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Effect of Pruning Time on Yield and Quality of Apple (*Malus domestica*) Varieties in Arsi Highlands, Ethiopia

Gizaw Wegayehu Tiahun[1]*, Fekadu Gebretensay[2], Demis Fikre[1], Awoke Ali[3], Dasta Tsagaye[1] and Nimona Fufa[1]

[1]*Kulumsa Agricultural Research Center (KARC), P.O. Box 489, Asella, Ethiopia*
[2]*Debre Zeit Agricultural Research Center, P.O. Box 32, DebreZeit, Ethiopia*
[3]*Fogera National Rice Research and Training Center, Wereta, Ethiopia*

Abstract

An apple tree pruning experiment was conducted to investigate the effect of pruning time on yield and quality of apple fruits at Kulumsa Agricultural Research Center, Southeast Ethiopia, during the cropping seasons of 2019 and 2020, in two sets each year. Eight treatment combinations of two varieties (Ana and Princesa) and four times of pruning (immediately after harvest, when entering dormancy, just before dormancy break, and no pruning (control)) were studied in the warmest and coldest seasons of the production year. The treatments were laid out in a randomized complete block design (RCBD) with factorial arrangements in three replications. The interaction effect of apple varieties with the time of pruning was statistically significant ($P \leq 0.01$) in all yield and yield-related attributes: total fruit yield per tree (kg), marketable fruit yield per tree (kg),number of total and marketable fruits per tree, and average fruit weight (g). Similarly, the interaction effect showed non-significant differences ($P<0.05$) on the quality attributes of fruit length, fruit diameter, and total soluble solids (obrix), except for fruit PH. From the results obtained, variety by time of pruning combination suggests that pruning applied on apple trees just before dormancy break could be recommended for higher productivity and quality of apple in the Kulumsa area. In general, further research needs to be done in different apple-growing areas, including other domestically adapted and produced varieties, for conclusive recommendations in the country.

Keywords: Bud break; Dormancy; Pruning time; TSS

Introduction

Apple *(Malus domestica)* is a fruit-bearing deciduous tree of the Rosaceae family native to Asia and Europe (Janick and Moore, 1996; Ferree and Warrington, 2003). The round (pome-shaped) apple fruit is one of the most extensively farmed fruits in the world. Its colors range from green to red. When grown from a seed, an apple tree can take six to ten years to start bearing fruit and reach maturity. Small to medium-sized trees with a central trunk that splits into multiple branches, apple trees can grow to heights of 5 to 10 meters [1].

In 2018, world apple production was 111 million tons (FAOSTAT, 2018). China is the world's leading apple producer, followed by the United States, Poland, and Turkey (FAOSTAT, 2019) [2]. In Africa, South Africa, Egypt, and Algeria are the three largest apple producers, with total production of 872,093, 731,940, and 511,816 tons, respectively (FAOSTAT, 2019). The introduction of apple trees to the tropical country of Ethiopia can be traced back to the 1950s. British Protestant missionaries first introduced apple seedlings for planting within the grounds of their homes in the town of Chencha, in the Gamo highlands of southwestern Ethiopia (Hayesso, 2008; Ashebir et al., 2010; Girmay et al., 2014) [3].

In the tropics, apple trees need careful management to maintain high yields. This includes bending shoots, pruning tops, and dropping leaves from trees. The flowers are also removed to encourage growth until the first fruit is set, usually after two years of life. Pruning can also be defined as removing part of the plant to achieve the desired crown structure and exploiting leaf density by removing non-productive branches of fruit trees (Rom and Ferree, 1985). Ferree et al. (2003) define pruning as "the art and science of cutting away a portion of the plant for horticultural purposes". Summer pruning in apple orchards can be traced back to the 17th century and has attracted scientific attention since 1903 (Marini and Barden, 1987) [4]. Pruning during dormancy, when defoliation occurs, is most important to control vigor. This process requires a skilled workforce and is time-consuming and expensive. This is the plant's ability to divert some of its water and nutrients from one part of the growing point to another.

Excessive tree vigor can affect flower bud formation and fruit set, reducing fruit quality, causing poor growth, and delayed fruiting. Thus, pruning is done to restrict excessive vegetative growth and maintain a balance of leaf-to-fruit ratio, fruit size, fruit color, and other quality attributes [5]. It increases auxin activity by approximately 60%, gibberellins by 90%, and cytokinins by 90% (Grochowska et al., 1984). Pruning increases the transfer of photosynthesis to fruit and roots and regulates flower bud formation. As knowledge of the importance of light blocking and apple orchard management grows (Jackson, 1980), interest in the effects of summer pruning is growing again. Summer pruning improves light penetration and distribution within the canopy (Lakso et al., 1989) and improves fruit color by removing elongation and part of the leaves. It was shown to be a valuable method of controlling tree growth (Day et al., 1989; İkinci, 1999; Hossain et al., 2006; Demirtaş et al., 2010a; Bayazit et al., 2012), increasing flowering (Day et al., 1989), increasing fruit color (Taylor and Ferree, 1984; İkinci, 1999; Hossain and Mizutani, 2008; Bayazit et al., 2012), increasing soluble solids concentration (İkinci, 1999; Miller et al., 2001; Hossain et al., 2006; Demirtaş et al., 2010a), increasing flower bud formation (Miller, 1982), and decreasing content of titratable acid (İkinci, 1999; Hossain et al., 2006; Hossain and Mizutani, 2008) [6].

***Corresponding author:** Gizaw Wegayehu Tiahun, Kulumsa Agricultural Research Center (KARC), P.O. Box 489, Asella, Ethiopia, E mail: gizawweg21@gmail.com

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Removal of the apical portion of the shoots by pruning alters the hormonal status between the meristems, resulting in stimulation of the lateral buds, induction of branching, and increased photosynthesis in the basal leaves (Mika, 1986). The relationship between vegetative and reproductive growth influences the quantity and quality of fruit produced by apple trees. Pruning a young tree controls its shape by developing a strong, well-balanced framework of scaffold branches. Unwanted branches should be removed or cut back early to avoid the necessity of large cuts in later years. The preferred method of pruning and training apple trees in the home garden orchard is the central leader system [7]. Pruning in late winter consists of removing undesirable limbs as well as tipping terminals to encourage branching. Summer training is most beneficial if done in early June (Rob, 2003).

The main purpose of pruning and training is to develop a strong tree framework that can support fruit production and remove dead, diseased, and broken branches. Proper pruning increases crop quality and value. Apple trees need pruning every year. Fruit quantity and quality are determined by the relationship between vegetative and reproductive growth, and excessively vigorous wood can result in fruit loss [8]. Apple trees need plenty of sunlight, and shade is a limiting factor for apple fruit development. Large penetrations into the canopy of a standard and unpruned apple tree gradually decrease with the depth of the penetration. The top layer of the canopy still has 60-100% full sunlight, but the middle layer only has 30-59%. The bottom layer of the canopy is even thinner. Therefore, pruning is essential for apple fruit growth (Ferenc, 2008) [9].

Improper pruning times and pruning methods reduce fruit yield and fruit quality, generally resulting in upright branches and severe branch breakage when the fruit is heavily loaded. This can significantly reduce tree productivity and shorten tree life. Improved and commercial apple varieties are available in Ethiopia, and cultivation is becoming common in some potential highland areas [10]. However, apple fruit productivity and quality are still inferior to imported fruit. The timing of apple orchard pruning is among the main factors contributing to the low productivity and quality of apples in this country. Hence, this experiment was initiated for the purpose of investigating how the timing of pruning affects the yield and quality of apple fruits [11].

Materials and Methods

Description study area

The study was carried out at the Kulumsa Agricultural Research Center (KARC), which is situated in Tiyo District, Arsi Administrative Zone of the Oromia Regional State, 167 km southeast of Addis Ababa, at an elevation of 2210 m.a.s.l. during the main growing seasons of 2018, 2019, and 2020. The center is latitude 8° 00̲ to 8° 02γN and longitude 39° 07γ to 39° 10γE. According to Abayneh et al. (2003), it is situated on topography that is extremely gently undulating and has a gradient of 0 to 10% [12]. The region has a wet agro-climatic condition, with an average annual rainfall of 832 mm and a unimodal rainfall pattern that has a protracted rainy season from March to September and a peak season from June to August. There are three main types of soil in the area: eutric vertisol, vertic livisol, and vertic cambisol. The mean annual maximum and lowest temperatures are 23.2 and 10 °C, respectively (Abayneh et al. 2003) [13].

Experimental materials, treatments, design, and field management

A pruning time experiment on two commonly grown low-chill apple varieties, Ana and Princesa was carried out in the orchard of GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), situated at KARC. A total of eight (8) treatment combinations comprised of four times of pruning (immediately after harvest (IAH), when entering dormancy (WED), just before dormancy break (BDB), and control (no pruning) and two varieties of apple (Ana and Princesa) were studied [14]. The treatments were laid out in a factorial arrangement using a randomized complete block design in three replications. A total of 96 apple trees (4 years old) were assigned to the experiment from both varieties; out of these, trees 4 were used as an experimental unit (plot) and received pruning treatment. In the first year of the experiment (2018), all apple trees in the orchard were simultaneously defoliated and pruned for uniformity. During the coldest and warmest months of the year in 2019 and 2020, the pruning treatments were employed in two independent sets of evaluations. In the coldest seasons (1st set) started from the first week of September, treatments were applied every two weeks for four weeks. During the warmest season (2nd set) started at the end of April, treatments were applied in a similar fashion as before. All the experimental fruit trees have received the recommended agronomic management practices, including weeding, watering, cultivation, fertilization, training, etc., during the experimental period [15].

Data collection and statistical analysis

Data on fruit yield and yield-related attributes, including total fruit yield per tree, marketable fruit yield per tree, total number of fruits per tree, marketable number of fruits per tree, and average fruit weight, were collected. The quality parameters collected were fruit length (cm), fruit diameter (cm), total soluble solids (obrix) and fruit PH [16].

Data for the above parameters were subjected to analysis of variance (ANOVA) according to the method described in Gomez and Gomez (1984) using R software (R Core Team, 2020). Significant differences between treatment means were compared at 5% level of significance using the least significant difference test. To test for homogeneity of error variance, we used the maximum F-ratio as a shortcut, as recommended by Hartley (1950), given that the experiment was conducted over two sets of the 2019 and 2020 years [17].

Results and Discussions

Yield and yield components

Total and marketable fruit yield per tree: The analysis showed that there were highly significant differences (P≤0.01) in the total and marketable fruit yields of the two apple varieties pruned at four different physiological stages (Table 1). As a result, in both of the year's pruning seasons, variety Ana produced considerably higher total and marketable fruit yields per tree when pruned just before dormancy break (BDB), followed by the unpruned control (NP) [18]. When compared between the two pruning seasons, pruning during the coldest season yielded more than pruning during the warmest season in each of the four pruning times tested for both varieties. Ana was found to be superior to Princesa in fruit yield regardless of the time and season of pruning, showing varietal differences. Nevertheless, the time of pruning did not significantly affect fruit yield per tree in the case of variety Princesa, though the coldest season pruning provided higher fruit yields than the warmest season pruning [19]. However, the fruit defoliation rate is high during the fruiting season, probably due to the highest number of fruits per tree and the failure of the tree to supply nutrients for the control (unpruned), especially for the Ana variety.

The Princesa variety was considered a pollinator, was planted in a 1: 4 ratio (1 Princesa to 4 Ana), was inherently low-yielding, but had

Table 1: Interaction effects of time of pruning and variety on marketable and total yield of apple fruits in 2018 and 2019.

Treatment Combinations		Total fruit yield (kg plant^{-1})		Marketable fruit yield (kg plant^{-1})	
Variety	**Time of pruning**	**Warmest season**	**Coldest season**	**Warmest season**	**Coldest season**
Ana	IAH	2.98^{bc}	4.58^{c}	1.63^{b}	3.63^{b}
Ana	WED	2.39^{c}	3.98^{c}	1.44^{b}	3.2^{b}
Ana	BDB	4.72^{a}	8.26^{a}	3.2^{a}	7.12^{a}
Ana	NP	3.61^{b}	5.98^{b}	1.85^{b}	4.11^{b}
Princesa	IAH	0.66^{d}	1.19^{d}	0.45^{c}	0.99^{c}
Princesa	WED	1.15^{d}	1.94^{d}	0.65^{b}	1.44^{c}
Princesa	BDB	0.63^{d}	1.56^{d}	0.4^{c}	1.2^{c}
Princesa	NP	0.73^{d}	1.09^{d}	0.42^{c}	0.92^{c}
Mean		2.11	3.57	1.26	2.83
Significance level		**	**	**	**
LSD (5%)		0.82	1.27	0.46	0.96
CV (%)		32.8	30.18	32.65	28.85

Means within a column having the same letters are not significantly different. * and ** are significant at 5% and 1% probability levels, respectively. CV: coefficient of variation; LSD: least significant difference. IAH: immediately after harvest; WED: when entered into dormancy; BDB: just before dormancy break; NP: no pruning (control).

a significant impact on total and marketable fruit yield. Fruit yields were numerically higher and lower from pruning the variety when it entered dormancy and was left unpruned, respectively, for this variety; however, it was statistically non-significant [20]. The yield potentials of both apple varieties were expressed when pruning was done during the coldest months (September and October), though differences were obtained among the four pruning schedules. From the results obtained, the lowest fruit yield was obtained from apple trees that were pruned immediately after harvest without waiting and letting the plants undergo dormancy. Therefore, the optimum time for pruning apple trees in the study area could be during dormancy but before they are broken.

Day et al. (1989) reported that pruning at the right time could increase flowering. Bound (1999) suggests that the vegetative wood in a tree competes with fruit for carbohydrates, and because a small tree has a much smaller vegetative mass than a large tree, it can convert a higher percentage of its photosynthetic production into fruit rather than vegetative growth, with higher fruit yields per tree or hectare. This argument can also be applied to pruned trees just before dormancy break versus unpruned trees, as well as the inherent natures of the two apple varieties included in this experiment [21].

Number of fruits per tree and fruit weight: Analysis of variance revealed that the time of pruning significantly ($P \leq 0.01$) affected the total number of fruits per tree, the number of marketable fruits per tree, and the average fruit weight (g) (Table 2). Markedly, the highest total and marketable numbers of fruits were recorded from pruning time before dormancy break (BDB) for both varieties, followed by the unpruned control (NP), while the least total and marketable fruit numbers were obtained from pruning that happened immediately after harvest (IAH), which also holds true for both varieties. Similar to fruit yield per tree as discussed above, Ana was superior to Princesa in total and marketable fruit number per tree. Likewise, pruning during the coldest months yielded more fruits per tree than in the warmest season for both varieties [22].

The total average number of fruits per tree recorded from Ana increased from 48.51 (warmest season) to 107.8 (coldest season) when pruning occurred before dormancy break. However, the average number of marketable fruits per tree increased from 41.89 to 93.08 during the same pruning time and months, respectively. In contrast, the lowest values were obtained from the control (un-pruned) trees of the Princesa variety in the warmest months for both the total and marketable number of fruits per tree [23].

The highest average fruit weight (144.93 g) was scored from the Ana variety when pruned immediately after harvest (IAH), followed by pruning when entered into dormancy (WED) and the control (NP). The lowest average fruit weights were recorded from the Princesa variety (44.7 g and 54.25 g) when pruned during the warmest and coldest seasons, respectively, before dormancy break [24]. The results confirmed that in both varieties, the number of fruits per tree and average fruit weight were negatively correlated. This is a physiological reality: the higher the number of fruits per tree, the higher the competition for sink, which leads to reduced fruit size and weight, whereas the smallest the number, the lower the competition, which results in bigger fruits and weight.

Princesa variety, when pruned in the physiological stage just before dormancy break, fruit numbers and weight found from the coldest season or months pruned trees tended to be slightly higher. The market value of apple fruit is determined primarily by the segregation of fruit into various size and color categories. Analysis of fruit distribution into selected representative commercial size categories revealed that the coldest season pruning increased the percentage of fruits in the largest size category [25].

This result might be related to the number of fruits per tree and other factors, showing that the pruning time immediately after harvest resulted in fewer fruits but larger fruits per tree. There may have been an increase in photosyntate available to the fruit of colder-season pruned trees due to an increase in photosynthetic photon flux density and/or the removal of competitive sinks, that is, waterspouts. Moreover, improved light exposure may have strengthened fruit sink activity, thus increasing fruit size, as explained in Day et al. (1989) [26].

The total and marketable number of fruits per tree and average fruit weight obtained from the warmest-season pruned trees probably resulted from a reduced pool of available assimilate, as over 20% of the foliage is usually removed with summer pruning, as reported by Mika (1986). Similarly, fruit set and size can be decreased by competition from vegetative shoots (George et al., 1996; Jackson and Palmer, 1997a, b) and from other fruits (Lakso et al., 1995). However, fruit size was adversely affected by the time of pruning, showing irregular results with other attributes, resulting in the highest mean from pruning immediately after harvest for the Ana variety. This might be due to multiple factors determining fruit size (Bound and Summers, 2000).

Table 2: Interaction effects of time of pruning and variety on marketable and total yield of apple fruits in 2018 and 2019.

Treatment Combinations		Total number of fruits per tree		Marketable fruit number per tree		Average fruit weight (kg)	
Variety	**Time of pruning**	**Warmest season**	**Coldest season**	**Warmest season**	**Coldest season**	**Warmest season**	**Coldest season**
Ana	IAH	17.33^{c}	38.83^{c}	14.31^{c}	31.79^{c}	119.1^{a}	144.93^{a}
Ana	WED	17.93^{c}	39.83^{c}	14.45^{c}	32.11^{c}	83.35^{b}	102.74^{b}
Ana	BDB	48.51^{a}	107.8^{a}	41.89^{a}	93.08^{a}	63.57^{c}	77.85^{c}
Ana	NP	31.16^{b}	77.12^{b}	23.69^{b}	52.65^{b}	73.23^{bc}	87.99^{bc}
Princesa	IAH	6.38^{de}	14.17^{e}	5.31^{de}	11.8^{e}	67.75^{bc}	82.1^{c}
Princesa	WED	10.8d^{d}	24^{d}	8.28^{de}	18.4^{d}	64.44^{c}	78.69^{c}
Princesa	BDB	10.31^{de}	25.76^{d}	8.58^{d}	21.4^{d}	44.7^{d}	54.25^{d}
Princesa	NP	5.81^{e}	12.92^{e}	4.79^{e}	10.64^{e}	74.17^{bc}	89.1^{bc}
Mean		18.53	42.51	15.16	33.99	73.7	89.7
Significance level		**	***	***	***	**	**
LSD (5%)		4.52	9.67	3.4	6.51	15.75	
CV (%)		20.68	19.28	20.95	16.24	18.1	16.68

Means within a column having the same letters are not significantly different. *, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively. CV: coefficient of variation; LSD: least significant difference. IAH: immediately after harvest; WED: when entered into dormancy; BDB: just before dormancy break; NP: no pruning (control).

Table 3: Main effect of time of pruning and variety of quality characteristics of apple fruits in 2018 and 2019.

	Fruit length (cm)		Fruit diameter (cm)		Total soluble solid (^{o}Brix)	
Variety	**Warmest season**	**Coldest season**	**Warmest season**	**Coldest season**	**Warmest season**	**Coldest season**
Ana	5.51^{a}	6.34^{a}	5.07^{a}	6.14^{a}	10.34^{b}	11.15^{b}
Princesa	4.59^{b}	5.26^{b}	4.73^{b}	5.75^{b}	10.76^{a}	11.61^{a}
Mean	5.05	5.8	4.9	5.95	10.55	11.38
LSD (5%)	0.15	0.17	0.19	0.23	0.26	0.28
Significance	**	**	**	**	**	**
Time of pruning						
IAH	5.29^{a}	6.08^{a}	5.05^{a}	6.12	11.08^{a}	11.95^{a}
WED	5.14^{ab}	5.91^{ab}	5.02^{ab}	6.09	10.10^{c}	11.22^{bc}
BDB	4.76^{c}	5.46^{c}	4.77^{b}	5.77	10.41^{bc}	10.89^{c}
NP	5.02^{b}	5.76^{b}	4.77^{b}	5.81	10.61^{b}	11.45^{b}
Mean	5.05	11.61	4.9	5.95	10.55	11.38
Significance level	**	**	*	Ns	**	**
LSD (5%)	0.27	0.24	0.27	0.32	0.37	0.4
CV (%)	4.9	5.05	6.72	6.52	4.16	4.21

Means within a column having the same letters are not significantly different. . *and ** are significant at 5% and 1%, probability levels, *, significant at 5%. CV: coefficient of variation; LSD: least significant difference. IAH: immediately after harvest; WED: when entered into dormancy; BDB: just before dormancy break; NP: no pruning (control).

The highest mean value of fruit size can be correlated with the smallest fruit number per tree [27].

Fruit qualities as affected by time of pruning and variety

The main effect of apple varieties and times of pruning significantly ($P<0.01$) influenced the fruit size and quality parameters; fruit length (cm) fruit diameter (cm) and total soluble solids (Table 3). The highest values of fruit length and diameter were recorded from Ana variety and pruning immediately after harvest (IAH).

These results are consistent with those of Bound and Summers (2000), who found that pruning during the dormant winter period, resulted in better fruit quality than when pruning was delayed until after fruit set. The mechanism by which this occurs is not clear but may involve cell numbers and size. Although summer pruning is used to improve fruit color, it can adversely affect fruit size, sugar content, and fruit skin finish (Bound and summers, 2000) [28].

On the contrary, the highest mean values of fruit total soluble solids (TSS) were registered for the Princesa variety and pruning times immediately after harvest. The Princesa variety out produced statistically higher magnitudes of TSS for pruning before dormancy breaks and no pruning (control) in the coldest and warmest seasons [29]. The increase in the mean values associated with pruning apple trees during the coldest months of the year might be due to the fulfillment of the chilling requirements of the crop. These findings are consistent with Taylor and Ferree (1984) and Bound and Summers (2000), who found fruit total soluble solids increased with pruning severity in winter and reduced with summer pruning; however, the converse was true for spring-pruned trees. It is also well documented that canopy light distribution is important for high-quality apple production (Heinicke, 1966; Jackson, 1970; Robinson et al., 1983). In agreement with the current findings, pruning increases fruit color (Taylor and Ferree, 1984; İkinci, 1999; Hossain and Mizutani, 2008; Bayazit et al., 2012), as it does for soluble solids concentration (İkinci, 1999; Miller et al., 2001; Hossain et al., 2006; Demirtaş et al., 2010a) (Table 4).

Pruning treatments influenced the fruit PH of apple fruits significantly ($p\leq0.05$) in the warmest and coldest seasons (Table 4). Analyses of the PH contents of apple fruits showed that in the coldest season, pruned trees generally had a higher magnitude of fruit PH for the Princesa variety of pruned trees when they entered dormancy,

Table 4: Interaction effect of time of pruning and variety on apple fruits PH at Kulumsa in 2018 and 2019.

Treatment Combinations		Fruit pH	
Variety	Time of pruning	Warmest season	Coldest season
Ana	IAH	3.54^{cd}	3.76^{cd}
Ana	WED	3.53^{d}	3.74^{d}
Ana	BDB	3.53^{d}	3.74^{d}
Ana	NP	3.58^{c}	3.8^{c}
Princesa	IAH	3.77^{a}	4.0^{a}
Princesa	WED	3.79^{a}	4.03^{a}
Princesa	BDB	3.71^{b}	3.93^{b}
Princesa	NP	3.77^{a}	4.0^{a}
Mean		3.65	3.87
Significance level		*	*
LSD (5%)		0.04	0.05
CV (%)		1.03	1.05

Means within a column having the same letters are not significantly different. *, significant at 5%. CV: coefficient of variation; LSD: least significant difference. IAH: immediately after harvest; WED: when entered into dormancy; BDB: just before dormancy break; NP: no pruning (control).

followed by unpruned trees immediately after harvest. Numerically, the fruit's PH has increased while pruning time has changed from the warmest to the coldest season. This might be due to the higher water content of the soil and the fruit at harvest. Previously reported results highlighted that pruning treatments conducted on 9-year-old peach and early and mid-season peach varieties budding on strong rootstock decreased titratable acidity value in trees with summer pruning more than in those with winter pruning (Hossain and Mizutani, 2008; and İkinci et al., 2014) [30].

Conclusion and Recommendation

Fruit yield and quality of apples can be influenced by interactions among the genetic potential of varieties, plant nutrient uptake, and various agronomic management techniques. To improve fruit quality and yield and reduce over cropping, mature trees should be pruned. This experiment demonstrated that the time of pruning can affect apple fruit yield, fruit weight, fruit number, fruit size, fruit total soluble solids, and fruit PH. The specific mechanisms by which this occurs are not clear, but it might be the difference between varieties and their responses to crop management practices, in this case pruning at different physiological stages. From the results obtained, pruning just before dormancy break was found to increase fruit number and yield per apple tree, as well as it showed significant effect on fruit size (fruit length and fruit diameter) and fruit PH. Besides, when the pruning occurs during the coldest months of the season showed the optimum results in all fruit yield and yield related traits as well as for quality parameters measured for both varieties. Therefore, just before dormancy break during the coldest months could be recommended for apple production under Kulumsa and other areas of similar conditions. Further research is required to substantiate the suggestion that time of pruning just before dormancy break results in an increase in fruit yield over different apple growing environments.

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