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Research Article

Examination of the Effectiveness of Fruit Thinning in the Case of Idaho and Gala Must Early Apple Varieties

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Apple (*Malus domestica* Borkh.) is the most important fruit in the EU. The total yield is more than 11 million tons.year^{-1}, 15% of which is that of the early apple varieties. Several papers have already been published on the efficacy of crown and fruit thinning in the 20th century. Nowadays, hybrid varieties and intensive crown types are used in modernized systems. Our research was carried out in a Hungarian orchard during two cultivation periods. We studied two early apple varieties (Idaho, Gala Must) to determine how fruit thinning affected the quantity and quality of fruits. We found that the effectiveness of non-thinned technology is similar or slightly better compared to fruit thinning, after the second harvest. The average yield of Idaho apples per tree per harvest was 35.9 vs. 24.8 kg, while that of Gala Must was 50.8 vs. 59.2 kg (with thinning vs. without thinning). To assess quality, we measured water-soluble sugars, NO_3^-, NO_2 and vitamin C content. Immediately, after the harvest, a surprisingly high vitamin C content was found in the fruits (4.4 mg.100 g^{-1} on average), which, however, decomposed after 3 months of storage. We also determined the pathway of the decomposition of vitamin C.

Keywords: fruit thinning, (*Malus domestica* Borkh), water-soluble sugar (BRIX%), NO_3;NO_2, vitamin C

1 Introduction

Apple (*Malus domestica* Borkh.) is cultivated across the temperate world. The genus apple *Malus* belongs to the subfamily Pomoideae of the Rosaceae family. In the evolution of the cultivated varieties the following species occurred in Europe: *Malus sylvestris*, *Malus orientalis*, *Malus* baccata, *Malus prunifolia*, and *Malus mandshurica* (Pethő & Nyéki, 1984). According to Korban and Skirvin (1984), there are more than 30 primary apples species, and most can be readily hybridized.

Nowadays, we use hybrid varieties and intensive crown types in a modernized system. Following the Central Asian countries, the EU is one of the biggest apple producers. The early-season apple cultivation is an important part of the fruit production of EU. Apple production of the EU is around 8.0–8.5 mil. tons of fruit, processed varieties of which are used by the food industry in the form of juice, baby food or jam (Apáti, 2020).

Besides being produced and consumed in large amounts, apple is important due to its nutritional value. However, in recent years, apple production in the EU has faced challenges:

1. the ever-increasing investment costs,
2. the lack of capacity and increasing costs of transportation,
3. the labour shortage (especially during the harvest).

To offset these production issues, we need to use the most economical early apple cultivation system.

Fruit thinning is a widespread system for increasing quality, size, and yield, during which the most favourable foliage/fruit ratio is optimized (Inántsy, 1995). This can be done by pruning or with chemicals, but both procedures are labour-intensive (150–180 hours.ha^{-1}) and costly. Until the 20th century, hand thinning and pruning were the main management practices to reduce the crop

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load of apple trees. Nowadays, when human labour has become expensive or unavailable, chemical and automated mechanical crop load management practices for flower and fruit thinning have been developed and integrated into the production process of apples (Dennis, 2000). The effectiveness of fruit thinning depends on the form of the crown. According to Duhanaj et.al. (2015), fruit thinning increased yield per tree by 11.3% and 12.8%, respectively, for slender spindle and pyramidal shaped crowns. It can be very effective but the mode of action of the thinning agents for flower thinning rely on damaging floral tissues and inhibiting pollen tube growth, which can load or contaminate the environment (Kon et al., 2018).

World overpopulation, scarcity of water and finite arable land require more efficient use of these natural resources. To remain sustainable, current apple production utilizes high-density orchards on semi-dwarfing, precocious rootstocks. However, relatively little attention has been paid to achieving yield increases through fruit thinning in modern apple orchards (Fallahi et al., 2019). Blossom thinners are caustic and reduce fruit set by damaging different flower parts, including anthers, stigma, style, and pollen tubes, and thus prevent fertilization. Early thinning of apples is important because of its impact on fruit size and next season flower bud initiation (Fallahi & Willemsen, 2002). Availability of the existing post-bloom thinners for apple and the prospects for additional thinners are limited. The application of blossom thinners may present a risk of over-thinning in areas with unpredictable weather. Therefore, there is a search for such post-bloom thinners or thinner supplements that may be useful at different physiological stages of fruit development (Fallahi et al., 2014). Early thinning of apples is important because of its impact on fruit size and the next season's flower bud initiation, but hand-thinning is a costly practice and an unacceptable alternative (Fallahi & Greene, 2009). Note that the efficacy of thinning is poor when fruits are smaller than 10 mm and improved when fruits are relatively large, between 12 and 20 mm. A possible explanation for the thinning efficacy responses is that a deficit in carbon supply supporting young fruitlets growth is a necessary prerequisite for the fruit thinning chemicals to induce fruit drop in the developing fruitlets. These results may indicate that in cool years it is better to wait for relatively large fruit sizes before fruit thinners are applied. (Robinson & Lakso, 2004). In the past, a two- or three-spray thinning program was used in the U.S. state of Washington on difficult cultivars, consisting of the chemical bloom thinner Elgetol at bloom time. In 1989, Elgetol was removed from the market by the manufacturer because it was a contact spray that damaged flower parts and prevented fertilization of the ovule. Thus, it was logical to look for other products that had a similar mode of action. Sulf-carbamide, a foliage desiccant used on potatoes, onions, and alfalfa, and tested as a dilute full-volume spray on apple blossoms, was found to be an effective blossom thinner. Chemical rates of 0.25% to 0.5% (v/v) applied at 80% of bloom open reduced fruit set by 25% to 50% compared to controls (Williams, 1993). However, the results of chemical thinning are highly influenced by the type of chemical, weather conditions, cultivar, and blossom pattern (Sagredo, 2008).

Our aim is to study the effectiveness of manual fruit thinning from the aspect of average yield, size, $NO_3^-NO_2$ concentration, and vitamin C content of fruits. A further aim is to determine the pathway of decomposition of vitamin C.

2 Material and Methods

2.1 Material

Our research work was carried out in a Hungarian intensive technology orchard during two apple cultivation periods, 2021–2022, in Hungary. The soil type of the orchard was black chernozem. Drip irrigation was applied, the capacity of which was 8 l water per hour per tree. Nutrients were applied in the form of a Polyfeed complex liquid fertilizer. The manual fruit and crown thinning were carried out on fifty apple trees per variety, the used crown type was pyramidal, stock MM106, the distance between plants 2 m, and the distance between lines 6 m. The investigated varieties were Idaho and Gala Must.

2.2 Methods

Idaho is an early-season apple, a selection of American Idared. Its tree is mid-size, the fruit is ball-shaped, red coloured, its flesh is white, crisp, and sweet. The diameter of the fruits is 60–75 mm on average. It is not self-fertile. Currently, it is an experimental variety in the EU.

Gala Must is an early-season apple from New Zealand, and it is a Delicious × Orange Red hybrid. Its tree is mid-size, the fruit is ball-shaped, and orange-red coloured, its flesh is white, crisp, and sweet. The diameter of the fruits is 60–75 mm on average. It is self-fertile, and an excellent pollen donor (Bokor, 2022).

The method of the applied fruit- and crown thinning: For reaching the optimal foliage/fruit ratio, manual fruit thinning was used. For each variety, 50 apple trees were thinned by fruit thinning technology and a control 50 apple trees were not thinned. The fruit thinning was carried out from the middle of May to the first week of June.

The following method was used to provide potential to the developing fruits on the tree to reach a larger mature mass: location of the fruits on the canes and removal of the more underdeveloped, damaged, and deformed fruits.

Determination of water-soluble sugar concentration: The water-soluble sugars (sucrose, glucose, fructose) were determined in the fresh biomass of fruits in the BRIX% unit. The BRIX% corresponds to the percentage of sugar in the solution, i.e. 1% equals to 1 g of sugar in 100 g of solution. For the measurement, a Milwaukee MA871 type digital reflectometer was applied. Three fruits from each of 50 trees of each variety were investigated. The average BRIX% results were compared.

Measurement of vitamin C content: For measuring (not bold) vitamin C content, an assay of apple samples was quantified by high-performance liquid chromatography (HPLC). The analysis of vitamin C (L-ascorbic) was performed on 3–3 parallel apple samples, and the vitamin C content was calculated in mg.100 g^{-1} of the material (Furusawa, 2001).

The method of $NO_3^-NO_2^-$ and chloride contamination control: The nitrate-nitrite was determined using a FIAstar 5,000 type spectrophotometer. The method is suitable for determining the nitrate-nitrite content of vegetables and fruits by linear regression in the range of 0.5–5 mg. 0.001 m^3 NO_3^- and NO_2^- extract. The nitrate content of the sample was determined by the difference between the amount of nitrate-nitrite and the amount of nitrite. For determining the chloride content, a Dionex Aquion ion chromatograph was applied.

3 Results and Discussion

3.1 Results of Fruit and Crown Thinning

The number of buds was the base of the flower coverage of trees. We usually counted 4–6 inflorescences in a flower bouquet.

Table 1 shows the numbers of darts and flowers of Idaho and Gala Must varieties. Table 2 shows the yield of thinned apple trees in kg.

After the harvest, the apple fruits yield was classified according to their diameter size. The diameter of the apples was between 45–75 mm (Figs. 1–2).

3.2 Result of the Water-Soluble Sugar Concentration

The sugar content measured on the day of harvest and following three months of storage showed the following results (Table 3). The alkali/acid ratio changed from an average pH 5.5 to 7.0.

Table 1 Number of darts and flowers of the apple varieties (50–50 trees average)

Idaho		Gala Must	
darts	flowers	darts	flowers
314–502	1,570–2,510	194-382	970–1,910

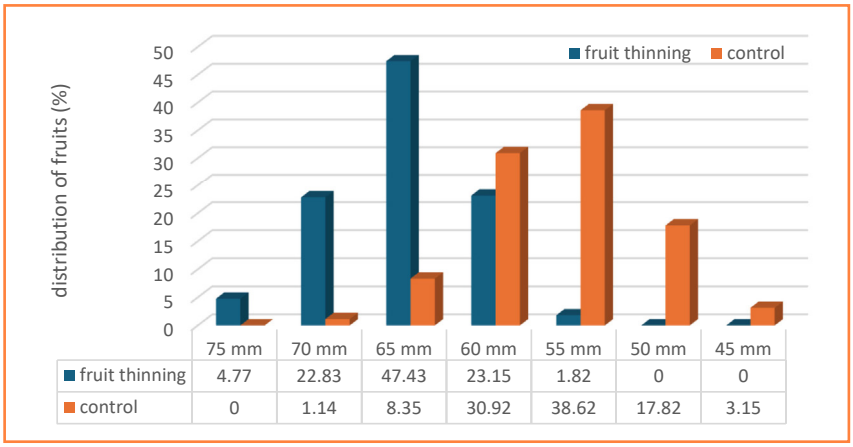


Figure 1 Percentage distribution of the total fruit yield of Idaho variety, according to the diameter of the apples

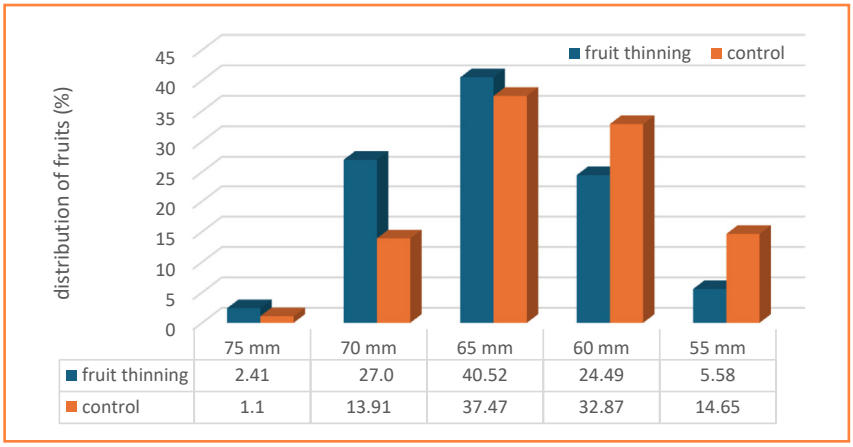


Figure 2 Percentage distribution of the total fruit yield of Gala Must variety, according to the diameter of the apples

Table 2 The effect of fruit and crown thinning on yield 50–50 trees, average (kg)

Idaho				Gala Must			
	time	fruit thinning	control		time	fruit thinning	control
1. harvest	August 18	588.2	97.5	**1. harvest**	August 24	282.5	70
2. harvest	August 24	900	620	**2. harvest**	August 31	1415	953.2
3. harvest	August 31	387.5	1,105	**3. harvest**	September 07	1,270.7	1,481.2
Total fruit yield:		1,875.7	1,822.5	**Total fruit yield:**		2,968.2	2,504.4

Table 3 Water-soluble sugar concentration of fruits on the day of harvest. Brix% (n = 3) (2021)

Idaho				Gala Must			
	time	fruit thinning	control		time	fruit thinning	control
1. harvest	August 18	12.5	12.8	**1. harvest**	August 24	12.1	11.4
2. harvest	August 24	11.8	11.9	**2. harvest**	August 31	11.3	13
3. harvest	August 31	12.3	12.1	**3. harvest**	September 07	11.9	11.9

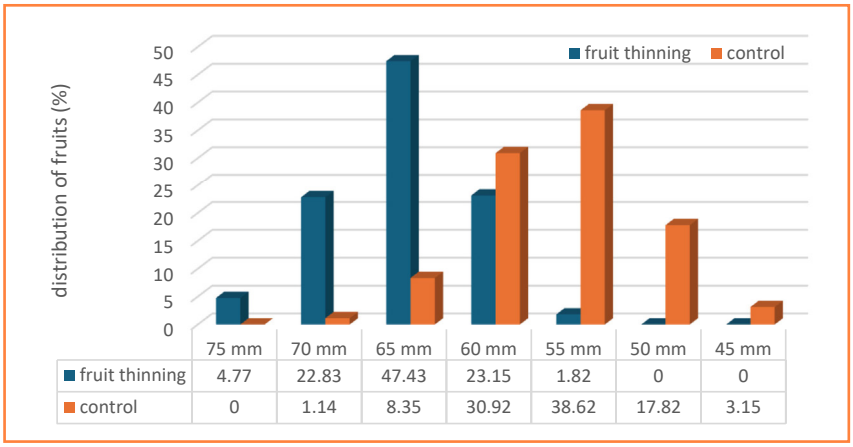


Figure 3 Vitamin C did not appear in any of the apple samples at 2.236 nm

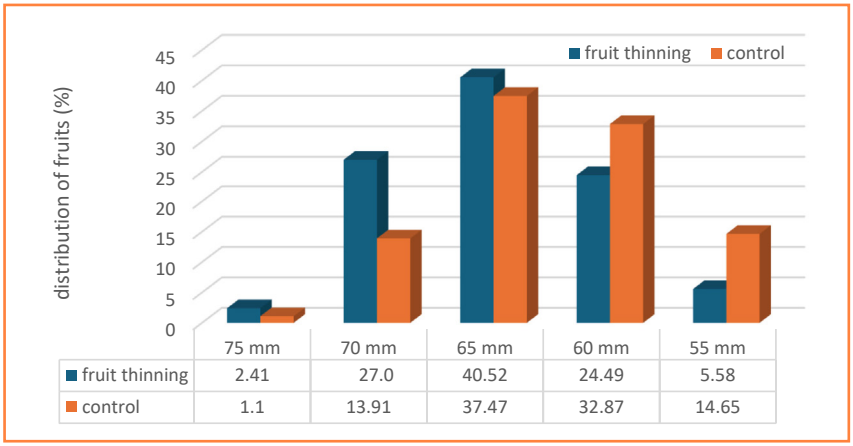


Figure 4 Results of added vitamin C at 2.236 nm

The water-soluble sugar content measured following three months of storage did not show significant differences either by variety or thinning technology. The sugar content of BRIX% 10.5, prescribed by the EU regulation, was found in the fruits for all measurements.

3.3 Results of Vitamin C Content Measurements

The vitamin C content of freshly harvested Gala Must apple fruits reached the expected, internationally published values of an average of 4.43 mg.100 g^{-1}. However, the values of the Idaho variety were substantially lower: 2.57 mg.100 g^{-1}, on average. Following three months of storage, we received a surprising result. Measurements did not detect vitamin C in any of the apple samples. To prove our measurements, added vitamin C was also used. The recovery rate was 90.5% (Figs. 3–4).

3.4 Pathway of Decomposition of Vitamin C

Following the vitamin C measurement, the pathway of the decomposition of ascorbic acid ($C_6H_8O_6$) was determined. Detailed

analytical material tests determined the following decomposition processes in the flesh and skin of the fruits.

ascorbic acid ($C_6H_8O_6$) → monodehydroascorbate reductase (MDAR) → dehydroascorbic acid (DHA)

During the decomposition process, a small concentration of free radical hydrogen peroxide H_2O_2 could be detected in fruits. On the surface of fruit skin little dark spots appeared, which are typical symptoms of calcium deficiency.

3.5 Result of the $NO_3^-NO_2$ and Chloride Contamination Control

In the Table 4 you can see the result of nitrate-nitrite and chloride measurement ($mg.kg^{-1}$) in the case of the two varieties, according to the control and fruit thinned groups

Table 4 Result of nitrate-nitrite and chloride measurement ($mg.kg^{-1}$)

Idaho			Gala Must		
	fruit thinning	**control**		**fruit thinning**	**control**
NO_2	<1	<1	**NO_2**	<1	<1
NO_3	3	1	**NO_3**	1	5
Cl-	46	38	**Cl-**	25	34

4 Conclusions

The χ^2-test, a pure fit test, was used to determine whether a significant difference could be detected in the yield results of both apple varieties separately, on the one hand, in the harvests after fruit thinning, and on the other hand, in the harvests without prior fruit thinning. We found that in the case of both apple varieties, there is a significant difference between the yield of successive harvests, regardless of whether fruit thinning took place before the harvest or not. The χ^2-test of homogeneity analysis was used to determine whether the yield results of the three-three simultaneous harvests after fruit thinning for both apple varieties and also the three-three simultaneous harvests without prior fruit thinning for both apple varieties, come from the same basic population. We found that in the case of the Idaho and Gala Must apple varieties, the yields of the simultaneous three-three harvests come from significantly different basic populations, regardless of whether fruit thinning was done before the harvest or not. In other words, this means that the yield of the two apple varieties, regardless of whether there was fruit thinning or not, differs significantly from each other in favour of the yield of Gala Must. We experienced a single exception, namely, during the first harvest, both with fruit thinning and without fruit thinning, Idaho achieved a significantly higher yield than Gala Must.

The χ^2-test was also used to determine whether, for both apple varieties separately, a significant difference could be detected in the yield results of the pairs of harvests after fruit thinning and those without prior fruit thinning. We also found that in the case of both apple varieties, within the same harvest, there is a significant difference between the yield per pair of harvests with fruit thinning and those without fruit thinning. Namely, in the case of both Idaho and Gala Must, during the first two harvests, after fruit thinning, we achieved a significantly higher yield than without fruit thinning. On the other hand, also in the case of both apple varieties, the third harvest resulted in a significantly higher yield in the case without fruit thinning.

4.1 Discussion

From the experimental results of the two early apple varieties we concluded that the effectiveness of fruit thinning depends on the variety. From an economic aspect of view, it pays off if the purchase prices of apples are high during the first harvest, or if they do not decrease at all in the given year. The trade of early apples can also depend on storage problems. During our material research, we determined that following three months of storage, vitamin C decomposed in the flesh of the apples. In this way, it loses its value for the processing industry. Short-term storage, as well as the low nitrate-nitrite and chloride content, allows it to be used as baby food and in pastries.

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