FRUIT QUALITY INDICATORS OF APPLE (*MALUS DOMESTICA* BORKH.) CULTIVARS BRED IN UKRAINE

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ABSTRACT

As a result of the evaluation of the physical and biochemical quality indicators of the fruit of thirteen apple cultivars of Ukrainian breeding, it was found that the fruits of ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Amulet’, ‘Perlyna Kyieva’, ‘Harant’, ‘Edera’, ‘Radohost’, ‘Todes’ and ‘Askol’da’ are characterized by high stability of market traits based on the maximum diameter of the equatorial dimension, which varies depending on the cultivar, from 70 mm to 78 mm. The firmness of the fruit flesh of the evaluated cultivars in the harvest maturity was over 7.0 kg·cm⁻² but in ‘Solomiya’ and ‘Dmiana’ this indicator was 11.1 kg·cm⁻². The fruits of ‘Harant’ and ‘Todes’ were distinguished by a high dry matter content (over 18%). The highest content of soluble solids (14.5%) was accumulated in the fruits of ‘Dmiana’, and the maximum amount of sugars (11.6%) in the fruit of the ‘Ornament’. The fruits of ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Amulet’, ‘Edera’, ‘Perlyna Kyieva’, ‘Kateryna’ and ‘Dmiana’ were characterized by excellent taste quality based on the values of the sugar-acid index (20–25). In the fruits of ‘Kateryna’, ‘Dmiana’ and ‘Solomiya’, a stable pectin content (over 1%) was found. The fruits of ‘Harant’ accumulated a high content of ascorbic acid (11.5 mg·100 g⁻¹ of fresh weight), while ‘Kateryna’, ‘Radohost’, ‘Solomiya’ and ‘Askol’da’ contained over 240 mg·100 g⁻¹ of fresh weight of polyphenols. According to the complex of the quality indices, the fruits of ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Perlyna Kyieva’, ‘Askol’da’ and ‘Dmiana’ were distinguished by high commercial value and excellent consumption properties. The fruits of ‘Kateryna’, ‘Ornament’, ‘Dmiana’ and ‘Solomiya’ were characterized by stable carbohydrate content, while ‘Harant’ and ‘Askol’da’ by a stable high content of ascorbic acid and polyphenols, respectively.

Key words: ascorbic acid, dry mass, flesh firmness; fruit size, pectins, polyphenols, sugars

INTRODUCTION

Apples are one of the most popular and frequently consumed fruits in the regions of temperate climate, where their production rises year after year. Good appearance, crunchy flesh, pleasant taste and aroma result from morphological, physiological and biochemical characteristics of fruit, which are determined largely by the genotype, agricultural practices, weather conditions of the year as well as the degree of ripeness (Ali et al. 2004; Nour et al. 2010; Ciesa et al. 2013; Skordas et al. 2013). It is known that the chemical diversity (aroma

and taste), as well as sensory and nutritional qualities are higher in older apple cultivars compared to modern ones (Ciesa et al. 2015; Donno et al. 2012). Oszmiański et al. (2018) reported that in 22 old apple cultivars the content of polyphenols ranged from 1348.40 to 4310.52 mg per 100 g of dry weight, sugars from 7.41 to 11.99 g per 100 g of fresh weight, pectins from 0.64 to 2.24 g per 100 g of fresh weight. In studies of Panzella et al. (2013), Faramarzi et al. (2015) and Feliciano et al. (2010), all older apple cultivars from southern Italy, Iran, and Portugal showed higher polyphenol content than commercial apple cultivars.

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Thus, the biochemical composition of the fruits must be assessed not less meticulously than physical quality indices, such as mass, size, color and firmness (Amiri et al. 2014). Besides, apples are the most important source of polyphenolic compounds in European countries, thanks to their wide availability throughout the year (Wolfe et al. 2003). The pro-health properties of apple fruits are also enhanced by high contents of vitamins, minerals, easily digestible carbohydrates, dietary fibers and pectin (Jensen et al. 2009; Ferretti et al. 2014).

Cultivars that have fruits able to retain their useful properties for a long time while being suitable for processing, are considered to be particularly valuable (Conceição de Oliveira et al. 2003; Lee & Chan 2011). A good balance between marketable and consumer fruit qualities is an important characteristic of the cultivar used in breeding programs. Apples assigned for fresh consumption and for processing should meet certain requirements. The dessert quality of the fruits is primarily determined by harmonious taste, which depends mainly on the interrelation of sugars and acids (Harker et al. 2002). The essential traits needed for industrial processing of apples for concentrates, juices, puree, and dried fruits are the content of organic acids, pectins and polyphenolic substances (Nótin et al. 2011).

The assortment of apple orchards in Ukraine is enriched with new cultivars every year, including those bred at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (NAAS). The new cultivars possess a number of valuable traits, in particular immunity or resistance to fungal diseases, excellent taste and high storability. There is also a trend to grow organically regional cultivars better adapted to local climatic and soil conditions in which they can optimally develop their traits (Hecke et al. 2006). Here, we present results of a field experiment aimed at characterizing the physical (mass, size, pulp density) and biochemical (dry matter, soluble solids, sugars, organic acids, vitamin C, pectins, polyphenols) fruit quality of the apple cultivars bred in Ukraine to determine their suitability for fresh consumption and processing.

MATERIALS AND METHODS

During 2016–2019 the fruits of 13 apple cultivars – autumn cultivars ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Amulet’, and winter cultivars ‘Kateryna’, ‘Perlyna Kyieva’, ‘Ornament’, ‘Harant’, ‘Edera’, ‘Radohost’, ‘Todes’, ‘Askol’da’, ‘Dmiana’, ‘Solomiya’ – that were bred by the Institute of Horticulture of NAAS were evaluated. The experiment was performed in the Western Forest-Steppe, aiming to select cultivars that are the most adapted to these conditions and of high consumer quality.

The climate of the Western Forest-Steppe of Ukraine is moderately continental, characterized by sufficient moisture. The mean air average temperature in January is -6°C , in July $+19.5^{\circ}\text{C}$, and for the period of growth and development of apple fruits is 18.6°C (based on long-term data). In 2016 this index was similar to long-term data: 18.5°C , and was higher by 0.6, 1.6 and 2.0°C in 2017, 2018 and 2019, respectively. The specified period was the most humid in 2018, with 229.13 mm of precipitation, but that still was 91.87 mm less than the long-term average. The period of fruit growth and development in 2019 was characterized by the least moisture: 111.77 mm. The sum of active temperatures of 10°C and above during the period of growth and development of apple fruits was 2807.0°C in 2016, 2537.7°C in 2017, 2749.3°C in 2018 and 2798.1°C in 2019. The ratio of precipitation amount to the sum of active temperatures $\geq 10^{\circ}\text{C}$ was in the range from 0.4 in 2019 to 0.8 in 2018 with intermediate values of 0.5 in 2017 and 0.6 in 2016.

The soil of the plot is forest gray, loamy, the humus content is 2.3–3.5%, pH 5.9–6.7. Fertilization of the orchard with nitrogen was carried out in early spring, and with phosphorus and potassium in late July. The rate of application was calculated based on the results of leaf diagnostics. Calcium chloride was applied 4 times foliarly during the growing season in the total amount of $55\text{ kg}\cdot\text{ha}^{-1}$. The orchard was protected from pests and phytopathogenic organisms according to the integrated system common to the region of cultivation.

The apple orchard from which the fruits were collected for analysis was planted in 2010, in a 5×3 m scheme of. Trees were grafted on 54–118 clonal rootstock, and canopies shaped with central leader. Pruning of the trees was carried out annually.

Apple fruits for analysis, with a characteristic shape and color for the cultivar, were selected during fruit picking, at harvest ripeness. The degree of ripeness of the fruits was determined by the iodine-starch test. The degree of starch degradation in the studied cultivars was at the level of 6–6.5 points on a 9-point scale. Each sample had 2 kg of fruits. All studies were conducted in the Laboratory of Post-harvest Quality of Fruit and Berry Products of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine.

Physical indicators

The average fruit mass was determined by weighing on laboratory scales with the precision of 0.05 g; maximum diameter of the equatorial dimension was measured with sliding calipers; flesh firmness was evaluated with Wagner FRUIT TEST portable penetrometer with FT 30 FT716 nozzle, the diameter of 11 mm. Ten fruits of each cultivar were used for analysis.

Biochemical indicators

The segments of equal size were cut at the four sides of the fruit in the longitudinal direction and ground using the laboratory homogenizer in order to prepare an analytical sample. The samples were weighed with an accuracy of 0.005 g.

The method of drying the sample to a constant weight at a temperature of 98–100 °C was applied to establish the dry matter content; and the refractometric method to determine soluble solids content (Kondratenko et al. 2008).

Organic titrated acids

In order to extract the acids, 25 g of the ground sample were transferred into a 250 ml volumetric flask with not more than 150 ml of hot distilled water. The flask was kept in the water bath for 30 min at 80 °C and cooled. The content of the flask was made up to 250 ml with distilled water and filtered through a filter into a conical flask, into which 20 ml of the extract were transferred with a pipette, and then 3–4 drops of phenolphthalein

were added, titrated with 0.1 N sodium hydroxide until a pink color appeared, which corresponds to a pH of 7.0. At least two parallel measurements were carried out and the average value of the index was determined. The content of titrated acids in the sample was calculated using the formula with the index of the titer of 0.1 N sodium hydroxide and coefficient of the recapitulation for malic acid (Kondratenko et al. 2008).

Ascorbic acid

In order to extract ascorbic acid, the batch was ground in a porcelain mortar with the addition of broken glass and a mixture of 2% -oxalic acid and 1% -hydrochloric acid (80 + 20, vol + vol) and transferred to a 100 ml volumetric flask and filtered. The obtained extraction was titrated with a solution of 2,6-dichlorophenolindophenol (Tillman's paint). The ascorbic acid content in the sample was calculated using the formula applying the index of the titer of the Tillman's paint (Kondratenko et al. 2008).

Sugars

The extraction of the sugars from the fruits was conducted using hot distilled water. The obtained extract was purified from the proteins and pigments by precipitating them with the acetic plumbum. Sucrose was subjected to hydrolysis to glucose and fructose by heating in the presence of 10% hydrochloric acid. Hydrolysis products were oxidized with the Fehling solution. The optical density of the obtained solutions was established using a KFK-3-0.1 spectrophotometer at the wavelength of 640 nm. Sugar content in the sample was calculated using the formula applying the indicator of the calibration graph. The standard glucose solutions with different concentrations were used for the formation of the calibration graph of optical density (units of optical density) dependence on glucose concentration (mg per ml) (Voznesenskyi et al. 1962; Jermakov 1987).

The sugar-acid index

The sugar-acid index (SAI) was determined as the ratio of total sugar content to titrated acids content.

Pectic substances

In order to determine pectin content, the sample was purified from sugars and pigments with ethyl alcohol.

The extraction of soluble pectin was carried out with water, and of protopectin – with 1N sulfuric acid, hydrolysis of the latter to galacturonic acid – with heating. The 0.2%-carbazole solution was added to the extraction of the soluble pectin and protopectin acidified with the concentrated sulfuric acid in order to form a colored complex. The optical density of the attained solutions was determined using a KFK-3-0.1 spectrophotometer at the wavelength of 535 nm. The content of soluble pectin and protopectin in the sample was calculated using the coefficient of the recapitulation for apple pectin and indices of the calibration graph. The standard solutions of the galacturonic acid with different concentrations were applied for the formation of the calibration graph of the optical density (unit of the optical density) dependence on the mentioned acid concentration (μg per ml) (Voznesenskyi et al. 1962; Jermakov 1987).

Polyphenolic substances

In order to extract the polyphenols, the sample was ground in a porcelain mortar with a small amount of ethyl alcohol and filtered under the vacuum on a Buchner funnel into the Bunsen flask through the blue-tape paper filter, on which the rest was rinsed in small amounts of ethyl alcohol until the complete sample decolorization. The volume of alcohol used (in ml) was noted. 7.9 ml of the distilled water, 0.1 ml of the extract, and 1 ml of the Folin–Denis reagent were flowed into the vial, mixed, 1 ml of the saturated sodium carbonate solution was added in 3 minutes and mixed again. After an hour, the optical density of the vial content was determined using KFK-3-0.1 spectrophotometer at the wavelength of 640 nm. As the control, the mixture was prepared as follows: 8 ml of distilled water and 1 ml of the Folin–Denis reagent were flowed into the vial, mixed, 1 ml of the saturated sodium carbonate solution was added in 3 minutes and mixed again. No less than 3 parallel measurements were conducted and the average value of the optical density was determined. Content of the polyphenolic substances in the sample was calculated applying the indicators of the calibration graph. The standard solutions of chlorogenic acid with different concentrations were used for the formation of the

calibration graph of the optical density (optical density unit) dependence on the abovementioned acid concentration (μg per ml) (Voznesenskyi et al. 1962; Jermakov 1987).

Statistical analysis

Statistical analysis of the research data was carried out using STATISTICA 13.1 (StatSoft, USA) software. The results were presented in the form of mean values with their standard errors ($\bar{x} \pm \text{SE}$). The Shapiro–Wilk test was used to evaluate the assumptions of normality and homogeneity of variances. The significant differences between the means were determined by applying one-way ANOVA analysis. The results were presented at a level of reliability of $p < 0.05$.

RESULTS AND DISCUSSION

Physical indicators

Maximum diameter of the equatorial dimension

According to the requirements of the inland and international standards, apple fruits are divided into three grades depending on the maximum diameter of the equatorial dimension. In particular, the fruits with the mentioned index of not less than 70 mm are classified as the highest commercial grade, not less than 65 mm as the first grade. The mean value of the maximum diameter of the equatorial dimension among all investigated cultivars was 72.5 mm, while the corresponding index for ‘Amulet’, ‘Skifs’ke Zoloto’, ‘Todes’, ‘Askol’da’, ‘Perlyna Kyieva’, ‘Edera’, and ‘Teremok’ was higher (from 78.0 mm to 72.0 mm) (Table 1). ‘The fruits of ‘Dmiana’ were the smallest with the maximum diameter of 65.0 mm. (Table 1). ‘Ornament’, ‘Harant’ and ‘Kateryna’ had the highest variability of fruit diameter (CV 10–15.7%) caused by weather conditions of the years studied. The impact of growing conditions on physical indices of fruit quality is common knowledge. Fukuda and Moriyama (1997) showed the dependence of apple fruit quality on their morphological peculiarities; the size and mass of early ripening cultivars are determined not only by the number of cells, but also their size, while the late ripening cultivars are determined by the number of cells only.

Table 1. Physical characteristics of apple fruits' presented are averages for 2016–2019 (n = 4)

Cultivar	Maximum diameter of the equatorial dimension		Fruit mass		Flesh firmness	
	mm	CV (%)	G	CV (%)	kg per cm ²	CV (%)
'Teremok'	76.3±0.3 ^a	3.8	164.3±9.7	6.0	7.7±0.3 ^b	3.3
'Skifs'ke Zoloto'	77.5±5.9	9.5	171.7±13.9	22.2	7.4±0.5 ^b	10.6
'Amulet'	78.0±3.5	5.0	189.4±20.4	12.3	7.7±0.3 ^b	4.4
'Kateryna'	66.0±8.0	12.3	158.2±3.4	1.9	8.7±0.6	6.6
'Perlyna Kyieva'	75.0±5.5	9.2	191.4±17.9	12.6	11.0±0.5 ^a	4.5
'Ornament'	69.0±12.2 ^b	15.7	172.7±25.8	13.3	9.2±0.4	4.9
'Harant'	76.3±4.6	10.0	178.3±23.9	11.9	9.2±0.1	16
'Edera'	72.0±3.8	6.6	168.2±9.0	10.9	9.6±0.7	9.4
'Radohost'	70.0±3.6	7.9	147.4±13.8	14.3	8.3±0.3	4.6
'Todes'	76.0±4.5	6.0	199.7±25.7	13.1	9.6±0.2	2.4
'Askol'da'	76.0±1.6	3.5	180.6±9.8	9.2	8.1±0.4	6.7
'Dmiana'	65.0±6.8	9.2	111.9±28.9 ^b	22.8	10.9±1.0 ^a	8.9
'Solomiya'	70.0±5.7	5.2	148.8±14.9	8.8	11.1±0.7 ^a	8.5
SE	2.5		26.0		0.7	
x	72.5		169.5		9.1	

^{a,b} are values of the indices that differ significantly from the mean (x) for the studied group at P < 0.05

Fruit mass

The fruits of the studied cultivars accumulated mass ranging from 111.9 g ('Dmiana') to 199.7 g ('Todes'). The variability of the fruit mass of 'Dmiana' was high and differed significantly from the mean for the group by this parameter. The apples of 'Skifs'ke Zoloto', 'Amulet', 'Perlyna Kyieva', 'Ornament', 'Harant', 'Todes' and 'Askol'da' had a higher mass than the mean value of this index for the studied group (169.5 g), from 171.7 g to 199.7 g. 'Skifs'ke Zoloto' and 'Dmiana' were unstable for this trait (CV 22.2% and 22.8% respectively) whereas this index for 'Teremok', 'Kateryna', 'Askol'da' and 'Solomiya' was from 1.9% to 9.2% was constant and did not depend on the growing conditions. In the research carried out by Mitre et al. (2009) apple fruit mass varied from 117.0 g to 185.5 g.

Flesh firmness

Flesh firmness is one of the fruit structure characteristics. It is considered a key factor determining fruit ripening. The reduction of apple fruit's firmness can be attributed to the modification of cell walls, loss of turgor, and degradation of starch and pectin substances. The intensity of these transformations affects the apple fruit quality (Orosz-Tóth et al. 2019). Flesh firmness should be taken into account when selling

fresh apples for processing and for cold storage (Vanoli et al. 2015). In our research, fruits of late autumn ripening cultivars 'Teremok', 'Amulet', 'Skifs'ke Zoloto' had flesh firmness from 7.4 to 7.7 kg cm⁻², which is less than the mean value of this index for the whole group (9.1 kg cm⁻²). Among winter ripening cultivars, 'Solomiya', 'Perlyna Kyieva', 'Dmiana', 'Edera', 'Todes', 'Harant', 'Ornament', the flesh firmness was higher than the mean for the group – from 11.1 kg cm⁻² to 9.2 kg cm⁻² for 'Kateryna', 'Radohost' and 'Askol'da' this index was lower – from 8.7 kg cm⁻² to 8.1 kg cm⁻² and the coefficients of variation varying from 1.6% ('Harant') to 9.4% ('Edera') (Table 1). The fruits of the scab-resistant cultivars grown in Hungary had flesh firmness of 5.9–9.6 kg cm⁻² (Orosz-Tóth et al. 2002). The maximum values of this index for Hungarian apples corresponded to the mean one calculated by us for the Ukrainian cultivars.

The fruits of the apple cultivars evaluated here growing in nonirrigated conditions have the maximum diameter of the equatorial dimension and fruit mass that meet the requirements of international and inland standards and flesh during harvest maturity varying from 7.4 kg cm⁻² to 11.1 kg cm⁻². This is necessary for ensuring excellent apple storability.

Biochemical indices of the fruit quality

Dry matter

Dry matter (DM) of the fruits here evaluated varied from 15.8% ('Amulet' and 'Skifs'ke Zoloto') to 18.1% ('Harant' and 'Todes'), differing considerably from the mean value of this index for the group of thirteen cultivars (16.8%); this exceeded standard error. Fruits of 'Edera', 'Ornament' and 'Radohost' accumulated dry matter at a level of mean value and above, namely: 17.1%, 17.2%, and 17.5%. The coefficients of variation (lower than 7%) prove the stability of the DM content in the fruits of all the cultivars (Table 2). High DM content indicates their favorability for processing apple powders. These values did not differ compared with the results of the research of Oszmiański et al. (2018) (12.3–17.1% of DM) and Palmer et al. (2010), (10.8% for 'Royal Gala' and 20.1% for 'Scifresh').

Soluble solids

Apple fruits, grown in Pakistan, accumulated from 9.9% to 16.75% of soluble solids (SS) (Aziz et al. 2013). In our research, the lowest content of the SS was detected in the fruits of 'Todes', 'Kateryna' and 'Dmiana' (from 12.3% to 14.5%) that did not differ from the mean value for the group (13.4%) and exceeded the standard error. Fruits of 'Solomiya', 'Perlyna Kyieva' and 'Ornament' had the mean SS value for the group 13.7–14.6% (Table 2).

Considering the high content of these substances and their stability (SV 1.4–8.7%) under the conditions of the Western Forest-Steppe of Ukraine, fruits of the studied cultivars can be a good raw materials for making fruit powders for the juices.

Sugars

Total sugars content in the studied apple cultivars ranged from 9.8% ('Todes') to 11.6% while the mean value of this index for the group was 10.7%. The highest sugar content in the fruits was scored in 'Perlyna Kyieva', 'Amulet', 'Kateryna' and 'Dmiana' (11.0–11.2%). Sugar content in the apples cultivated in the intensive orchards of Austria and Slovenia was 11.5–16.0% (Hecke et al. 2006), and in Pakistan 7.57–20.13% (Aziz et al. 2013). Given indices had a greater range of variation between the minimum and maximum values. The results we obtained were within the data reported by Akagić et al. (2019) 7.1% to 8.5% of monosaccharides, while in our experiment the range was 7.0–10.2%. The rest of the studied cultivars contained between 8.6% and 7.0%. Reducing sugars content in the fruits of 'Kateryna' (10.2%) and 'Ornament' (9.8%) was maximum, and minimum for 'Dmiana' (7.6%) and 'Solomiya' (7.0%). Those indices differed considerably from the mean value for the group and were beyond the standard error. Cultivars 'Ornament', 'Todes', 'Edera' and 'Radohost' did not have a stable reduced sugars content during the years of the study, and CV was higher than 16.0% (Table 3).

Table 2. The content of dry matter and soluble solids in apple fruit, given are averages for 2016–2019 (n = 4)

Cultivar	Dry matter		Soluble solids	
	%	CV (%)	%	CV (%)
'Teremok'	16.6 ± 1.3	6.9	12.8 ± 0.7	6.6
'Skifs'ke Zoloto'	15.8 ± 0.4 ^b	2.5	13.1 ± 0.5	6.3
'Amulet'	15.8 ± 0.4 ^b	2.0	13.5 ± 0.5	5.7
'Kateryna'	17.7 ± 0.3 ^a	1.4	14.0 ± 0.9 ^a	8.7
'Perlyna Kyieva'	16.7 ± 0.5	2.8	13.8 ± 0.5	4.9
'Ornament'	17.2 ± 0.8	4.3	14.6 ± 0.9	7.8
'Harant'	18.1 ± 0.4 ^a	1.8	13.0 ± 0.2	6.8
'Edera'	17.1 ± 1.3	6.8	13.0 ± 0.6	7.7
'Radohost'	17.5 ± 1.0	4.8	13.3 ± 0.5	6.5
'Todes'	18.1 ± 0.7 ^a	3.4	12.3 ± 0.6 ^b	4.6
'Askol'da'	16.1 ± 0.4	2.0	13.0 ± 0.5	6.5
'Dmiana'	15.5 ± 0.6 ^b	4.1	14.5 ± 0.2 ^a	1.4
'Solomiya'	15.9 ± 0.5	3.0	13.7 ± 0.9	2.0
SE	0.5		0.4	
x	16.8		13.4	

^a, ^b are values of indicators that differ significantly from the average (x) for the studied group at P < 0.05

Table 3. The content of organic matter in apple fruit, given are averages for 2016–2019 (n = 4)

Cultivar	Total sugars		Monosaccharides		Titrated acids		Sugar-acid index
	%	CV (%)	%	CV (%)	%	CV (%)	
‘Teremok’	10.4±0.8	9.0	9.1±0.7	12.2	0.51±0.10	27.4	20
‘Skifs’ke Zoloto’	10.5±0.4	6.0	8.7±0.7	14.4	0.52±0.08	26.9	20
‘Amulet’	11.2±0.8	11.0	8.7±0.5	8.3	0.48±0.10	33.3	23
‘Kateryna’	11.2±0.7	8.1	10.2±1.2 ^a	12.9	0.45±0.10	8.8	25
‘Perlyna Kyieva’	11.0±0.4	4.8	8.9±0.5	9.2	0.54±0.15	27.8	20
‘Ornament’	11.6±0.7 ^a	7.5	9.8±1.6 ^a	21.2	0.41±0.05 ^b	14.6	28
‘Harant’	10.5±0.6	6.9	8.2±1.1	14.3	0.63±0.12	17.4	17
‘Edera’	10.4±0.5	7.8	7.9±0.9	17.0	0.55±0.06	18.1	20
‘Radohost’	10.6±0.4	6.6	8.6±1.0	17.3	0.68±0.09	20.5	16
‘Todes’	9.8±0.4 ^b	4.6	8.4±1.1	16.7	0.79±0.12 ^a	15.1	12
‘Askol’da’	10.4±0.4	6.2	8.6±0.6	11.6	0.58±0.05	15.5	18
‘Dmiana’	11.2±0.8	6.4	7.6±0.4 ^b	5.1	0.48±0.08	14.7	23
‘Solomiya’	10.6±0.9	7.2	7.0±0.6 ^b	7.5	0.67±0.18	25.3	16
SE	0.3		0.4		0.06		
x	10.7		8.6		0.56		20

Note: see Table 2

Titrated acids (TA)

Titrated acidity is an important index for apple fruit evaluation (Lo Piccolo et al. 2019). Apple cultivars grown widely throughout the world accumulate titrated acidity at a level of 0.57–1.50% (Wang et al. 2019). In the Western Forest-Steppe of Ukraine, the highest amount of these substances was accumulated by the fruits of ‘Todes’ (0.79%), and the lowest by ‘Ornament’ (0.41%); the mean value for these cultivars was 0.56%. The stability of this index in the fruits of the mentioned cultivars was average, proved by CV of 15.1% and 14.6%, respectively. The most variable (CV above 26.9%) while being lower than the mean value, was the content of the organic acids in the fruits of ‘Skifs’ke Zoloto’, ‘Teremok’, ‘Perlyna Kyieva’, and ‘Amulet’ (from 0.54% to 0.48%). High acid content in the fruits of ‘Solomiya’ (0.67%) was not stable (CV 25.3%) (Table 3).

Sugar acid index (SAI)

The ratio between the content of sugars and acids affects the taste, aroma, and further use of the apple fruit (Wu et al. 2007; Mikulic Petkovsek et al. 2010; Wang et al. 2019). The above-mentioned substances

are the main determinants of the fruit organoleptic quality (Ma et al. 2019). The sweet taste of apples is determined by large sugars content, while sour taste is determined by the content of titrated acids (Pochitskaya et al. 2019). The fruits with SAI lower than 20 have a strong sharp taste and are suitable for processing, including making cider; those with SAI above 20 are considered dessert and suitable for fresh consumption (Lee et al. 2003). Cultivars bred in Ukraine have a mean SAI of 20, with the highest value of 28 (‘Ornament’) and the lowest one of 12 (‘Todes’). SAI of the fruits of ‘Kateryna’, ‘Amulet’ and ‘Dmiana’ was higher than the mean value for the group (25 and 23, respectively). That is an indicator of their harmonious and balanced taste. The fruits of ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Perlyna Kyieva’ and ‘Edera’ have SAI values at the mean level for the group. These cultivars are of universal purpose and can be consumed both fresh and processed. The fruits of cultivars with SAI lower than 20, namely ‘Harant’, ‘Radohost’ and ‘Solomiya’, can be used for making cider if picked at harvest maturity (Table 3). Lee (2003) stated that the cultivars with SAI lower than 20 can be regarded as cider cultivars.

Pectic substances (PS)

Pectins are necessary for the human body. As polyelectrolytes, gel formers and emulsifiers, they are used in medicine for the treatment and prevention of various diseases, as well as in the food industry (Pavel & Makarkina 2018). PS content in apple fruits is 0.3–2.4% of the raw mass (Shyrko & Jaroshevych et al. 1991; Dadashev et al. 2000; Potkina et al. 2016). More than 1.0% of PS was accumulated by the fruits of almost all Ukrainian cultivars studied here, except for ‘Askol’da’, ‘Skifs’ke Zoloto’ and ‘Amulet’ (from $0.93 \pm 0.12\%$ to $0.97 \pm 0.19\%$). Fruits of ‘Perlyna Kyieva’, ‘Edera’, ‘Solomiya’, ‘Ornament’, ‘Harant’ and ‘Radohost’ had PS values comparable to the mean value of this index for the group (1.04%). Fruits of ‘Radohost’ had the highest PS among the researched cultivars, beyond the standard error. The fruits of resistant cultivars of Belarus origin are able to accumulate from 0.76% (‘Zorka’) to 1.31% (‘Navavita’) of pectin substances (Kazlouskaya & Yarmolich 2019), and those grown in Pakistan – 0.10–1.3% (Aziz et al. 2013). That is comparable to the data obtained in our research. Fruits of ‘Ornament’, ‘Dmiana’ and ‘Kateryna’ (CV 9.8%, 12.1% and 13.1%, respectively) cultivars distinguished themselves for the stability of the PS content among the studied group. The rest of the cultivars were characterized with average and low stability of PS content (Table 4). The steadily large amount of the pectin substances (more than 1%), in the fruits of ‘Kateryna’, ‘Ornament’, ‘Dmiana’ and ‘Solomiya’ is the indicator of their high gel capacity, and fruits of the mentioned cultivars may be used for making high-sugar preserves and for pectin production.

Ascorbic acid

Ascorbic acid (AA) is the most known prophylactic vitamin (Baron 2009). In addition, it helps in many processes, being a cofactor for mono- and dioxygenases and histone demethylases as well as an intensifier of iron absorption in the human organism (Di Matteo et al. 2010; Truffault et al. 2017; Granger & Eck 2018). The daily intake of AA should be 30–250 mg depending on the age, employment, and health condition of the person (NIH 2019). Apple fruits do not synthesize large amounts of AA due to their physiological and morphological peculiarities.

For example, AA content in apple fruits from Pakistan is $1.3\text{--}7.38 \text{ mg} \cdot 100 \text{ g}^{-1}$ (Aziz et al. 2013), and from Germany $5.5\text{--}13.4 \text{ mg} \cdot 100 \text{ g}^{-1}$ (Kschonsek et al. 2018). AA content in the fruits of studied Ukrainian cultivars varies from $3.8 \text{ mg} \cdot 100 \text{ g}^{-1}$ (‘Solomiya’) to $11.5 \text{ mg} \cdot 100 \text{ g}^{-1}$ (‘Harant’). The C-vitamin potency of the latter cultivar is significantly higher compared to others and is beyond the standard error. It was stated that even such low vitamin C content is enough to contribute to better availability of the P-active substances (Granger & Eck 2018). Among the evaluated cultivars, only ‘Harant’ had high AA ($11.5 \text{ mg} \cdot 100 \text{ g}^{-1}$) content with the coefficient of variation being 7.9%. Fruits of ‘Askol’da’, ‘Todes’ and ‘Kateryna’ accumulated $6.1 \text{ mg} \cdot 100 \text{ g}^{-1}$ to $6.7 \text{ mg} \cdot 100 \text{ g}^{-1}$ of the AA, which is higher than the average value for the investigated group of cultivars ($5.7 \text{ mg} \cdot 100 \text{ g}^{-1}$). AA content in the fruits of the rest of the cultivars changes substantially depending on the year (Table 4).

Polyphenolic compounds (PC)

Apple polyphenols are potent acceptors of free radicals, like antioxidants and antiphlogistics drugs (Ferretti et al. 2014). Apple fruits’ antioxidant properties are mostly connected with a high amount of flavonoids, or, more precisely, of catechin and epicatechin, in the skin and pulp (Hyson 2011; Pei et al. 2016). Our results have shown that PC content in the fruits of cultivars bred in Ukraine fluctuated from $127 \text{ mg} \cdot 100 \text{ g}^{-1}$ (‘Todes’) to $262 \text{ mg} \cdot 100 \text{ g}^{-1}$ (‘Solomiya’), while for Canadian cultivars it ranged from $99 \text{ mg} \cdot 100 \text{ g}^{-1}$ to $451 \text{ mg} \cdot 100 \text{ g}^{-1}$ (Khanizadeh et al. 2008). In the apples grown in Hungary the range was from $194 \text{ mg} \cdot 100 \text{ g}^{-1}$ to $479 \text{ mg} \cdot 100 \text{ g}^{-1}$ (Ficzek et al. 2013), and in Germany from $99.6 \text{ mg} \cdot 100 \text{ g}^{-1}$ to $495.3 \text{ mg} \cdot 100 \text{ g}^{-1}$ of the raw mass (Kschonsek et al. 2018). In our cultivars the mean PC content was $206 \text{ mg} \cdot 100 \text{ g}^{-1}$ of the raw mass; higher contents from 209 to $262 \text{ mg} \cdot 100 \text{ g}^{-1}$ were accumulated in the fruits of eight cultivars. Two cultivars were characterized with high polyphenolic stability (CV 7.4% and 13.0%, respectively) but ‘Harant’ was characterized by high variability of this trait (CV 26.0%). PC content in the fruits of ‘Solomiya’, ‘Amulet’, ‘Todes’ and ‘Harant’ is beyond the standard error and differed significantly from the mean value for this group of cultivars (Table 4).

Table 4. The content of biologically active substances in apple fruits, given are averages for 2016–2019 (n = 4)

Cultivar	Pectic substances		Ascorbic acid		Polyphenolic substances	
	%	CV (%)	mg per 100 g of fresh weight	CV (%)	mg per 100 g of fresh weight	CV (%)
‘Teremok’	1.01±0.18	22.0	5.4±1.8	44.4	210±14	7.4
‘Skifs’ke Zoloto’	0.96±0.23	24.6	4.6±0.8	28.1	195±35	20.4
‘Amulet’	0.97±0.19	26.6	3.9±0.8	29.7	165±19 ^a	17.6
‘Kateryna’	1.04±0.15	13.1	6.7±1.5	19.4	245±33	15.3
‘Perlyna Kyieva’	1.05±0.25	32.1	3.9±1.1	44.1	194±17	11.5
‘Ornament’	1.07±0.12	9.8	4.5±1.4	26.8	217±35	16.3
‘Harant’	1.24±0.21	15.3	11.5±1.0 ^a	7.9	133±39 ^a	26.0
‘Edera’	1.05±0.12	16.4	5.6±1.2	33.5	209±32	20.3
‘Radohost’	1.14±0.16 ^a	18.5	5.4±0.8	18.8	241±43	18.0
‘Todes’	1.03±0.28	27.5	6.4±1.7	26.2	127±16 ^a	10.8
‘Askol’da’	0.93±0.12	17.9	6.1±1.2	31.0	256±23	13.0
‘Dmiana’	1.02±0.14	12.1	4.3±1.5	32.0	224±44	38.6
‘Solomiya’	1.07±0.20	7.6	3.8±0.9	20.0	262±24 ^b	21.4
SE	0.04		2.5		23	
x	1.04		5.7		206	

Note: see Table 1

CONCLUSIONS

Apple fruits of all evaluated cultivars are suitable for fresh consumption. Fruits of ‘Teremok’, ‘Skifs’ke Zoloto’, ‘Perlyna Kyieva’, and ‘Edera’ are of universal purpose, can be consumed fresh, and are a good raw material for the production of natural juice and puree. Cider can be made from ‘Harant’, ‘Radohost’ and ‘Solomiya’ fruits. The stable high amount of pectin, more than 1%, in the fruits of ‘Kateryna’, ‘Ornament’, ‘Dmiana’ and ‘Solomiya’ is an indicator of their good gelling ability, which proves their suitability for making jams, marmalades, as well as a raw material for pectin production.

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