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Peculiarities of quality formation of apples (*Malus domestica* Borkh.) of 'Dmiana' variety

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Abstract. The appearance, size and taste of fruit are among the main indicators of quality and marketability. These characteristics are determined by the content and ratio of biochemical components, which are influenced by the biotic and abiotic factors involved in cultivation. Studies have shown that the dry matter content of Dmina fruits is independent of rootstocks and planting schemes. However, the sugar content was significantly higher in fruits grown on M.26 rootstock with a planting scheme of 4.0×1.0 m and significantly lower in fruits grown on M.9 rootstock with the same planting scheme: 11.3% and 9.8%, respectively. Titratable acids were found in fruits grown on rootstock M.9 with a planting scheme of 4.0×0.5 m. In addition to the influence of planting scheme and rootstock, weather conditions also affected the biochemical content of Dmina fruits. Cool nights during the initial growth and development period contributed to dry matter accumulation, but negatively affected sugar synthesis. The correlation coefficients for all rootstock variants were higher than 0.703 and 0.911, respectively. The content of titratable acids depended significantly on the average daily and night-time air temperatures in the month before harvesting; this dependence was indirect and the correlation coefficients were high in all variants with rootstocks.

Key words: dray matter, sugars, titrated acids, *Malus*.

INTRODUCTION

The fruits of fruit crops are an attractive and nutritious food product, thanks to their color, shape, unique taste and aroma, rich in minerals, vitamins and other useful components of the composition (Cassano et al., 2003; Vanolia & Bucchiri, 2012; Shevchuk et al., 2021a; Shevchuk et al., 2022). Cultivated apple tree (*Malus x domestica* Borkh) (family *Rosaceae*, subfamily *Maloideae*) originated and domesticated in Central Asia and then spread to Europe and Asia thousands of years ago (Robinson et al., 2001), is one of the most common targets worldwide (Juniper & Mabberley, 2006). World production of apples in 2021 reached 93.1 million tons, of which the largest share fell on China - 45.9 million tons, the second place in terms of production was shared by Turkey and the United States at 4.5 million tons, slightly less of them were produced by the Poland (4.1 million tons). Ukraine in the world ranking of apple producers was in 12th place with a gross harvest of 1.3 million tons (https://www.fas.usda.gov/data/production/commodity/0574000).

Apples are among the most nutritious fruits in a healthy diet, particularly due to their sugar content (fructose > glucose > sucrose), organic acid content (0.2–0.8%) (Shevchuk et al., 2021b), vitamins (mainly vitamin C at 2.3–31.1 kg per 100 g of dry solids), minerals (ash content of 0.34–1.23%) and dietary fibres (2–3% with pectic substances accounting for less than 50% of apple fibres) (Kiczorowska & Kiczorowski, 2005). Campeanu et al. (2009) emphasise that apples have a well-known therapeutic value in treating various diseases; they reduce gastric secretion activity, remove toxins and have a diuretic effect. Furthermore, apples are among the most important fruits in temperate climates, renowned for their consumer value and suitability as a raw material for producing many processed goods (Mukhtar et al., 2010).

In addition to the genetic characteristics of varieties, the quality of fruits is determined by a number of environmental factors, in particular, air temperature and light regime, which significantly depends on their location in the crown (Musacchi & Serra, 2018). The weather of the growing year can greatly affect the appearance of the fruits (Bi et al., 2011; Zheng et al., 2009; McCluskey, 2010; Houston et al., 2018), that changes the commodity structure of the grown crop (Sugiura et al., 2013; Lesk et al., 2016; Dalhaus et al., 2020). Another corrective link for fruit quality is the orchard design, irrigation and pruning system (Sharma et al., 2008) and the cultivation technology itself (Tahir, 2006; Melke & Fetene, 2014). The choice of garden design and rootstock belongs to the latter. The latter has an important influence on apple productivity, including early fruiting (Tubbs, 1973), tree growth and development, fruit yield and quality, resistance to biotic and abiotic stresses, nutrient assimilation (Chaplin & Westwood, 1980), bud break (Brown et al., 1985) and fruit size (Jackson & Blasco, 1975). Currently, the dwarfing rootstocks M.9 and M.26 are used to create industrial apple orchards in many countries worldwide (Webster & Hollands, 1999). According to Lord et al. (1985), rootstock has a greater effect on tree growth and yield than on apple quality. This view is supported by other researchers, who have noted that apple quality is affected by variety and, within each variety, by rootstock and applied technology. The genotype of the variety, as well as the various physical characteristics of the fruit, such as its shape, size, weight, pulp hardness and organic substance content, is of maximum and decisive importance (Dowarah et al., 2021). While fruit quality can be modified, it cannot be radically changed without genetic manipulation (Castle, 1995). The results of the selection process are new varieties of apple trees that require a thorough study of their productivity and resistance to various biotic and abiotic factors. The influence of the rootstock and fruit quality must also be considered, as these factors significantly impact sales potential. One of the latest developments by breeders at the Institute of Horticulture of the NAAS of Ukraine is a late-ripening apple tree variety called ‘Dmiana’. Consumers usually evaluate apples based on their appearance (colour, size, shape and lack of defects), followed by taste. However, the buyer's willingness to purchase the product again may depend on the latter (Musacchi & Serra, 2018). Our research aimed to determine the effect of rootstock and planting scheme on the organic matter content of ‘Damiana’ apples.

MATERIAL AND METHODS

Research into the characteristics of the Dima apple variety was conducted at the Institute of Horticulture of the National Academy of Agricultural Sciences of Ukraine, which is located in the village of Novosilky. It is 4 km from Kiev, 187 m above sea level (50°27'16"N, 30°13'25"W) and in the Forest-Steppe natural and climatic zone of Ukraine. This natural and climatic zone has a temperate continental climate, characterised by sufficient moisture. The average temperature in the coldest place in January is -6 °C and in the warmest place in July it is 19.5 °C.

The soil at the site is a grey forest medium loam with a humus content of 2.3–3.5%. The soil solution has a weakly acidic reaction (pH = 5.9–6.7). The garden was fertilised with nitrogen fertilisers in early spring and with phosphorus and potassium fertilisers at the end of October. The application rate was calculated based on the results of foliar diagnostics and agrochemical analysis of the soil. During the vegetation period, calcium chloride was applied foliarly four times in a total amount of 55 kg per hectare and 2,000 litres of water.

The Syngenta integrated protection system was used to control pests and phytopathogenic microorganisms in the experimental plantation.

The ‘Dmiana’ variety plantations, from which the fruit selection for research was made, were created in 2017 using rootstocks m.9 (dwarf), M.26 (semi-dwarf) and MM.106 (medium growth). Two planting schemes were used: 4.0×0.5 m (5 thousand/trees per hectare) and 4.0×1.0 m (2.5 thousand/trees per hectare), with ten trees in each variant. The plantations' crowns are formed using the spindle method and the plantations are pruned annually.

Apples with the characteristic shape and colour of the variety were selected at harvest for the study. The degree of ripeness was determined using an iodine-starch test and by measuring pulp hardness. The degree of starch degradation in ‘Dmiana’ apples in all variants and in all years of the study was 6–6.5 points out of 9, and the pulp hardness exceeded 9.5 kg cm^2. The weight of the apples in each sample selected for analysis was 2 kg.

The research was conducted in the Post-Harvest Quality of Fruit and Berry Products Laboratory at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine. All studies were performed in triplicate.

Weather conditions during the apple tree growing season were recorded by an ‘Inspector Meteo’ weather station installed by the Ukrainian company IT-Lynx in an experimental orchard area. The effect of the sum of night and average daily air temperatures, the sum of active air temperatures of 10 °C and above, and the sum of precipitation on the biochemical components of the fruit was analysed for the entire fruit growth and development period, as well as for the initial June–July period and the pre-harvest August–September period. The average night-time air temperature was calculated for each month separately. This was based on the average daily air temperature from 10 pm to 6 am.

Biochemical parameters

The laboratory sample was prepared by grinding fruit segments with a laboratory homogenizer.

Dry matter (DM)

The dry matter content of the apples was determined using the drying method. A weighed amount of crushed fruit (5–6 g) was added to a container of quartz sand, mixed thoroughly, covered with a lid, and placed in an oven to dry until it reached a constant weight. The boxes were weighed before and after drying. Prior to weighing, the boxes were pre-cooled in an oven (Kondratenko et al., 2008). The dry matter content of apples is presented as a percentage.

Sugars

The crushed apple sample was extracted using hot distilled water. The extract was then purified of proteins and pigments using lead acetate. Sucrose was hydrolysed to produce glucose and fructose by heating with the addition of 10% hydrochloric acid. Fehling's solution was then used for oxidation. The resulting solutions' optical density was determined using a ULAB 102UV spectrophotometer at 640 nm. A calibration graph constructed using standard glucose solutions with different concentrations (kg mL^{-1}) (Kondratenko et al., 2008) was used to calculate the sugar content in apples. The content of titratable acids in fruit is given in kg 100^{-1}.

Organic titrated acids

A 25 g sample of apples was subjected to acid extraction and then washed with hot distilled water. The flask containing the extract was then placed in a water bath at 80 °C for 30 minutes and left to cool. Three to four drops of phenolphthalein were added to a 20 mL sample and the mixture was titrated with 0.1 N sodium hydroxide solution until a pink colour appeared, corresponding to a pH of 7.0. The average value was obtained from three parallel measurements. The content of titratable acids in the sample was calculated using the formula, the titration index of the 0.1 N sodium hydroxide solution, and the conversion factor to malic acid (kg mL^{-1}) (Kondratenko et al., 2008). The content of titratable acids in fruit is given in kg 100^{-1}.

Statistical analysis

Statistical data processing was performed using STATISTICA 13.1 (StatSoft, Inc., USA). The results are presented as mean values with their respective standard errors (mean ± SE). Differences between replicates, as well as between-variety mean values, were determined by ANOVA. One-way ANOVA and the Tukey HSD post hoc test were employed for statistical analysis. The results were presented at a significance level of $P < 0.05$. The significance of the influence of weather and climatic factors on the content of dry matter, sugars, and titratable acids in apples was analysed using the 'Data Analysis' tab in Excel.

RESULTS AND DISCUSSION

During the period of fruit growth and development (June–September), average daily air temperatures did not differ significantly during the years of research. They were 21.2 °C in 2020, 19.8 °C in 2021, and 21.6 °C in 2023. However, analysing the average daily temperatures by month during this period revealed that June was the coldest month in 2020 and September in 2021, with average daily temperatures of 13.7 °C and 13.4 °C, respectively. The sum of active air temperatures of 10 °C and above during the apple tree's growth and development periods varied from 2.427 °C in 2021 to 2.647 °C in 2020. In 2023, the sum of active air temperatures of 10 °C was 2595 °C. The highest night-time temperatures were recorded in June 2021 (639.0 °C); however, during the same year, the pre-harvest period was the coolest and the sum of night-time temperatures ten days before harvesting was 110.4 °C (Table 1).

During the apple growth and development period of the research years, the sum of active air temperatures of 10 °C and above ranged from 2,427 °C in 2021 to 2,647 °C in 2020, with an intermediate value of 2,595 °C in 2023. The lowest temperatures were recorded in June and July 2023 at 603.3 °C and 669.2 °C respectively. The hottest months in terms of the sum of active temperatures of 10 °C and above were July 2021 and September 2020, with respective sums of 564 °C and 775.0 °C (Table 1).

Table 1. Indicators of weather during the growth, development and ripening periods of apples

Years	June	July	August	September	Average
Average daily air temperatures, °C					
2020	13.7	22.7	22.2	18.8	21.2
2021	21.8	25.0	21.1	13.4	19.8
2023	20.1	21.6	24.0	19.2	21.6
Sum of night temperatures, °C					total
2020	544.1	555.8	520.7	168.6	1,789.2
2021	529.2	639.0	544.7	110.4	1,823.3
2023	481.1	552.5	615.5	151.9	1,801.0
Sum of active temperatures 10 °C and higher					
2020	689.0	705.0	689.0	564.0	2,647.0
2021	653.0	775.0	655.0	344.0	2,427.0
2023	603.3	669.2	745.3	577.2	2,595.0
Sum of precipitation, mm					
2020	56.5	38.1	14.6	23.2	132.4
2021	16.7	33.6	57.6	23.0	130.9
2023	38.1	72.7	8.6	7.1	126.5

The hydrothermal coefficients, namely the ratio of precipitation to the sum of active air temperatures of 10 °C and above throughout the apple growth and development period, did not differ significantly year on year. In particular, they were 0.50 in 2020, 0.54 in 2021 and 0.49 in 2023. However, during the period of fruit growth and development in the last of these years, there was significant unevenness of moisture. July was the wettest month in 2023, with 72.7 mm of precipitation, equating to a hydrothermal coefficient of 1.09. August and September were the driest months, with 8.6 and 7.1 mm of precipitation respectively, equating to a moisture coefficient of 0.12 in both months (Table 1).

Under these weather conditions, the dry matter content of 'Dmiana' apples grown on m.9 with a planting scheme of 4.0×0.5 m varied from 14.3% in 2021 to 15.8% in 2023. This tendency towards higher dry matter content was also observed in 2023 with the other two rootstocks and this planting scheme. Notably, on the M.26 rootstock, the dry matter content of 'Dmiana' apples was 15.7% in 2023, 15.2% in 2020, and 14.6% in

2021. Apples accumulated the least dry matter on the MM.106 rootstock with a planting scheme of 4.0×0.5 m in 2021 (14.6%), and the most in 2023 (16.2%) (Table 2).

Table 2. Dry matter content in apples of 'Dmiana' cultivar grown on different rootstocks and at different planting densities

Rootstock	2020	2021	2023	Average ± SE
Planting scheme 4.0×0.5 m				
M.9	14.6 ± 0.35^{a}	14.3 ± 0.43	15.8 ± 0.32^{c}	14.9 ± 0.48^{a}
M.26	15.2 ± 0.35^{b}	14.6 ± 0.38	15.7 ± 0.29	15.2 ± 0.38
MM.106	15.0 ± 0.38	14.6 ± 0.38	16.2 ± 0.32^{cb}	15.3 ± 0.48
Planting scheme 4.0×1.0 m				
M.9	14.8 ± 0.26	14.0 ± 0.32^{d}	15.5 ± 0.29	14.8 ± 0.43^{a}
M.26	15.6 ± 0.23^{b}	14.6 ± 0.17^{d}	16.2 ± 0.32^{b}	15.5 ± 0.47^{b}
MM.106	14.8 ± 0.20	14.5 ± 0.23	15.6 ± 0.26^{c}	15.0 ± 0.33

[a, b] – indicates the level of significance of differences between rootstock variants within the same planting scheme at $P < 0.05$;

[c, d] – values of indicators that are likely to differ from the average (x) for the years of the study for the studied group at $P < 0.05$.

No significant difference in dry matter content was observed in fruits grown on different rootstocks with a 4×1.0 m planting scheme. Apples from all rootstocks in the 2023 harvest had the highest SR, while the 2021 harvest had the lowest. In particular, the amount of dry matter in apples collected from trees with the M.9 rootstock was 15.5% in 2023 and 14.0% in 2022. For the M.26 rootstock, the respective values were 16.2% and 14.6%, and for the MM.106 rootstock, they were 15.6% and 14.5%. Intermediate values of dry matter content were recorded in 2020. Similar data regarding the influence of rootstock on dry matter content was obtained by a scientist in the US state of Florida. In particular, he noted that fruits collected from trees grown on rootstocks M.26, M.9 and M.27 did not differ in dry matter content (Castle, 1995). Budagovski 9 rootstock (Gjamovski et al., 2011). So the density of the trees has a significant impact on the quality of the fruit. The dry matter content of apples grown on rootstocks M.9, M.26 and MM.106 with a planting pattern of 4.0×1.0 m did not differ significantly from that of apples grown on the same rootstock with a planting pattern of 4.0×0.5 m. In 2020, the SR content of fruits grown on rootstock M.9 with planting schemes of 4.0×0.5 m and 4.0×1.0 m differed by 0.2%. In 2021 and 2023, the difference was 0.3%. On rootstock M.26, the difference in dry matter content was 0.4% in 2020, not detected in 2021, and 0.5% in 2023. The dry matter content of apples grown at different planting densities on rootstock M.26 did not differ significantly. In 2020, the dry matter (DM) content of trees planted at 4.0×0.5 m was 15.2%, which was 0.4% less than that of trees planted at 4.0×1.0 m. In 2021, no difference was found. In 2023, the dry matter content was 0.5% higher with an additional 5,000 trees per hectare. Apples grown in a 4×0.5 m planting pattern on MM.106 rootstock had a slightly higher dry matter content than those grown in a 4×1 m planting pattern. These differences were 0.2%, 0.1% and 0.6% in 2020, 2021 and 2023 respectively (Table 2).

Table 3. Correlation dependence of the content of dry solids, sugars and titrated acids in the fruits of apple trees of the Dmiana variety

Research options	Night, t °C			Average daily t °C			Sum of active temperatures of 10 °C and above			Sum of precipitation, mm		
	June–July	August–September	total	June–July	August–September	total	June–July	August–September	total	June–July	August–September	total
Dry matter												
M.9	-0.988	0.997	-0.528	-0.361	0.913	0.600	0.080	-0.193	-0.108	0.919	-0.948	-0.810
M.26	-0.999	0.966	-0.673	-0.524	0.971	0.446	0.259	-0.012	0.074	0.975	-0.990	-0.690
MM.106	-0.952	0.997	-0.388	-0.210	0.837	0.719	-0.078	-0.345	-0.263	0.845	-0.885	-0.892
Sugars												
M.9	-0.947	0.995	-0.372	-0.193	0.827	0.731	-0.095	-0.361	-0.280	0.836	-0.877	-0.900
M.26	-0.999	0.967	-0.669	-0.520	0.970	0.450	0.255	-0.017	0.069	0.974	-0.989	-0.693
MM.106	-0.911	0.793	-0.905	-0.811	0.988	0.068	0.610	0.373	0.451	0.985	-0.969	-0.359
Titratable acids												
M.9	0.914	-0.983	0.287	0.914	-0.983	0.287	0.184	0.444	0.365	-0.783	0.831	0.935
M.26	0.969	-1.000	0.441	0.969	-1.000	0.441	0.019	0.289	0.206	-0.875	0.911	0.864
MM.106	0.909	-0.980	0.274	0.909	-0.980	0.274	0.197	0.456	0.377	-0.775	0.823	0.940

When establishing the correlation between dry matter content and weather conditions during the growth and development of apple trees, the influence of plantation density was not taken into account, since statistical analysis did not reveal a significant difference in dry matter content depending on the tree planting scheme. Correlation analysis revealed an inverse relationship between dry matter content and night air temperature during the growth and development period (June–July) with correlation coefficients of 0.988, 0.999 and 0.952 for rootstocks M.9, M.26 and MM.106, respectively. A direct dependence of dry matter content on night temperatures was found for the period August–September, the correlation coefficient was 0.966 (Table 3).

According to the correlation analysis, the dry matter content is significantly and directly influenced by other temperature factors, namely the average daily air temperature and the sum of active temperatures of 10 °C and above for the period. The corresponding correlation coefficients were higher than 0.837 and 0.814. An inverse relationship was found between the dry matter content of Damiana apples and the amount of precipitation during the period of growth and development. The respective correlation coefficients were 0.948 for apples grown on M.9 rootstock and 0.961 for apples grown on M.26 rootstock, and 0.885 for apples grown on MM.106. Researchers from different continents have noted the negative impact of elevated night temperatures on dry matter content during apple ripening. In particular, Canadian researchers found that the dry matter content of the apple varieties they studied was higher in the cool growing season than in the warm one, by about 4% (or 30% relative) in absolute terms (Toivonen, 2015; Toivonen & Lannard, 2020). Similar data were obtained in our study: apples grown on M.9 rootstock with 4.0×0.5 and 4.0×1.0 m trees accumulated the highest dry matter content in 2023, 15.8% and 15.5%, respectively. In the same year, apples of the Dmiana variety grown on the other two rootstocks contained more dry matter than in 2020 and 2021, regardless of the density (Table 2). Nighttime air temperatures during the first months of fruit growth and development were the lowest in 2023, at 481.1 °C in June and 552.5 °C in July (Table 1). Richardson et al. (2004) argue that elevated nighttime temperatures can lead to a slowdown in photosynthetic production due to nighttime leaf respiration. Otherwise, plastic matter would be distributed in the fruit as starch, especially in the early stages of fruit development. Other researchers have noted that low temperatures during the half-growth period accelerate starch purification, i.e. its conversion to sugar (Smith et al., 1979; Ap Rees et al., 1981).

The total concentration of sugars soluble in cell juice is determined by the soluble solids in apple fruits, which account for 80%. The number of the latter in 'Dmiana' apples did not differ significantly depending on the rootstock in the 4.0×0.5 m planting scheme. However, apples grown on M.26 rootstock in 2020 and 2023 had significantly higher sugar content at 11.1 and 10.9 kg 100^{-1} respectively, while fruits grown on MM.106 rootstock in 2023 contained significantly less sugar at 10.3% (Table 4).

A more significant effect of the rootstock on the amount of sugars in the fruits of the 'Dmiana' apple tree was established in the variant with a planting scheme of 4.0×1.0 m. In particular, fruits grown on rootstock M.9 in 2020 had a sugar content of 9.4 in 2021 – 9.8 and in 2023 – 10.3 kg 100^{-1}, the average for the years of research – 9.8 kg 100^{-1}. On the rootstock MM.106 in 2021 and 2023 – 9.9 and 10.4 kg 100^{-1}, respectively, the average for the years of research - 10.1 kg 100^{-1}, while the average value for the variants of the experiment was: in 2020 – 10, 1, in 2021 – 10.4 and in 2023 – 10.8 kg 100^{-1}. Apples harvested from the variant where the rootstock was M.26

had sugars significantly higher than the average for the rootstocks, namely in 2020 – 10.8, in 2021 – 11.4, in 2023 – 11.8 kg 100^{-1}, the average during the years of research – 11.3 kg 100^{-1} (Table 4).

Table 4. The sugar content of 'Dmiana' fruits depends on the rootstock and planting density

Rootstock	2020	2021	2023	Average ± SE
Planting scheme 4.0×0.5 m				
M.9	10.5 ± 0.15^{a}	9.7 ± 0.15^{ad}	10.6 ± 0.14^{A}	10.3 ± 0.28^{a}
M.26	11.1 ± 0.12^{Ac}	9.6 ± 0.09^{ad}	10.9 ± 0.09^{A}	10.5 ± 0.47^{A}
MM.106	10.5 ± 0.15^{a}	9.8 ± 0.15^{ad}	10.3 ± 0.09^{A}	10.2 ± 0.21^{a}
Planting scheme 4.0×1.0 m				
M.9	$9.4 \pm 0.^{12Ab}$	$9.8 \pm 0.^{12ab}$	10.3 ± 0.06^{ac}	9.8 ± 0.29^{Ab}
M.26	10.8 ± 0.09^{Ad}	11.4 ± 0.06^{A}	11.8 ± 0.12^{Ac}	11.3 ± 0.29^{A}
MM.106	10.1 ± 0.09^{A}	9.9 ± 0.07^{a}	10.4 ± 0.12^{ac}	10.1 ± 0.15^{A}

A, a – indicates the level of significance of differences between rootstock variants within the same planting scheme at $P < 0.05$;
c, d – values of indicators that are likely to differ from the average (x) for the years of the study for the studied group at $P < 0.05$.

The analysis of the influence of the planting scheme on the sugar content in the fruits of the Dmiana variety did not reveal any significant difference in any variant with rootstocks, however, it was established that the sugar content is significantly affected by the weather conditions of the year of cultivation. In particular, a close inverse relationship was established between the content of sugars in 'Dmiana' apples and the sum of night temperatures in June–July, the corresponding correlation coefficient in the version with rootstock M.9 was 0.947, with rootstock M.26 - 0.999, and rootstock MM.106 - 0.911. A direct close relationship was found between the content of sugars and the sum of the same temperatures and average daily air temperatures, but in the last month before harvesting, the correlation coefficients in all variants with rootstocks were higher than 0.793 and 0.827, respectively. The dependence of the content of soluble solids, a significant proportion of which are sugars in apples, on the increased amount of the average annual air temperature in the last 40 days before harvesting was observed by Japanese scientists (Sugiura et al., 2013). Other researchers noted that the increase in dry soluble substances, and with them sugars, was not always caused by the short-term effect of elevated temperatures in the pre-harvest period (Blankenship, 1987). Wang & Camp (2000) proved that a hot pre-harvest period can contribute to the reduction of soluble solids.

In addition to temperature factors, the amount of sugars in 'Dmiana' fruits depends significantly on precipitation during the period of their growth and development. It was established that the level of moisture in June and July has a close direct relationship with the sugar content of apples of the studied variety, the correlation coefficients in the variant with rootstock M.9 - 0.836, with M.26 - 0.974 and with MM.106 - 0.985, and with precipitation of the latter month before harvesting, an indirect relationship was found, the correlation coefficients in the variant with rootstock M.9 - 0.877, with M.26 - 0.989 and in the variant with rootstock MM.106 - 0.969. A number of scientists from different countries of the world previously stated about the ambiguous influence of the total amount of precipitation during the period of growth and development of fruits on the content of soluble solids, and at the same time, sugars

(Wei et al., 1999, Zhu et al., 2001; Wei et al., 2003; Lakatos et al., 2012). Similar dependencies, but when studying blackcurrant fruits, were established by Finnish and Norwegian researchers (Zheng et al., 2009; Woznicki et al., 2015).

The amount of titrated acids in 'Dmiana' apples was higher than the average in the variant with the M.9 rootstock with a planting scheme of 4.0×0.5 m, in 2020 their content was 0.58%, which is 0.4% higher than the average, and in 2023 - 0.53 kg 100^{-1}, also 0.6 kg 100^{-1} higher than the average. In the variant where fruits were grown on rootstock M.9 with a planting scheme of 1.0×4.0 m, the content of titrated acids was also higher than in fruits grown on rootstocks M.26 and MM.106, but this difference was not significant (Table 5). Similar data, but in comparison with other rootstocks, were obtained by Macedonian scientists, in particular, they found that apples grown on M.9 T 984 contained the highest levels of titratable acids compared to those grown on Budagovsky 9 (Gjamovski et al., 2011).

The titratable acid content of fruits grown on the MM.106 rootstock with a planting scheme of 1.0×4.0 m was significantly lower than average, particularly in 2021 and 2023, at 0.6 and 0.5 kg 100^{-1} respectively. The average titratable acid content over the years of research was also significantly lower for fruits grown on MM.106 rootstock with a planting scheme of 1.0×4.0 m and was 0.45 kg 100^{-1}, which is 0.5 kg 100^{-1} lower than the average (see Table 5).

Table 5. Titratable acids content of 'Dmiana' fruit grown on different rootstocks and at different planting densities

Rootstock	2020	2021	2023	Average ± SE
Planting scheme 4.0×0.5 m				
M.9	0.58 ± 0.02[a]	0.54 ± 0.02	0.53 ± 0.01[a]	0.55 ± 0.02[a]
M.26	0.49 ± 0.01	0.57 ± 0.01[a]	0.40 ± 0.02[bd]	0.49 ± 0.05
MM.106	0.50 ± 0.01	0.53 ± 0.02	0.49 ± 0.01	0.51 ± 0.01
Planting scheme 4.0×1.0 m				
M.9	0.50 ± 0.01	0.56 ± 0.02[c]	0.48 ± 0.02	0.51 ± 0.02
M.26	0.55 ± 0.02	0.53 ± 0.02	0.49 ± 0.02	0.52 ± 0.02
MM.106	0.48 ± 0.01	0.46 ± 0.01[b]	0.4 1 ± 0.01[bd]	0.45 ± 0.02[b]

[a,b] – indicates the level of significance of differences between rootstock variants within the same planting scheme at $P < 0.05$;
[c,d] – values of indicators that are likely to differ from the average (x) for the years of the study for the studied group at $P < 0.05$.

The correlation analysis revealed a close inverse relationship between the titratable acid content of 'Dmiana' fruits and temperature factors. Specifically, increased night-time and average daily air temperatures in the month prior to apple harvesting were found to negatively impact the synthesis of titratable acids, with correlation coefficients exceeding 0.765 for the two weather factors. Our results are comparable to those obtained earlier by Canadian and Italian researchers, who noted that a cool growing season favours the synthesis of titratable acids and that their content in apples is usually higher during such periods than in years with hotter weather (Takashi & Hisashi, 1988; Toivonen & Lannard, 2020).

In addition to temperature, moisture levels during growth and development significantly impact titratable acid content. There is a direct relationship between the two: increased precipitation leads to higher acidity in 'Dmiana' apples. The correlation coefficients were 0.935, 0.864, and 0.940 for the M.9, M.26, and MM.106 rootstocks, respectively.

CONCLUSIONS

Weather conditions during the period of growth and development of apple fruit of the Dmiana variety significantly affect the content of dry matter, sugars and titratable acids. Apples harvested from trees with a semi-dwarf M.26 rootstock accumulated more sugars than those grown on M.9 rootstock. However, the content of titratable acids was higher in apples grown on dwarf rootstock M.9. Tree planting schemes of 4.0×0.5 m and 4.0×1.0 m did not affect the content of dry matter, sugars and titrated acids in the fruits of the variety Dmiana, the difference in content was within the error. Thus, to obtain apple fruits with a high sugar content, it is recommended to create plantations on rootstock M.26, with planting schemes of 4.0×0.5 m and 4.0×1.0 m. To establish the effect of rootstock and planting scheme on the content of other organic and biologically active substances in the fruits of apple variety Dmiana, it is necessary to deepen and continue the research.

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