Ghulam Rasoul Samadi conceptualized and supervised the study.
- Nasir Ahmad Ziarmal, Ghulam Rasoul Samadi and Zabihullah Faizi processed and analyzed data(equally).
- Nasir Ahmad Ziarmal, Ghulam Rasoul Samadi and Zabihullah Faizi wrote the manuscript with input from all authors.
- All authors reviewed and approved the final version.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Data Availability Statement

Data are available upon request from the corresponding author, subject to approval of the relevant ethics committee.

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