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Influence of fertilization on fruit production and storage capacity in some apple varieties

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Abstract
Apple fruits are one of the most commonly consumed fruits that can be enjoyed almost all year round. In order to obtain high quality fruits, it is imperative to apply fertilizers according to maintain the proper nutritional balance in the trees. The current research has been carried out to investigate the influence of fertilization in three apple varieties from the first year of production. The results obtained in this study emphasize that tree fertilization is essential to ensure optimal growth, superior fruit quality and high yield. Proper fertilization in the first year of production helps to grow and develop trees properly. This hypothesis was validated in terms of tree growth parameters and yield (annual growths, trunk diameter, trunk cross-sectional area, yield efficiency), fruit physical and chemical characteristics (fruit length, fruit weight, firmness, soluble solid content, pH, water content of the fruits). The results of this research reveal clear and significant differences between unfertilized and fertilized trees in all varieties analyzed within each parameter analyzed. Moreover, it has been observed that fruits harvested from fertilized trees had a longer shelf life and preserved much better compared to those harvested from unfertilized trees.

Keywords: fruit quality, yield, annual growth, fruit firmness, TSS

Introduction

Apples (*Malus domestica* Borkh.) are among the most widely cultivated and consumed fruits globally, appreciated for their nutritional value, therapeutic effects and economic importance [19,21]. They are a key source of essential vitamins, minerals, dietary fiber, and antioxidants, which contribute to human health and well-being [31,4]. As one of the leading fruit crops in temperate regions, apples hold significant value in global agriculture, with millions of tons produced annually [13,15]. The cultivation of apple trees is not only a critical agricultural practice but also an important industry, supporting various sectors, including food processing, retail, and export [23, 27]

The successful cultivation of apples depends on various factors, including soil fertility, climate conditions, and effective orchard management practices. Among these, fertilization plays a pivotal role in optimizing growth, health, and productivity of apple trees [16]. Proper fertilization ensures that trees receive the necessary nutrients required for healthy vegetative development, robust root systems, and high-quality fruit production [20]. Nitrogen, phosphorus, potassium, and trace elements are particularly vital, as they support key physiological processes such as photosynthesis, cell division, and fruit development [17, 12].

Fertilization not only influences the growth rate of apple trees but also directly affects fruit quality, including size, taste, aroma, texture, and shelf life [7, 15]. A well-balanced fertilization strategy helps to optimize nutrient uptake, thereby enhancing fruit size, improving sugar content, and promoting uniform ripening [25]. Moreover, adequate nutrition strengthens the trees' immune system making them resistant to various pests, diseases, and environmental stresses, contributing to a sustainable and profitable orchard [28]. In contrast, nutrient imbalances or deficiencies can lead to poor tree performance, reduced yields, and suboptimal fruit quality [6].

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The interaction between fertilization and apple tree growth is complex, as the timing, type, and amount of fertilizer applied must be tailored to the specific needs of the variety, soil conditions, and climatic factors of the region. Research on fertilization practices in apple cultivation has demonstrated that proper nutrient management not only boosts yield and fruit quality but also contributes to long-term tree vitality and orchard sustainability. Consequently, understanding the effects of fertilization on tree health and fruit quality is crucial for developing effective orchard management strategies and achieving optimal production outcomes.

In this context, this study aims to explore the role of fertilization in apple cultivation, focusing on its impact on tree growth, fruit development, and overall productivity. In addition, the storage capacity of the apple fruits was also monitored in order to determine the differences in shelf life between fruits stemming from fertilized and unfertilized trees

Material and Method

The current research has been carried out in a family orchard that has been established in 2020 located in Păuca, Sibiu County, Romania (46°00′37″N 23°53′22″E). The apple cultivars chosen for this research were ‘Pinova’, ‘Idared’ and ‘Generos’ (Figure 1) which were grafted on M9 and M26 rootstocks.

(a) (b) (c)

Figure 1. Apple cultivars chosen for this study. (a) – Pinova; (b) – Idared; (c) – Generos (Source: Authors’ own collection)

The trees were planted in rows, 4 m apart and at 2 m distance between the trees/row. The intervals between the rows were grassed with frequent grass mowing and maintenance of 1.5 m wide herbicide strips under the trees along the rows. The study was conducted on 24 randomly chosen trees of each cultivar out of which 12 were subjected to fertilization while the other 12 were considered control. Four trees were treated as one repetition. The agricultural practices applied in the orchard are presented in Table 1.

Table 1. Agricultural practices applied in the orchard in 2022 and 2023

No.	Agricultural practice	Date
1.	Spraying with Kupferol, Ovipron + Mospilan	1st March
2.	Spraying with Cupridin 50 WP	7th March
3.	Application of manure - 5 kg/tree	25th March
4.	Spraying with Chorus 50, Karate Zeon – Pinova	15th April
5.	Spraying with Chorus 50, Karate Zeon Idared	18th April
6.	Mowing the grass between the rows	20th April
7.	Spraying with Chorus 50, Karate Zeon Idared	28th April
8.	Spraying with Kumulus DF	1st May
9.	Application of Liquid Fertilizer from Cow Manure - 10 L/tree	6th May
10.	Spraying with Affirm, Karate Zeon	27th - May
11.	Application of Foliq	3rd - June
12.	Mowing the grass between the rows	15th - June
13.	Spraying with Luna Experience, Decis 25 WG - 45 gr/ha	15th - September
14.	Fruit harvest	29th - September

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The weather conditions during the experimental years were favorable for apple tree cultivation (Table 2). The average annual temperature was ranging between 10.4-11.2°C which was slightly higher than the optimum annual temperatures recommended for apple trees (7.5 and 11°C). Air humidity varied between 70.90% and 72.60% which was in accordance with the optimum average annual humidity. The rainfall was higher in 2023 (993.10 mm) as compared to 2022 (670.51 mm) which was more evenly distributed during the growing season and led to an optimum growth and productivity of the apple trees. Extreme summer temperatures were recorded in both years, 34°C on the 23rd of July in 2022 and 35.6°C on the 27th of August in 2023. Based on the meteorological data, an increase of approx. 1°C was observed in 2023 comparing to 2022 regarding annual average temperatures which demonstrates the ongoing and unavoidable global warming process.

Table 2. Meteorological data of the experimental sites recorded in 2022 and 2023

Meteorological parameter/year	2022	2023
Average annual temperature:	10.4°C	11.2°C
Average annual maximum temperature:	16.8°C	17.5°C
Average annual minimum temperature:	4°C	5.1°C
Average annual humidity:	70.90%	72.60%
Rain or snow precipitation total annual:	670.51 mm	993.10 mm
Annual average visibility:	9.7 km	9.8 km
Annual average wind speed:	8.2 km/h	8.4 km/h
Total days with rain:	146	179
Total days with snow:	31	35
Total days with thunderstorm:	39	36
Total days with fog:	42	28
Total days with hail:	1	1
Days of extreme values		
The highest temperature	34°C on 27th August	35.6°C on 23rd July
The lowest temperature	-22°C on 10th February	-20°C on 25th January
The maximum wind speed	82.8 km/h on 26th July	

Source: https://en.tutiempo.net/climate

On the 15th of February 2022 and 2023 trunk diameters were measured at 30 cm height using and electronic caliper. Afterwards, the trunk cross-sectional area (TCSA) and growth rate (GR) were calculated using the following equations:

$TCSA = \pi r^2$, *where r – radius of the circle* [29];

$GR\ (\%) = \frac{D2-D1}{T}\ x\ 100$, *where D1 is the trunk diameter from 2022 and D2 is the trunk diameter from 2023* [18].

Annual shoot growth was determined by measuring 10 annual shoots/tree with a flexible measuring tape and then averaged.

Observations regarding fruit number and fruits per tree were made at the moment of harvest. Based on the fruit production/tree yield efficiency for each variety was then calculated using the formula below:

$Yield\ efficiency = \frac{yield/tree\ (kg)}{TCSA\ (cm2)}$ [14]

To determine the physical and chemical properties of the fruits, these were subjected to various measurements and analyses after harvest. In this regard, fruit length, fruit weight, fruit firmness, total soluble solids (TSS), fruit pH and fruit water content were determined using an analytical balance, portable refractometer and fruit firmness tester. The water content of the fruits was determined after dehydrating the fruits in the oven until constant weight was recached. The difference between the masses gives the quantity of water evaporated during the drying proces which was calculated using the following formula:

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$$Water\ content\ (\%) = \frac{fresh\ weight - dry\ weight}{fresh\ weight}\ x\ 100\ [1]$$

After data collection, these were subjected to statistical analyses in order to determine significant differences between the means. First, the analysis of variance was assessed and when the null hypothesis was rejected, Tukey's HSD test was performed to detect statistically significant differences between the means of different cultivars and treatments at the confidence level of $p<0.05$.

Results and Discussion

Regarding the trunk diameter, the results of this research show that phytosanitary treatments and fertilizer application to the three varieties analyzed had positive effects on the growth of the trunk diameter. The results of the Tukey test as presented in Figure 2, show that there are statistically significant differences between the unfertilized and fertilized trees in both experimental years. Thus, the largest trunk diameter was recorded in 'Pinova' variety in fertilized trees in both years (2.08 and 2.29 cm) followed by 'Idared' (1.79 and 2.21 cm) and 'Generos' (1.57 and 2.22 cm).

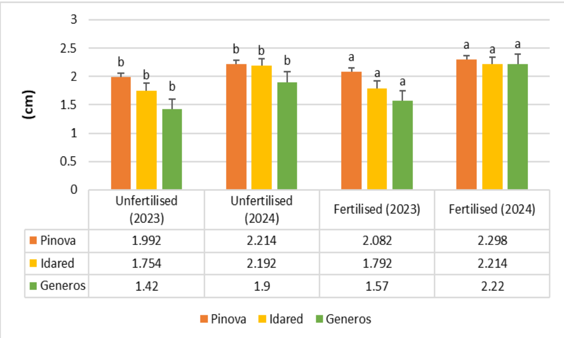

Figure 2. Trunk diameter growth of apple trees Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees according to Tukey's HSD test at p<0.05.

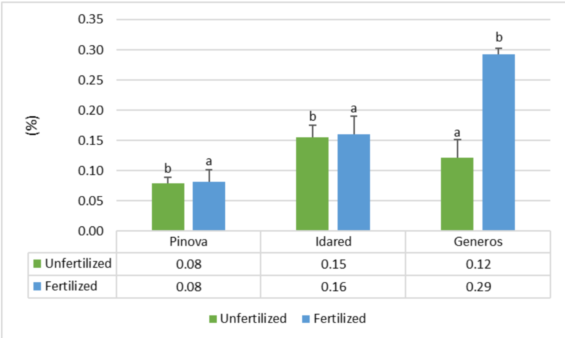

Figure 3. Grow rate of the trunk in apple trees Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees according to Tukey's HSD test at p<0.05.

The results obtained show that the growth rate of trees was more pronounced in the case of fertilized trees compared to unfertilized trees. These differences can be explained by the fact that the application of fertilizers required by trees, especially in the first years of development, can bring multiple benefits to the plant: it contributes to improved growth, the development of a stronger root system and increased resistance to diseases and pests. Therefore, it can be claimed that the importance of fertilizers and their application under assimilable forms leads to a more balanced and vigorous growth of trees [10]. However, the results also show that not all varieties have the same capacity to absorb nutrients or do not have the same needs. Liquid fertilizers are widely used in agriculture due to their benefits over solid alternatives. One of the main advantages is their quick absorption rate. Liquid fertilizers provide instant nutrient availability to plants, enabling quick repair of shortages being applicable all through the year as long as soil temperatures do not drop below 0°C. Immediacy is vital during critical growth phases like blooming and fruit setting, when the plant's nutritional demands can increase significantly. Quick absorption can boost crop yields and quality over time [24]. Although the growth rate after fertilization was significant in all varieties studied, compared to trees grown naturally without fertilizers, the most considerable growth was observed in Generos variety, followed by 'Idared', while the lowest growth rate was observed in Pinova variety (Figure 3).

Similar to trunk diameter, the cross-sectional area of the trunk was also larger in the case of fertilized trees than in those without fertilization. The differences were statistically confirmed by Tukey's HSD test. The results indicate that among the three varieties analyzed, the largest trunk cross-sectional area was recorded in 'Pinova' (an increase of 25%) followed by the 'Generos' (with an increase of 59%) as compared to the unfertilized variants named also as control (Figure 4).

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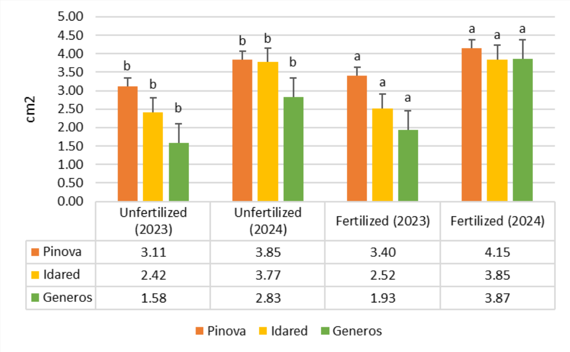

Figure 4. Trunk cross-sectional area
Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees according to Tukey's HSD test at p<0.05.

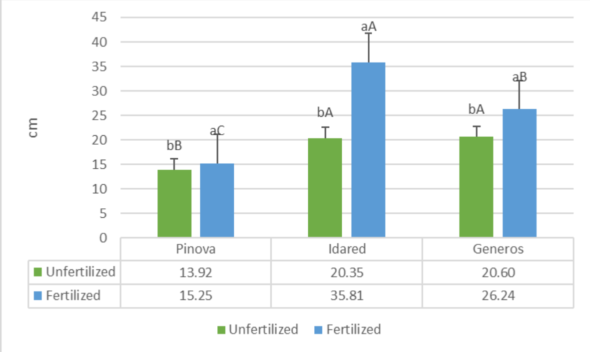

Figure 5. Annual shoot growth
Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees, while capital letter indicate significant differences between the cultivars according to Tukey's HSD test at p<0.05.

Regarding annual shoot growth, the results of the Tukey's HSD test indicate significant differences between the experimental treatments (Figure 5) indicating a positive effect of fertilizations on the length of annual shoot growth. The largest differences were recorded in Idared and Generos varieties, for which the annual growth lengths were 35.81 cm and 26.23 cm respectively. Although the average length of annual growths in the case of the Pinova variety was not very different under the influence of the fertilizers applied, these differences were statistically ensured according to Tukey's HSD test.

Researchers in the field of pomology have investigated several methods for determining yield efficiency in fruit trees. Since planting density works in conjunction with yield per tree to determine productivity per ha, researchers used canopy sizes to estimate planting density and then estimated the potential yield per ha. This approach is applicable only in case of unpruned trees. Once the canopy is reduced, and especially when the trees are pruned differently according to tree sizes, the potential yield per hectare becomes almost a meaningless calculation [3]. Another way to determine tree size is to measure the trunk near the graft point. This method of measuring tree size is less affected by canopy pruning variance and is very similar to the size of an unpruned canopy. Thus, comparing yield to trunk size can be used to determine relative productivity per ha. Yield efficiency does this by comparing yield per tree to the trunk cross-sectional area about 30 cm above the graft point. Although yield efficiency does not measure yield per ha, it enables direct comparison of trees of different sizes without the requirement to plant them at optimal densities. The results of this research show that fertilized trees have a significantly higher ratio than non-fertilized trees in terms of production efficiency (Table 3). In all varieties analyzed, the fertilized trees gave a significantly higher yield than the unfertilized ones. It can also be seen that all varieties reacted positively to the administration of fertilizers, which led to an increased production efficiency.

Physical and chemical properties of fruits are fundamental not only for their sensorial characteristics and nutritional value but also crucial for agricultural efficiency, post-harvest management and food processing. For these reasons research should be done to improving the quality and shelf-life of fruits, ensuring a stable food supply, and making fruits more accessible and beneficial for consumers worldwide [5, 30]. Considering both physical and chemical properties of the fruits, considerable variation were observed between the cultivars analyzed and also between the fertilized and unfertilized samples. In this regard, the result show that fruit diameter ranged between 6.47 and 7.42 cm (Figure 6). Beside the differences detected between the cultivars, clear significant differences were recorded between the experimental treatments as well.

Table 3. Yield efficiency of the investigated apple tree varieties under study

Variety/Treatment	Unfertilized	Fertilized
Pinova	0.64 ^{bA}	1.02 ^{aA}
Idared	0.59 ^{bA}	1.16 ^{aA}
Generos	0.42 ^{bB}	0.94 ^{aA}

Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees according to Tukey's HSD test at p<0.05.

In this regard, Pinova variety had the lowest values registered in comparison to other varieties in both experimental treatments. However, fruit size, color and taste are variety specific traits, the results show that fertilization had a positive effect on fruit size in all varieties under study. The highest value for fruit diameter was recorded in Generos variety in the case of fertilized trees (7.4 cm). The lowest value for fruit diameter was recorded in Pinova variety without fertilization (6.47 cm).

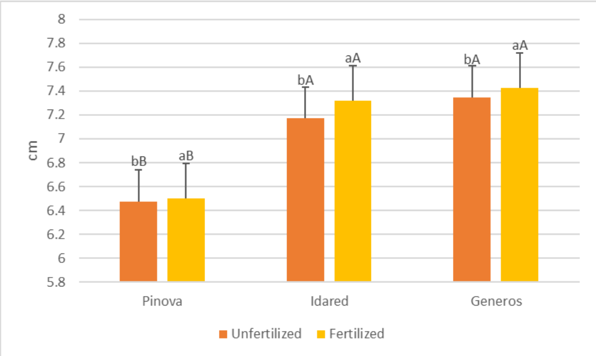

Figure 6. Fruit diameter
Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees, while capital letter indicate significant differences between the cultivars according to Tukey's HSD test at p<0.05.

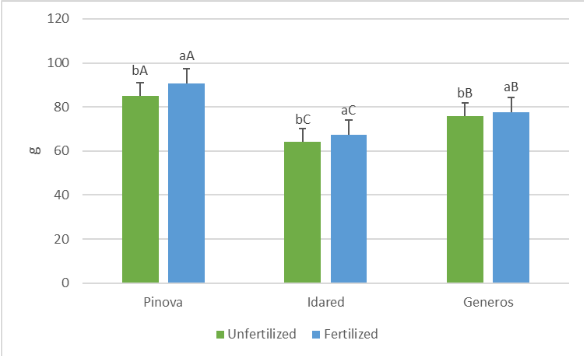

Figure 7. Fruit weight
Different lowercase letters above the bars denote significant differences between fertilized and unfertilized trees, while capital letter indicate significant differences between the cultivars according to Tukey's HSD test at p<0.05.

Fruit weight is another important fruit quality trait after fruit size [2]. Among the varieties studied, the highest fruit weight was obtained for Pinova variety, when fertilizers were applied and the lowest value for fruit weight was obtained for Idared variety in lack of fertilization (Figure 7). Similar to fruit size, it can also be seen that not only fertilization but also the variety has a significant influence on fruit weight being a specific character of each variety.

After fruit color, size and weight, fruit firmness is another crucial characteristic directly impacts consumer's sensory experience, influencing their appeal and desirability. The firmness or softness of fruits depends on the amount of water, fiber, and pectin which are present in fruit pulp and which is a direct result of their chemical profile. For example, apples tend to be crunchy due to their high cellulose content, while peaches are soft because of their lower pectin and higher water content [11]. Furthermore, skin thickness, firmness, and the presence of natural preservatives (e.g., antioxidants like vitamin C) define how long fruits can maintain their qualities after harvest. For example, apples have a waxy coating that helps slow down dehydration and spoilage, while berries require careful handling due to their delicate skin and high-water content. In this study, fruit firmness (texture) and sugar content (total soluble solids) of fruits were measured to determine their quality and their storage capacity. These characteristics are important since they influence market prices, with overripe fruits often sold at a discount or used for processing, while perfectly ripe fruits fetch higher prices in fresh markets. Therefore, in this context, fruit firmness, total soluble solid content, fruit pH and water content were determined at one-month interval through 6 months to reveal fruit quality and their storage capacity of the three apple cultivars both in the presence and lack of fertilization.

Regarding fruit firmness it was observed that all varieties regardless the treatments, exhibited a decrease in fruit firmness varying between 28.67 and 54.76% in unfertilized and 21.76-52.71% in fertilized tree fruits during the storage period (Figure 8). Fruits coming from fertilized trees succeeded to maintain their firmness for a longer period of time. The firmest fruits were Generos followed by Pinova and Idared varieties.

The results of this research highlight a positive influence of fertilization on the total soluble solids' content in the harvested fruits. The highest TSS content was identified in Pinova variety (16°Brix), followed by 'Idared'. 'Generos' had a slightly lower content (14°Brix). In all experimental variants, during storage an increase in TSS was observed (Figure 9). The highest values were recorded in 'Pinova' in both experimental variants. Generos variety, after 2 months showed a decrease in TSS content both in fertilized and unfertilized variants.

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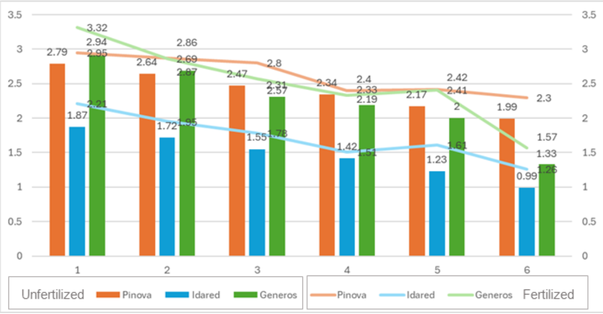

Figure 8. Fruit firmness dynamics during 6 months of storage

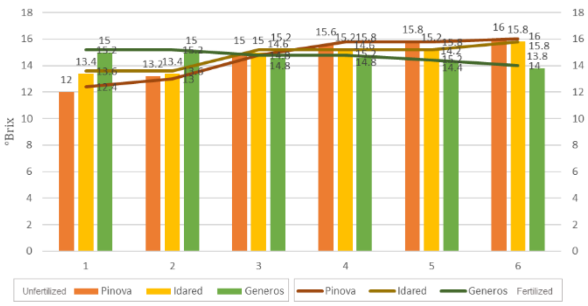

Figure 9. Total soluble solids' dynamics during 6 months of storage

The highest pH values were identified in Generos variety, followed by Pinova and Idared. During the 6 months of storage, the acidity of the fruits followed an upward trend with a slight decrease in acidity after 3 months of storage of the fruit at a temperature of 4 °C. This decrease in pH can be explained by the activity of some microorganisms and the conversion of sugar into alcohols and organic acids that contribute to the decrease in the pH value of fruits [9]. The same fluctuations were observed in both fertilized and unfertilized variants. Small differences were recorded however these differences were not statistically assured according to the statistical analyses performed (Figure 10).

The water content of the fruits coming from unfertilized trees ranged between 81.48% and 84.22%, the highest content being recorded in the fruits of Generos variety (Figure 11). The same trend was observed in the case of fertilized fruits, but the water content was higher in all the varieties analyzed. The highest value was recorded for the Generos variety (86.30%) and the lowest for the Idared variety (83.87%). Fertilization can promote better root development and function, which enhances the plant's ability to take up water from the soil. Nutrients like nitrogen and phosphorus are essential for root growth, osmotic regulation of cells, which helps retain water within the fruit. Potassium acts in synthesis of sugars and starches, which further contribute to the water-holding capacity of the fruit [22, 8].

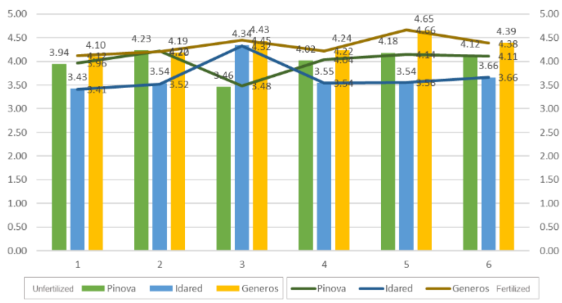

Figure 10. pH dynamics of fruits during 6 months of storage

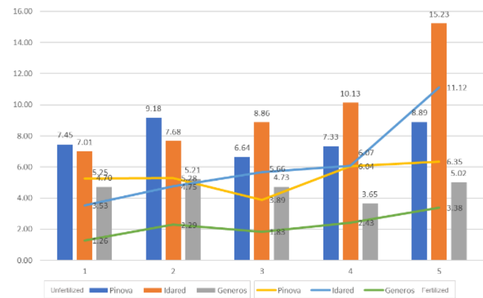

Figure 11. Dynamics of fruit water content during 6 months of storage

Conclusions

Based on the results of the current research, it can be concluded that fertilization plays an essential role in fruit tree growth and fruit quality. Proper fertilization provides trees the necessary nutrients for optimum growth, directly influencing vegetative growth through the harmonious development of shoots and leaves, which are essential for photosynthesis and, consequently, for the overall health of the tree. Well-nourished trees are more resistant to attacks from pathogens and harmful insects due to their better general health and faster recovery capacity. Balanced fertilization contributes to increasing the size of the fruit, improving taste, enhancing sugar content and aroma, and ensuring uniform ripening. It also positively influences the external appearance of the fruit. Moreover, trees benefiting from a well-planned fertilization program produce higher number of fruits, resulting in higher yield and profitability of the crop. To achieve these benefits, it is crucial that fertilization is carried out wisely, considering the specific needs of each variety, the stage of development, and the pedoclimatic conditions of the area. Varieties that have shown the best performance were 'Generos' and 'Pinova' which are recommended to be cultivated not only for the taste and aroma of the fruits, their prolonged shelf life after harvest, but also for their productivity and disease resistance.

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