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# Influence of Mechanical Flower Thinning on Fruit Set and Quality of 'Arisoo' and 'Fuji' Apples

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**Abstract:** This study aimed to identify the efficiency of mechanical flower thinning (MFT) and its influence on apple fruit quality. In the first experiment, 'Arisoo' apple flowers were subjected to MFT with one hundred sixty-two (half) and three hundred twenty-four (full) strings at the same rotor (300 rpm) and tractor (6 km/h) speeds. Hand thinning was performed as a control. The number of removed flowers in each terminal and lateral flower cluster was slightly higher in MFT with full-strings than that of MFT with half-strings. The fruit set rate was lower in MFT with full-strings than that of MFT with half-strings. However, the use of full-strings during mechanical thinning increased the leaf damage rate compared to half-strings. Except *a** value, MFT with full-strings improved flesh firmness, soluble solids content (SSC) and titratable acidity (TA), and reduced starch pattern index of fruits at harvest compared to the control. In the second experiment, 'Fuji' apple flowers were subjected to chemical thinning, MFT (300 rpm, 6 km/h), and MFT + chemical thinning treatments and compared with hand thinning (control). The thinning efficiency of MFT was similar to that of chemical thinning and MFT + chemical thinning treatments in terms of the removal of flowers and fruit set rates. Compared to the control, MFT, chemical thinning, and their combined treatments improved flesh firmness and SSC of fruits at harvest. TA was highest in the chemical thinning treatment compared to other thinning treatments. However, fruit size, weight, and *a** value were unaffected by any treatment. In conclusion, the use of full-strings during MFT achieved optimal results in 'Arisoo' apples. In 'Fuji' apples, MFT treatment alone achieved effective results and the addition of chemical thinning after MFT had no supportive role in thinning efficiency and fruit quality.

**Keywords:** *Malus domestica* Borkh; mechanical thinning; strings; flowers; fruit set; fruit quality

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## 1. Introduction

Apple trees are very productive; therefore, adjusting the crop load in trees is essential to achieve marketable quality fruit [1,2]. Flower thinning is a method of crop load management and manual (hand) and chemical thinning are the most widely used thinning methods in many apple orchards worldwide, including Korea [3–7]. However, hand thinning is time-consuming and can lead to increased production costs. Chemical thinning is often limited by weather conditions, cultivars, and short flowering periods [8,9]. Therefore, mechanical flower thinning (MFT) has been developed as an alternative to hand and chemical thinning approaches in apple orchards.

Most studies reported that MFT reduced flower density and fruit set rate in trees and improved fruit quality at harvest [10–13]. Generally, the spindle rotor and tractor driving speeds are the main factors for achieving effective results using the MFT method [11,14]. Pflanz et al. [15] reported that the results of mechanical thinning also depend on the training form and cultivar growth habit used. Interestingly, Kon et al. [16] reported that the use of different numbers of strings attached to the spindle of a mechanical thinner influences the efficiency of mechanical thinning. Additionally, a combination of hand or chemical thinning with MFT has been shown to achieve optimal results in flower thinning and fruit quality in some apple cultivars [17,18]. According to previous studies, many factors influence the efficiency of MFT; therefore, flower thinning in apple trees using MFT technology should be tested or this method should be adjusted for specific apple cultivars.

In Korea, 'Fuji' is the most widely cultivated apple cultivar and accounts for ~67% of the total apple cultivation area [19]. 'Arisoo' is a new apple cultivar recently popularized among growers and consumers owing to its remarkable quality characteristics [20]. Hence, the increased production of these apple cultivars with excellent fruit quality is economically essential, and MFT could be an environmentally friendly technology and an alternative to the chemical flower thinning. However, MFT is not widely used in Korea; therefore, it is necessary to determine a tree-adaptable MFT technology for each specific apple cultivar.

Most MFT experiments have mainly focused on rotor and tractor speeds and have used the maximum number of strings during MFT [11,16]. However, the effect of using different numbers of strings during MFT has not been widely reported. Therefore, in the first experiment in this study, we evaluated the influence of using different numbers of strings on the thinning efficiency and fruit quality of 'Arisoo' apples. In the second experiment, we investigated the effects of MFT, chemical thinning, and their combination on the thinning efficiency and fruit quality of 'Fuji' apples. The removal of flowers in each terminal and lateral flower cluster, fruit set rate, and improvement in fruit quality characteristics were assessed in both experiments.

## 2. Materials and Methods

### *2.1. Plant Materials and Field Trials*

'Arisoo' and 'Fuji' apple trees were selected from the experimental trials of the Apple Research Institute, Gunwi, Gyeongsangbuk-do, Korea. Two experiments were performed in this study in 2021. Five-year-old 'Arisoo' apple trees were planted with a 3.0 m × 1.5 m spacing, and seven-year-old 'Fuji' apple trees were planted with a 3.0 m × 1.5 m spacing. For both cultivars of this study, the apple trees were trained in the slender-spindle training form and grafted into M.9 rootstock. The selected apple trees were uniform in flower density and tree size, and planted in the same environmental conditions. Both experimental trials were managed with an integrated pest management system, and irrigated with a drip irrigation system.

### *2.2. Treatments, Methods, and Timing of MFT*

In our previous studies, we evaluated the effects of different rotor and tractor speeds on locally cultivated 'Hongro' apple cultivar, and MFT treatment with 300 rpm rotor speed and 6 km/h tractor speed proved to be the most effective [21]. Therefore, those speeds were selected as standards for the MFT method in both experiments of the present study. In the first experiment, three thinning treatments were used: hand thinning (control), MFT with half-strings (162 strings), and MFT with full-strings (324 strings). In the second experiment, four thinning treatments were used: hand thinning (control), MFT (300 rpm, 6 km/h), chemical flower thinning, and a combination of MFT (300 rpm, 6 km/h) + chemical flower thinning. Full-strings were used for MFT in the second experiment.

In this study, the Darwin S-300 (Fruit Tec Co., Markdorf, Germany) mechanical flower thinner was used for both experiments (Figure 1). In the full-setting of Darwin S-300, a total of 36 string bars were fitted along the spindle and 9 strings were included in each string bar (324 strings in total). For the first experiment, the control treatment was performed by hand thinning of all flowers in each terminal and lateral flower cluster except the central flower (king flower). Hand thinning was performed at 80% blooming on 20 April 2021. MFT treatments (with half- or full-strings, Figure 1) were performed at 60–80% blooming on 19 April 2021. For the second experiment, hand thinning was performed by the same procedure as the first experiment on 24 April 2021. Chemical thinning was performed by spraying 120-fold dilution of lime sulfur (8.33 mL/L) (Be′ 22, Hwangbuja, Enbio Co., Jecheon, Korea) on apple trees at 20% (22 April 2021) and 100% (25 April 2021) blooming, as described by Win et al. [22]. Chemical thinning treatment was applied using a hand sprayer at a volume of 500 L ha$^{-1}$. During spraying, other apple trees were covered with waterproof clothes to prevent contamination from chemical thinning solutions. MFT was performed at 60–80% blooming on 23 April 2021. The combined treatment (MFT + chemical thinning) was performed at 60% (23 April 2021) and 100% (25 April 2021) blooming.

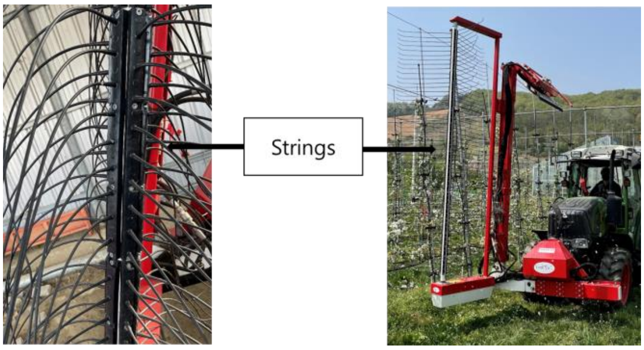


**Figure 1.** Photos of string bars attached to the spindle of the mechanical flower thinner. A total of 324 strings are included in a full-setting of the spindle of the mechanical flower thinner.

### 2.3. Assessments of Terminal and Lateral Flowers, Leaf Damage Rate, and Fruit Set Rate

For each tree, 10 individual branches were selected as model branches to assess the thinning efficiency of the treatments. The number of flowers removed by thinning treatments was counted in each terminal and lateral flower cluster before and after thinning treatments, as described by Solomakhin and Blanke [11]. The fruit set rate was calculated as the number of fruits per 100 flower clusters in the same model branches at the end of June, as described by Yoo et al. [23,24]. To analyze the leaf damage rate in trees, the total number of leaves was counted in the same model branches before and after MFT, as described Solomakhin and Blanke [11]. For both experiments, the same assessment procedures were used.

### 2.4. Assessment of Fruit Quality Characteristics

The fruit's external characteristics, such as weight, size, shape, and skin color, and internal characteristics, such as flesh firmness, titratable acidity (TA), soluble solids content (SSC), and starch pattern index (SPI), were determined at harvest. 'Arisoo' apples were harvested on 30 August 2021, and 'Fuji' apples were harvested on 26 October 2021. The harvest dates for each cultivar were estimated based on SPI scores, and both apple cultivars were harvested around 6.5 SPI score. The number of fruits per tree were counted at harvest and yield was calculated as kg per tree. For all assessments of fruit quality characteristics, ten apple fruits were randomly collected from each apple tree at harvest. Fruit weight was measured using a weight scale (AND Co., Daejeon, Korea), fruit size (diameter and length) was measured using a caliper (CD-15APX, Mitutoyo, Kawasaki, Japan), and fruit skin color values ($L^*$, $a^*$, and $b^*$) was measured on the equator regions of the fruit skin using a chromameter (CR-400, Konica Minolta, Tokyo, Japan). After the assessment of external characteristics, fruit skins were removed from equatorial regions using a peeler, and flesh firmness (11-mm probe) was measured in triplicates using a penetrometer (FT-327, TR Co., Forlì, Italy) [25]. SPI was measured by cutting the fruit slices horizontally, dipping them into an iodine solution and scoring them using a 1–8 score chart as described by Blanpied and Silsby [26]. The apple juice extracted from each apple fruit were used for the determination of TA and SSC. TA was measured by titrating fruit juice sample with NaOH solution until the end point of pH 8.1 using the malic acid reduction method [27]. For SSC measurement, the fruit juice sample was analyzed using a refractometer (PR-201, Atago, Tokyo, Japan).

### 2.5. Statistical Analysis

The trial was arranged in a randomized block design with three replications of each treatment block and each block consisted of 10 apple trees. Data were subjected to analysis of variance (one-way ANOVA), and mean differences among the treatment effects were compared using Tukey's HSD test ($p < 0.05$). The SPSS software (SPSS, Version 25, IBM Corp., Armonk, NY, USA) was used for all statistical analyses. All data are expressed as means with standard errors.

## 3. Results and Discussion

### 3.1. Experiment One: Influence of Different Numbers of MFT Strings on Fruit Set and Quality of 'Arisoo' Apples

The thinning intensity of MFT with full-strings was higher than that of MFT with half-string bars (Figure 2). Additionally, MFT with full-strings increased the leaf damage rate in trees compared with MFT with half-strings (Table 1). Similarly, some studies reported that increasing the number of strings used in MFT increased the level of thinning in trees because of increased string contact with tree canopies [16,28]. Additionally, they reported that an increased number of strings increased the leaf damage rate and damage of vegetative tree structures; however, no noticeable damage in tree branches was observed in the present study. The number of removed flowers in each terminal and lateral flower clusters was slightly higher in MFT with full-strings than that of MFT with half-strings, but the results were not statistically different (Table 1). After thinning, the fruit set rate was assessed and found to be significantly reduced in both terminal and lateral flower clusters, especially after MFT treatment with full-strings, compared to hand thinning. The fruit set in the lateral flower cluster was not reduced by MFT with half-strings. Moreover, a higher number of string bars used in MFT led to a lower fruit set rate, which was consistent with the findings of previous studies [16,28].


**Figure 2.** Photos of 'Arisoo' apple flowers treated with half (162) strings before (**A**) and after (**B**) and full (324) strings before (**C**) and after (**D**) mechanical flower thinning treatments. Tractor was driven at 300 rpm rotor and 6 km/h tractor speeds for both treatments. Photos were taken in the same sample branch of each treatment.

**Table 1.** Leaf damage rate, number of removed flowers in terminal and lateral flower clusters, and fruit set rate in terminal and lateral flower clusters of 'Arisoo' apples after mechanical thinning with half-strings (162) and full-strings (324) bars at 300 rpm rotor speed and 6 km/h tractor driving speed.

| Thinning Treatment | Leaf Damage Rate (%) | Number of Removed Flowers (no.) | | Fruit Set Rate (%) | |
|---|---|---|---|---|---|
| | | Terminal Flower Cluster | Lateral Flower Cluster | Terminal Flower Cluster | Lateral Flower Cluster |
| Hand thinning (control) | n.a. | n.a. | n.a. | 64.0 ± 2.2 a | 56.5 ± 3.4 a |
| Mechanical thinning (162 strings) | 13.0 ± 1.1 [z] b [y] | 2.8 ± 0.2 a | 3.2 ± 0.3 a | 55.1 ± 3.1 b | 50.0 ± 3.9 ab |
| Mechanical thinning (324 strings) | 24.3 ± 3.6 a | 2.9 ± 0.2 a | 3.7 ± 0.2 a | 51.3 ± 3.2 b | 45.0 ± 1.8 b |

[z] Data are the mean ± standard error ($n$ = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$). n.a.: not applicable.

Fruit size (diameter and length) and weight were not enhanced by any MFT treatments (Table 2). The similar fruit shape (length/diameter ratio) was also observed in all treatments (Table 2). The number of fruits per tree and yield were slightly higher in hand thinning than both of full- and half-strings thinning treatments but the results were not statistically different among all treatments (Table 2). The increase in fruit size and weight is associated with the increase in cell number and cell size in fruits [29,30]. The fruit set rate and tree crop load level also influence fruit size [25]. No difference was observed in fruit weight at harvest among control and MFT treatments with different strings, similar to the previous studies [16,28]. Additionally, these studies reported that an increase in leaf damage negatively affects the increase in fruit size and fruit calcium content. Some studies reported that the reduction in yield was related with increased string thinning severity and spindle speed of MFT [10,11,31]. They additionally reported that a minor reduction in fruit yield could be acceptable if fruit size was increased to an economically stimulating level.

**Table 2.** Fruit weight and size of 'Arisoo' apples after mechanical thinning with half-strings (162) and full-strings (324) bars at 300 rpm rotor speed and 6 km/h tractor driving speed.

| Thinning Treatment | Fruit Weight (g) | Fruit Size (mm) | | Fruit Shape (L/D Ratio) | Fruits/Tree (No.) | Yield (kg/Tree) |
|---|---|---|---|---|---|---|
| | | Length (L) | Diameter (D) | | | |
| Hand thinning (control) | 216.2 ± 5.7 [z] a [y] | 68.9 ± 0.8 a | 81.1 ± 0.9 a | 0.9 ± 0.0 a | 67.6 ± 5.3 a | 13.9 ± 1.0 a |
| Mechanical thinning (162 strings) | 227.7 ± 9.7 a | 71.3 ± 2.2 a | 84.3 ± 2.4 a | 0.9 ± 0.0 a | 62.3 ± 4.7 a | 13.12 ± 1.1 a |
| Mechanical thinning (324 strings) | 229.5 ± 10.5 a | 69.6 ± 1.1 a | 83.5 ± 1.7 a | 0.8 ± 0.0 a | 56.7 ± 5.5 a | 12.7 ± 0.3 a |

[z] Data are the mean ± standard error ($n$ = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$).

Significantly higher flesh firmness, TA, SSC, and SPI values were achieved with MFT with full-string bars than hand thinning (Table 3). MFT with full-strings also improved flesh firmness, TA, and SPI values at harvest compared with MFT with half-strings. The $a^*$ value was higher after MFT with half-strings than after the control treatment. However, SSC and $a^*$ value did not differ between MFT with half-string bars and that with full-strings (Table 3). Fruit skin color is an essential external characteristic, and flesh firmness, SSC, TA, and SPI are important internal characteristics for marketability and consumer acceptance [32,33]. Optimal results of fruit quality characteristics were observed after MFT with full-string bars. The enhancement of fruit quality characteristics from the mechanically thinning trees could be explained by reduced competition among fruits in the flower clusters or trees, resulting in increased flesh firmness, SSC and TA, and decreased SPI of fruits at harvest [17,25,34,35]. A higher SPI index indicates higher starch degradation to sugar in the fruit, resulting in faster ripening [36,37]. Fruit quality and maturity would be expected to be slightly accelerated because of the reduction in fruit set and crop load in trees by an increased number of strings during MFT, similar to the findings of previous studies [16,28].

**Table 3.** Flesh firmness, soluble solids content (SSC), titratable acidity (TA), fruit skin color (*a** value), and starch pattern index of 'Arisoo' apples after mechanical thinning with half-strings (162) and full-strings (324) bars at 300 rpm rotor speed and 6 km/h tractor driving speed.

| Thinning Treatment | Flesh Firmness (N) | SSC (%) | TA (%) | Fruit Skin Color (*a** Value) | Starch Pattern Index (1–8) |
|---|---|---|---|---|---|
| Hand thinning (control) | 61.8 ± 0.9 [z] b [y] | 11.8 ± 0.1 b | 0.6 ± 0.0 b | 11.9 ± 1.2 a | 6.7 ± 0.1 a |
| Mechanical thinning (162 strings) | 61.5 ± 0.6 b | 12.7 ± 0.2 a | 0.6 ± 0.0 b | 13.5 ± 1.6 a | 6.6 ± 0.2 a |
| Mechanical thinning (324 strings) | 66.1 ± 0.9 a | 12.5 ± 0.2 a | 0.6 ± 0.0 a | 13.0 ± 1.2 a | 6.0 ± 0.2 b |

[z] Data are the mean ± standard error ($n$ = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$).

### 3.2. Experiment Two: Influence of Chemical Thinning, MFT, and MFT + Chemical Thinning on Fruit Set and Quality of 'Fuji' Apples

As shown in Table 4, the number of removed flowers per each terminal and lateral flower cluster did not differ among thinning treatments. The results observed in the fruit set rate of both terminal and lateral flower clusters between chemical thinning, MFT, and their combination were also nonsignificant. Compared with hand thinning (control), the fruit set rate in terminal flower clusters was significantly reduced in all thinning treatments but not in lateral flower clusters (Table 4). About 22% of the leaf damage rate was observed during MFT at 300 rpm rotor and 6 km/h. Most studies have reported that the thinning efficiency of MFT highly depends on rotor and tractor speeds [10,11,38]. In this study, MFT had a similar effect on flower removal and fruit set as chemical thinning and the addition of chemical thinning to MFT did not increase the thinning efficiency. Hehnen et al. [17] also reported that the fruit set did not differ between chemical thinning, MFT, and their combination in 'Buckeye Gala' apples, but these treatments had a greater effect than hand thinning. Lordan et al. [13] reported that the thinning efficiency of combined MFT + chemical thinning depended on the rotor and tractor speeds used, the difference in chemical compounds or concentration used, and the timing of chemical sprayed (at flowering or fruitlet stage). The above reasons might explain why the combination treatment had no greater effect than MFT alone in this study.

**Table 4.** The number of removed flowers in the terminal and lateral flower clusters and fruit set rate in terminal and lateral flower clusters of 'Fuji' apples after chemical thinning (lime sulfur), mechanical thinning (300 rpm rotor speed and 6 km/h tractor speed), and mechanical + chemical thinning treatments.

| Thinning Treatment | Number of Removed Flowers (No.) | | Fruit Set Rate (%) | |
|---|---|---|---|---|
| | Terminal Flower Cluster | Lateral Flower Clusters | Terminal Flower Cluster | Lateral Flower Cluster |
| Hand thinning (control) | n.a. | n.a. | 64.0 ± 2.1 a | 58.4 ± 2.5 a |
| Chemical thinning | 2.5 ± 0.2 [z] a [y] | 1.7 ± 0.3 a | 58.0 ± 1.8 b | 56.2 ± 3.0 a |
| Mechanical thinning | 2.5 ± 0.1 a | 1.5 ± 0.2 a | 54.1 ± 2.5 b | 53.5 ± 1.8 a |
| Mechanical + chemical thinning | 2.5 ± 0.2 a | 1.6 ± 0.3 a | 56.0 ± 2.2 b | 58.0 ± 2.8 a |

[z] Data are the mean ± standard error ($n$ = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$). n.a.: not applicable.

At harvest time, the fruit size (diameter and length), fruit shape (length/diameter ratio), and fruit weight did not differ significantly between treatments (Table 5). However, MFT thinning treatment slightly reduced the yield and number of fruits per tree compared to other thinning treatments (Table 5). Flesh firmness was significantly higher in all of the thinning treatments than the control (Table 6). SSC was higher after all thinning treatments than after the control treatment, with its highest value observed after chemical thinning.

Additionally, TA was higher after chemical thinning than after the control treatment but was not different from that after MFT alone and the combined treatment. The *a** value and SPI were not significantly affected by the different thinning treatments; however, SPI was lower after the combined treatment than after the control treatment (Table 6).

**Table 5.** Fruit weight and size of 'Fuji' apples after chemical thinning (lime sulfur), mechanical thinning (300 rpm rotor speed and 6 km/h tractor speed), and mechanical + chemical thinning treatments.

| Thinning Treatment | Fruit Weight (g) | Fruit Size (mm) | | Fruit Shape (L/D Ratio) | Fruits/Tree (No.) | Yield (kg/Tree) |
|---|---|---|---|---|---|---|
| | | Length (L) | Diameter (D) | | | |
| Hand thinning (control) | 336.0 ± 5.5 [z] a [y] | 81.3 ± 0.6 a | 74.4 ± 0.4 a | 0.9 ± 0.0 a | 71.0 ± 8.9 a | 24.9 ± 2.8 a |
| Chemical thinning | 338.2 ± 14.2 a | 80.3 ± 1.8 a | 74.1 ± 1.5 a | 0.9 ± 0.0 a | 67.3 ± 10.0 a | 23.3 ± 3.2 a |
| Mechanical thinning | 343.6 ± 6.6 a | 81.5 ± 0.6 a | 74.1 ± 0.9 a | 0.9 ± 0.0 a | 59.7 ± 5.2 a | 20.3 ± 1.6 a |
| Mechanical + chemical thinning | 339.3 ± 7.0 a | 80.67 ± 0.6 a | 74.6 ± 0.8 a | 0.9 ± 0.0 a | 66.3 ± 6.4 a | 21.3 ± 1.5 a |

[z] Data are the mean ± standard error (*n* = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$).

**Table 6.** Flesh firmness, soluble solids content (SSC), titratable acidity (TA), fruit skin color (*a** value), and starch pattern index of 'Fuji' apples after chemical thinning (lime sulfur), mechanical thinning (300 rpm rotor speed and 6 km/h tractor speed), and mechanical + chemical thinning treatments.

| Thinning Treatment | Flesh Firmness (N) | SSC (%) | TA (%) | Fruit Skin Color (*a** Value) | Starch Pattern Index (1–8) |
|---|---|---|---|---|---|
| Hand thinning (control) | 57.2 ± 1.2 [z] b [y] | 12.7 ± 0.1 c | 0.4 ± 0.0 b | 12.2 ± 0.9 a | 7.1 ± 0.3 a |
| Chemical thinning | 62.4 ± 1.0 a | 14.1 ± 0.2 a | 0.4 ± 0.0 a | 13.4 ± 0.9 a | 6.8 ± 0.1 ab |
| Mechanical thinning | 64.2 ± 0.6 a | 13.5 ± 0.2 b | 0.4 ± 0.0 ab | 12.9 ± 0.8 a | 6.7 ± 0.2 ab |
| Mechanical + chemical thinning | 65.7 ± 1.6 a | 13.5 ± 0.2 b | 0.4 ± 0.0 ab | 12.8 ± 0.8 a | 6.5 ± 0.1 b |

[z] Data are the mean ± standard error (*n* = 3). [y] Different letters within a column indicate significant differences among treatments by Tukey's HSD test ($p < 0.05$).

As indicated in the first experiment, MFT with full-strings did not improve the fruit weight and size of 'Arisoo' apples significantly. Similar to the first experiment, MFT at the same rotor (300 rpm) and tractor (6 km/h) speeds with full-strings did not improve the fruit weight and size of 'Fuji' apples either. Solomakhin and Blanke [11] reported that the largest fruit size was observed at the highest rotor speed, and MFT with 300 rpm did not improve fruit size compared with hand thinning in 'Golden Delicious Reinders' apples. Additionally, MFT did not affect the fruit weight of 'Royal Gala' apples [14]. However, an improvement in fruit size was also reported after combined treatment with MFT with chemical thinning in 'Buckeye Gala' apples [17]. Among all treatments, the reduction in fruit yield was observed lowest in the MFT treatment. The fruit yield could be varied depending on the use of different mechanical thinning device, spindle rotor speed, tree form, and apple cultivar [10,11,28,31]. Similar to the first experiment, MFT improved flesh firmness and SSC in 'Fuji' apples compared with hand thinning. Similar results were also observed after chemical and MFT + chemical thinning treatments. Win et al. [22] reported that chemical thinning could improve flesh firmness and SSC. However, Hehnen et al. [17] reported that the effects of MFT on flesh firmness, SSC, and TA were not greater than those of chemical thinning. They also reported that the combination of MFT + chemical thinning did not improve these quality characteristics, which is consistent with the findings of the present study. The enhancement of fruit quality characteristics after the thinning treatments might be attributed to decreased crop load or fruit set rate in trees, resulting in a greater leaf:fruit ratio in trees that increased the amount of assimilates partitioned from leaves to the fruits [10,39].

## 4. Conclusions

In the first experiment, the thinning efficiency of MFT with full-strings was higher than that of MFT with half-strings. A lower fruit set was also observed in MFT with full-strings compared to MFT with half-strings and control. In the second experiment, the thinning efficiency and fruit set after MFT treatment were almost similar to those observed after chemical thinning and combined MFT + chemical treatments. In both experiments, the thinning of apple flowers by MFT method improved flesh firmness, SSC and TA, and reduced SPI in fruits at harvest. However, it did not noticeably enhance fruit size, weight, and color. A minor reduction in the fruit yield per tree was observed in MFT treatments in both experiments. Overall, our results reveal that MFT would be an alternative to the hand or chemical thinning of apple flowers and could reduce time and labor costs. Further research is necessary to determine a tree-adaptable MFT technology depending on the specific apple cultivar and flower density of the apple trees.

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