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Fruit Quality and Contents of Some Bioactive Compounds in Selected Czech Sweet Cherry (*Prunus avium* L.) Cultivars under Conditions of Central Poland

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Abstract: Dynamic changes have taken place in the production of sweet cherry (*Prunus avium* L.) in Poland over the last 20 years. New cultivars with both early- and late-ripening dates have appeared, and modern high-intensity cultivation techniques are being implemented. The main attribute of the fruit, in addition to its unique taste, is its health-promoting properties. In this research, which was conducted at the Warsaw University of Life Sciences in 2021, our main objectives were to evaluate seven selected Czech cherry cultivars ('Jacinta'; 'Horka'; 'Tamara'; 'Helga'; 'Fabiola'; 'Kasandra'; 'Kordia') with regard to their dessert quality and contents of biologically active compounds, and to indicate the most valuable cultivar under the conditions of central Poland. The cultivars tested differed in both the fruit quality and health-promoting properties. 'Jacinta', 'Horka', Tamara' and 'Fabiola' had the largest fruits. The 'Fabiola' and 'Kordia' fruits had the highest firmness, while the 'Jacinta' and 'Horka' fruits had the highest soluble solid contents (SSCs) and titratable acidities (TAs). We found the highest SSC-to-TA ratio in the 'Fabiola' cultivar. 'Jacinta' proved to be the most valuable cultivar in terms of bioactive compounds, and it had the highest antioxidant activity (DPPH). Some of the traits were closely correlated with each other, mainly in relation to the biologically active compounds. Darker fruits contained more bioactive compounds and had a higher antioxidant activity. It was also proved that size of fruits as well as SSC and TA are also correlated with fruit color. Intensively colored fruit are larger and have higher SSC and TA. In sweet cherry fruit, the contents of polyphenols and flavonoids, as well as the high DPPH, are strongly determined by the high content of cyanidin-3-galactoside.

Keywords: firmness; soluble solid content; antioxidants; flavonoids; polyphenols; antioxidant activity

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1. Introduction

Sweet cherry is an important and valuable orchard species in temperate climates, and it is greatly appreciated by consumers [1]. The area of cherry orchards in Poland is about 11 thousand hectares, and the annual production of the fruit is about 50 thousand tons. According to the Polish Main Inspectorate of Plant Health and Seed Inspection, the most popular cultivars in Poland are 'Kordia' and 'Regina' (http://piorin.gov.pl/en/ accessed on 15 August 2022). Both cultivars ripen in the second half of July. Consumers expect a longer delivery of high-quality cherry fruit. In addition, there is a tendency to consume cherry cultivars with different flavors and organoleptic properties [2]. Therefore, there is an urgent need in Poland to produce different cultivars of early- and late-ripening cherries.

The cherry fruit quality characteristics, such as the size, mass, color, firmness, taste intensity, flavor, textural properties, etc., are fundamental factors, and they are highly related to the consumer acceptance [3,4]. Therefore, presently, the objective of breeding programs is to introduce cultivars to the market with these quality features [5].

The weight and size are the key characteristics that determine the commercial value of cherries. Consumers perceive cherries of a larger size as more attractive [6]. The

consumer acceptance is also undoubtedly influenced by the color of the fruit. Darker fruits are considered sweeter [7,8]. The sweetness of the fruit is regarded as one of the most attractive features of cherries. One of the standard parameters for determining the fruit sweetness is the soluble solid content (SSC) [9]. However, the unique flavor of cherries is not only due to the sugar content, but is also a combination of the ratio of sugars to acids. Researchers have found that malic acid is the most present organic acid in different cultivars of cherries [10–13].

It is not only the high quality of the fruit, which depends on the above-mentioned characteristics, that makes consumers find cherries extremely valuable. It is worth noting that demand for these fruits is steadily increasing, which is due not only to their sweet taste or attractive appearance, but also to their high antioxidant content [8]. Nowadays, increasing attention is being paid to healthy lifestyles and the consumption of products with high contents of vitamins and antioxidant substances. As indicated by many researchers, dietary habits are important in the prevention of some chronic diseases; they can reduce the risk of cancer, diabetes, obesity, cardiovascular diseases and neurodegenerative disorders [14–20]. Indeed, it appears that consumer awareness of the health properties of fruit has caused an increase in demand not only for the fruit itself, but also for fruit preparations (e.g., fruit drinks), and cherries are no exception [8]. Most cherry fruits have a reddish-purple color, which indicates that they have anthocyanins and exhibit strong antioxidant activity; thus, the production of reactive oxygen species and antioxidant stress is reduced. Mozetič et al. [21] and Mozetič et al. [22] also report nutraceutical effects of sweet cherries. The content of bioactive compounds in sweet cherry fruit is relatively high. Researchers have found many phenolic compounds in cherries including hydroxycinnamate, flavonols, procyanidins and anthocyanins [23–25]. The main group of them are the anthocyanins, which are responsible for the red color of both the skin and flesh. The main anthocyanins are 3-O-glucoside and 3-O-rutinose of cyanidin, while 3-O-rutinose of peonidin or pelargonidin is also present in smaller amounts [26]. Flavonols are also among the important substances contained in sweet cherry fruits, with epicatechin and quercetin-3-O-rutinose being the main compounds [27]. Researchers have also identified hydroxycinnamic acids and hydroxybenzoic acid derivatives in *P. avium* [28]. The contents of all these compounds largely depend on the genetic characteristics of the cultivar as well as the cultivation conditions, date of harvest, fruit maturity and light intensity. However, to a great extent, this composition can also vary depending on the location of the plantation. The location of the orchard affects the anthocyanin content of the fruit, changing its profile and determining the coloration of the skin [29]. Therefore, the study of these parameters is important, as cherries produced in Poland may have somewhat different colors and anthocyanin contents than the cherries of the same cultivars in other countries.

Sweet cherries have also quite low calories (only 63 kcal in 100 g), 80% water and low sodium compared to other substances. They also contain simple sugars and analogues (glucose, fructose and sorbitol), organic acids (malic and succinic acids), dietary fibers, carotenoids, melatonin, quercetin and other valuable elements. Furthermore they have vitamins C, B, A, E and K. Cherries also include minerals (calcium (14 mg/100 g), magnesium (10 mg/100 g), phosphorus (20 mg/100 g) and potassium (200 mg/100 g) [4,20,26,30–32].

For consumers, fruit with all the above-mentioned characteristics (such as the size, coloration, general visual appearance, good taste and health-promoting properties) are of great importance. This makes it all the more reasonable to determine the distinguishing quality features and health-promoting properties of the fruits of cultivars that are less well known in Poland but valued abroad.

In the present research, we aimed to evaluate seven selected Czech cherry cultivars ('Kordia'; 'Kasandra'; 'Tamara'; 'Fabiola'; 'Horka'; 'Helga'; 'Jacinta') with regard to the dessert quality of the fruit and the contents of some biologically active compounds, and to indicate the most valuable cultivar under the conditions of central Poland.

2. Materials and Methods

We collected the fruits of seven sweet cherry (*Prunus avium* L.) cultivars bred in the Czech Republic ('Kordia' (seedling of unknown origin); 'Kasandra' ('Burlat' × 'Sunberst'); 'Tamara' ('Krupnoplodnaja' × 'Van'); 'Fabiola' ('Kordia' × 'Van'); 'Horka' (originating from the open pollination of the 'Van' cultivar); 'Helga' ('Wczesna Riversa' × 'Moreau'); 'Jacinta' (originating from the open pollination of the 'Vega' cultivar)) in 2021 from an orchard located in central Poland, in the area of Nowy Dwór Mazowiecki (Mazowieckie province: 52°33′ N; 20°31′ E; 143 m a.s.l.). The average annual temperature in the region is about 7.5 °C, and the total precipitation is 450 mm. The soil in which we grew the plants was sandy–loamy, with a slightly acidic pH_{KCl} (6.0–6.5), and with 2.5% of humus.

We planted all the trees at the experimental site in 2005 as feathered maiden trees grafted on Colt rootstock at a 4.5 × 2.5 m spacing. We trained the tresses into a spindle crown shape to a 4.5 m height. We kept the rows of plants in herbicide fallow with turf grass between the rows. We used drip irrigation in the experimental orchard and grew all the cherry trees under the same standard agronomic techniques (fertilization, irrigation and pest control).

We performed the experiment in a split-plot design with four replications consisting of three trees for each tested cultivar (12 trees/cultivar, for a total of 84 trees in the whole experiment). The research was conducted at the Warsaw University of Life Sciences.

Sweet cherry fruits were collected at their physiologically mature stage, which was based on the color traits (sweet cherry color maps), harvest date and fruit size. We performed the sampling of the fruits from all of the trees of each cultivar from the inner and outer parts of the four subdivided quadrants of the canopy. We picked approximately fifty fruits per tree (approximately 150 fruits/replication, approximately 600 fruits/cultivar), and we randomly combined the fruits of each of the 12 trees/cultivars to obtain three representative biological replicates. For the quality traits, we handpicked the fresh fruits and transferred them to the laboratory, where we directly examined them. For the evaluation of the quality parameters, we used 30 fruits from each repetition. For the biologically active compound analysis, we proceeded with all the sweet cherry accessions immediately after harvest by removing both the stones and stems from the fruits. Subsequently, we froze the samples at −75 °C.

We present the average temperature and rainfall totals for the 2021 vegetation season for the experimental location in Table 1. We obtained accurate meteorological data from the area of the cherry plantation for 2021 from the portal Meteo: https://www.meteo.waw.pl/ (accessed on 30 November 2021).

Table 1. Meteorological conditions during 2021 vegetation season.

Month	Sum of Rainfall [mm·m^{-2}]	Average Temp. [°C]
March	18.3	4.0
April	55.3	6.5
May	62.3	12.4
June	69.2	19.7
July	118.8	21.7
August	140.1	17.2

2.1. Analytical Methods

- **Average fruit mass** (g): We measured the average fruit mass (g) on a TP 200 (OHAUS Europe GmbH, Nänikon, Switzerland) analytical balance;
- **Average fruit diameter** (mm): We measured the diameter of the fruit in two directions with a caliper. Then, we averaged the obtained results from each fruit;
- **Average weight of stone** (g): We removed the stones from 30 fruits from each repetition, and we then weighed them on a TP 200 (OHAUS Europe GmbH, Nänikon, Switzerland) analytical balance. We averaged the results for each cultivar;

- **Stone from the weight of the fruit** (%): After determining the weight of the whole fruit and weight of the stone using mathematical calculations, we calculated the percentage of the stone in the fruit for each cultivar;
- **Soluble solid content (SSC)** (Brix degrees): We refractionally determined the soluble solid content (SCC) (Brix degrees) according to the Polish Standard PN-EN 12143:2000 [33] (developed by the Polish Committee of Standardization) in the juice squeezed out from 30 fruits per replication at a 20 °C temperature. We determined the SSC using an Atago PR-32 digital refractometer (Atago, Tokyo, Japan);
- **Fruit firmness (FF):** We determined the fruit firmness (FF) as the value of the force needed to deform the fruit by a 3 mm diameter punch probe. We made the determinations using an Instron type 5542 tester (Instron, High Wycombe, UK). We determined the FFs of 20 fruits in three replications. Each fruit was measured twice on each fruit (in the horizontal and vertical planes), with a compression speed of 240 mm−1 during penetration to a 3 mm depth [34]. We express the FF in newtons (N);
- **Total (titration) acidity (TA):** We determined the total (titration) acidity (TA) according to the Polish Standard PN-EN 12147:2000 [35]. We measured the TA in water extract from an average sample of 30 minced fruits by titrating with 0.1 N sodium hydroxide (NaOH) to the endpoint of a pH of 8.1, using a TitroLine 5000 system (Si Analytics, Mainz, Germany). We express the results as the percentage of anhydrous malic acid;
- **Ratio of SSC value to titratable acidity**: We based the ratio of the SSC value to the titratable acidity on the SSC and TA values using mathematical calculations. We calculated the SSC/TA ratio for each cultivar;
- **External color of fruits**: We measured the external color with a Minolta CR-508i colorimeter (Minolta, Osaka, Japan) equipped with a 5 mm measuring head and observer 10° and illuminant D65. We calibrated the meter using the manufacturer's standard white plate. We quantified the color changes in the L*, a^* and b^* color spaces. We calculated the hue angle ($(h\circ = \tan^{-1}(b^*/a^*) + 180°)$ when $a^* < 0$ and $b^* > 0$) and chroma values ($C = (a^*2 + b^*2)1/2$) from the a^* and b^* values. The hue values refer to a color wheel. The red, yellow, green and blue colors were at angles of 0°, 60°, 120° and 240°, respectively. The chroma describes the vividness or dullness of the fruit color, and it is also known as color saturation [36].

In terms of the contents of bioactive compounds, all the reagents were of analytical purity gradients or HPLC grade and purchased from Sigma-Aldrich (Poznań, Poland) or Merck (Warsaw, Poland).

- **Analysis of total polyphenol content:** We conducted the analysis according to the Waterhouse method [37]. We measured the total polyphenol levels using a Marcel s330 PRO spectrophotometer (Marcel S.A., Warsaw, Poland) with Folin–Ciocalteau reagent. We extracted 5 g of material crushed in liquid nitrogen with 50 mL of 100% methanol. We replicated the extraction process twice by pouring the extracts into a 100 mL flask. One by one, we poured 1 mL of extract into a 50 mL flask, and we then added 35 mL of H_2O, 2.5 mL of Folin–Ciocalteau reagent and 7.5 mL of 10% $NaCO_3$. We supplemented the above-prepared solution with H2O and incubated it at 25 ± 2 °C for 20 min. We performed the measurements at a 750 nm wavelength. We used gallic acid as a standard at the following concentrations: 0.00, 0.05, 0.15, 0.20, 0.25 and 0.3 g/L. We calculated the polyphenol content using a formula: $(105.89 \cdot \text{absorbance}^2 + 25.318\ \text{absorbance})/\text{mass}\ 50$. We express the total polyphenol content in milligrams of gallic acid per 100 g^{-1} FW (fresh weight);
- **Analysis of flavonoid content:** We performed the analysis using the modified method of Marinova et al. [38]. We crushed 5 g of fruit in liquid nitrogen and used it to determine the flavonoids. We mixed the samples with 25 mL of 80% methanol, and then extracted them for 15 min. We performed the extractions twice. We sequentially added distilled water, 5% $NaNO_2$, 10% AlCl3 and 1M NaOH to the resulting samples at predetermined intervals. We performed the measurements using a Marcel s330 PRO spectrophotometer (Marcel S.A., Warsaw, Poland) at 510 nm. We calculated

the flavonoid content using a standard curve (y = 1.86x), performed with quercetin solutions and including the following concentrations: 0.00, 0.20, 0.60, 0.80 and 1.00 g·L. We express the total flavonoid content of the fruit as mg of quercetin equivalents (QE) per 100 g^{-1} FW (fresh weight);

- **Qualitative and quantitative analyses of anthocyanins**: We performed the analysis of the separation and contents of the anthocyanins using a Perkin-Elmer 200 series HPLC kit with a Diode Array Detector (DAD), according to modified method of Krupa and Tomala [39]. We performed the separation using a LiChroCART 125-3 (Merck KGaA, Darmstadt, Germany) column with a 1 mL/min flow rate. The column temperature was 25 °C. The mobile phase consisted of (A) water, (B) 20% formic acid and (C) acetonitrile, with variable parameters of the gradients A and C: 0–17.5 min A:B:C = 40:50:10; 17.5–22.5 min A:B:C = 35:50.15; 22.5–32.5 min A:B:C = 45:50:5. We detected the anthocyanins at 520 nm wavelengths by comparing the retention time on the achieved chromatograms with the standard ones. We express the contents of the particular compounds as mg of cyanidin-3-glucoside equivalent in 100 g^{-1} FW (fresh weight);
- **Antioxidant activity:** We determined the antioxidant activity according to the method of Saint Criq de Gaulejac et al. [40], which is based on the reduction of free radicals obtained from the $DPPH^+$ (1,1-diphenyl-2-picrylhydrazine, Sigma-Aldrich, Poznan, Poland). We calculated the antioxidant activity based on the absorbance measurements for the proper sample (fruit extract + $DPPH^+$) performed after 20 min at λ = 517 nm in relation to the control sample (H2O + $DPPH^+$). We calculated the flavonoid content using a standard curve (AA = (0.0597·2) − (0.754x) + 1.77), including the following concentrations: 0.01, 0.02, 0.05, 0.1 and 0.2 g·L. We express the results in mg of ascorbic acid equivalent per g of FW (fresh weight).

2.2. Statistical Analysis

We statistically analyzed the data collected during the study period via the Statistica 12.5 program (StatSoft Polska, Krakow, Poland) using one-way analysis of variance. We used a Newman–Keuls test for the evaluation of the significance of the differences between the means, accepting the significance level as 0.05.

We determined the degree of the correlation between the different variables by Pearson's linear correlation coefficients.

3. Results

3.1. Fruit Quality

According to the measurements and analyses, the tested cultivars substantially differed in terms of the fruit quality, and the differences were evident in basically every single parameter (Table 2).

3.1.1. Fruit Size (Weight and Diameter)

The largest fruits in terms of the mass and diameter were the cultivars 'Jacinta', 'Horka', 'Tamara' and 'Fabiola' (approximately 12 g in weight and 30 cm in diameter) (Table 2). We found the smallest fruits in the cultivar 'Helga' (below 8 g in weight and approximately 26 cm in diameter). The 'Kasandra' and 'Kordia' cultivars were approximately 9 g in weight and approximately 28 cm in diameter.

Table 2. Fruit quality characteristics with standard errors, depending on the cultivar.

Cultivar	Fruit Weight [g]	Fruit Diameter [mm]	Stone Weight [g]	Proportion of Seed in the Fruit [%]	Firmness [N]	SSC [°Bx]	TA [% of Malic Acid]	SSC/TA Ratio
Jacinta	$12.21 \pm 0.3^{A,*}$	30.60 ± 0.1^{A}	0.55 ± 0.03^{A}	4.52 ± 0.2^{B}	4.26 ± 0.2^{E}	16.30 ± 0.4^{A}	0.75 ± 0.02^{A}	21.74 ± 1.0^{B}
Horka	11.90 ± 0.06^{A}	30.64 ± 0.3^{A}	$0.46 \pm 0.01^{B,C}$	3.86 ± 0.1^{C}	$6.95 \pm 0.3^{B,C}$	15.78 ± 0.4^{A}	0.77 ± 0.01^{A}	20.63 ± 0.6^{B}
Tamara	12.58 ± 0.5^{A}	30.80 ± 0.3^{A}	$0.52 \pm 0.02^{A,B}$	$4.10 \pm 0.2^{B,C}$	7.51 ± 0.3^{B}	13.30 ± 0.2^{C}	0.52 ± 0.04^{C}	$25.50 \pm 2.1^{A,B}$
Helga	7.82 ± 0.3^{C}	26.20 ± 0.2^{C}	0.43 ± 0.02^{C}	5.50 ± 0.1^{A}	6.43 ± 0.4^{C}	13.50 ± 0.2^{C}	$0.57 \pm 0.01^{B,C}$	$23.78 \pm 0.4^{A,B}$
Fabiola	12.58 ± 0.6^{A}	30.53 ± 0.6^{A}	$0.51 \pm 0.01^{A,B}$	4.02 ± 0.2^{C}	8.52 ± 0.4^{A}	14.33 ± 0.7^{B}	0.51 ± 0.08^{C}	28.75 ± 2.4^{A}
Kasandra	9.65 ± 0.2^{B}	28.60 ± 0.4^{B}	0.49 ± 0.02^{B}	5.08 ± 0.2^{A}	5.59 ± 0.3^{D}	$13.93 \pm 0.3^{B,C}$	0.54 ± 0.01^{C}	$25.70 \pm 0.9^{A,B}$
Kordia	9.60 ± 0.3^{B}	28.43 ± 0.3^{B}	0.43 ± 0.03^{C}	4.50 ± 0.2^{B}	8.29 ± 0.07^{A}	13.53 ± 0.2^{C}	0.65 ± 0.02^{B}	20.85 ± 0.9^{B}

* Values with different letters are significantly different within a column. SSC—soluble solid content. Bx—Brix. TA—titration acidity.

3.1.2. Stone Weight

The fruits of the tested cultivars also differed in the stone weights (Table 2). The seeds of 'Jacinta' were the heaviest. We found only slightly lighter seeds in the cultivars 'Tamara' and 'Fabiola' (in each of the mentioned three cultivars, the weights were above 0.5 g). We found the lowest weight stones in the cultivars 'Helga' and 'Kordia' (below 0.45 g).

3.1.3. Proportion of Seed in Fruit

When considering the stone-to-fruit percentage, the 'Helga' cultivar had the smallest fruit with the lightest stone, as well as one of the highest stone-to-fruit percentage values (above 5%) (Table 2). The cultivar 'Kasandra', which was characterized by medium-sized fruit and a medium seed weight, had a high percentage of stone per fruit (similar to 'Helga'). The 'Horka' and 'Fabiola' cultivars, the fruits of which were the largest, had the lowest percentages of stone in the fruit (approximately 4%). Another cultivar with large fruit, 'Tamara', was characterized by a low proportion of stone in the fruit. The 'Tamara' cultivar had only a slightly higher value of the discussed parameter compared with 'Horka' and 'Fabiola', and it was also slightly lower than 'Jacinta' and 'Kordia' (in which the proportion of the stone in the fruit was approximately 4.5%).

3.1.4. Firmness

The 'Fabiola' and 'Kordia' cultivars had the firmness fruit (above 8 N) (Table 2). The cultivars 'Horka' and 'Tamara' showed good firmnesses (approximately 7 N), although they were significantly lower than the two mentioned above. The fruit of the 'Jacinta' cultivar had the lowest firmness, which was slightly above 4 N.

3.1.5. Soluble Solid Content (SSC)

According to the statistical analysis, the 'Jacinta' and 'Horka' cultivars had the highest soluble solid contents (SSCs) among the tested cultivars (approximately 16° Brix) (Table 2). We observed substantially lower SSCs in the cultivars 'Fabiola and 'Kasandra', in which the values of this trait were at approximately 14° Brix. 'Tamara', 'Helga', 'Kasandra' and 'Kordia' had the lowest soluble solid content at approximately 13° Brix. The soluble solid content of 'Kasandra' was only slightly higher than the cultivars with the lowest SSCs.

3.1.6. Titration Acidity (TA)

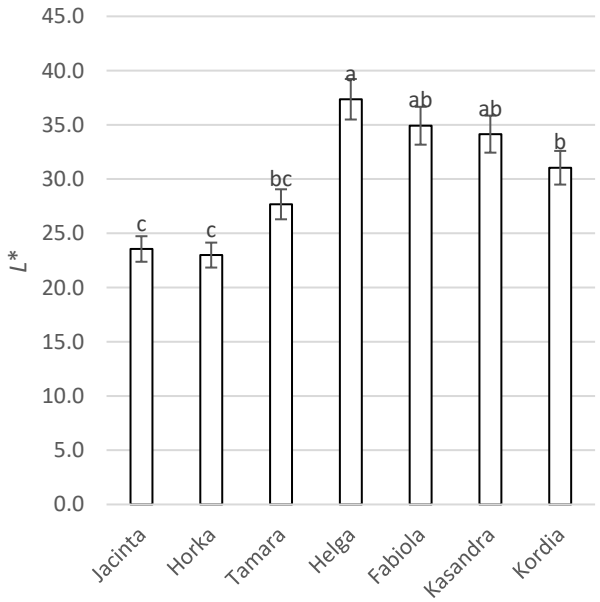
The tested cultivars also differed in their titration acidities (TAs) (Table 2). The cultivars with the highest SSCs ('Jacinta' and 'Horka') also had the highest titration acidities (over 0.7%). We recorded substantially lower values in the cultivars 'Kordia' (above 0.6%) and 'Helga' (slightly below 0.6%). The cultivars 'Tamara', 'Fabiola' and 'Kasandra' had the lowest acidities (approximately 5%), while the TA of the 'Helga' fruit was only slightly higher compared to these cultivars.

3.1.7. SSC/TA Ratio

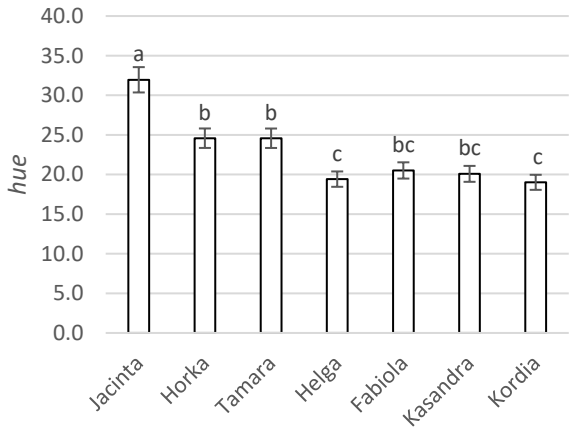
When considering the SSC/TA ratio, we only observed differences between the cultivars 'Fabiola', of which the value exceeded 28, and 'Jacinta', 'Horka' and 'Kordia', of which the values of the SSC/TA ratio were substantially lower (Table 2).

3.2. External Color

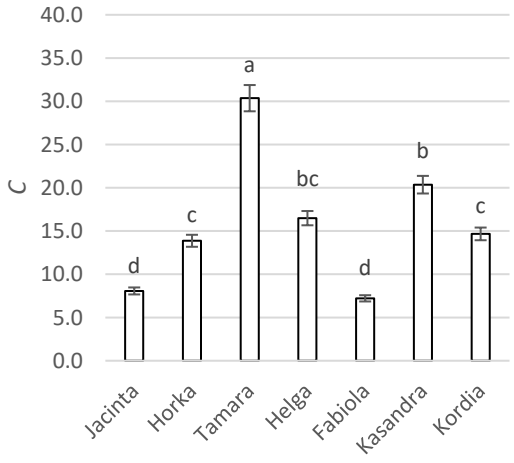
The cultivars substantially differed in terms of the fruit color. All the components (*L**, *hue (h*)* and chroma *(C)*) depended on the cultivar (Figure 1a–c, respectively).



(**a**)



(**b**)



(**c**)

Figure 1. External color of fruit: (**a**) *L**, (**b**) *hue* and (**c**) chroma (*C*), depending on the cultivar. Values with different letters are significantly different.

3.2.1. Value of L*

We found the highest value of the *L** parameter in the cultivar 'Helga' (above 37) (Figure 1a). We found slightly lower values of this component in the cultivars 'Fabiola' and 'Kasandra' (approximately 35). We recorded the lowest *L** values in the cultivars 'Jacinta' and 'Horka' (approximately 23). We found slightly higher values of the component in the cultivar 'Tamara' (below 28).

3.2.2. Value of Hue

We found the highest *h** value in the fruit of 'Jacinta' (approximately 32) (Figure 1b). We observed much lower *h** values in the fruits of 'Horka' and 'Tamara' (below 25). We found the lowest *h** values in the cultivars 'Helga' and 'Kordia' (below 20). Conversely, the cultivars 'Fabiola' and 'Kasadnra' had *h** values slightly higher than 20, and they did not substantially differ from the ' Horka', 'Tamara', 'Helga' and 'Kordia' cultivars.

3.2.3. Value of Chroma

Based on the measurements, we found the highest *C* values in the fruits of the 'Tamara' cultivar (above 30) (Figure 1c). We found significantly lower *C* values in the fruits of 'Kasandra' (approximately 20). The values of the component in the 'Horka' and 'Kordia' cultivars did not exceed 15, and they were significantly lower compared with those of the 'Kasandra' cultivar. Conversely, the fruits of the 'Helga' cultivar had a *C* value of approximately 16.5, which was only slightly higher than 'Horka and 'Kordia', and slightly lower than 'Kasandra'. We recorded the lowest *C* values in the fruits of the 'Jacinta' and 'Fabiola' cultivars (approximately eight).

3.3. Contents of Bioactive Compounds in Fruits

3.3.1. Analysis of Total Polyphenol Content

According to the analysis of the total polyphenol content in the fruit, the most abundant in these compounds were the cultivars 'Jacinta' and 'Kordia' (both above 700 mg·100 g^{-1} FW) (Figure 2). In the cultivars 'Horka', 'Helga' and 'Fabiola', the content of polyphenols did not exceed 500 mg·100 g^{-1} F.W. We found the least amount of polyphenol content in the fruits of the cultivar 'Kasandra' (slightly above 300 mg·100 g^{-1} FW). However, in the cv. 'Tamara', the polyphenol content was only slightly higher and was less than 400 mg·100 g^{-1} FW.

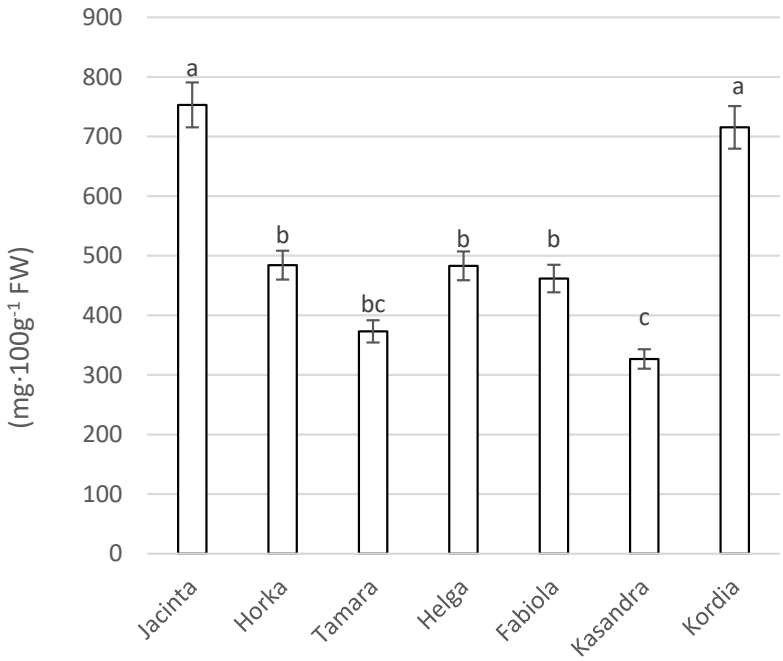


Figure 2. Polyphenol content, depending on cultivar. Values with different letters are significantly different.

3.3.2. Analysis of Flavonoid Content

The flavonoid content, similar to the polyphenol content, was determined by the cultivar (Figure 3). The cultivar 'Jacinta' was the richest in flavonoids (above 40 mg·100 g^{-1} FW). The cultivars 'Helga', 'Fabiola' and 'Kordia' had substantially less flavonoids (the value of this compound did not exceed 30 mg·100 g^{-1} FW). We recorded the lowest flavonoid content in the cultivars 'Tamara' and 'Kasandra' (less than 15 mg·100 g^{-1} FW). In the 'Horka' cultivar,

the flavonoid content was approximately 16 mg·100 g^{-1} F.W., and it was only slightly higher compared to 'Tamara' and 'Kasandra', and slightly lower than 'Helga', 'Fabiola' and 'Kordia'.

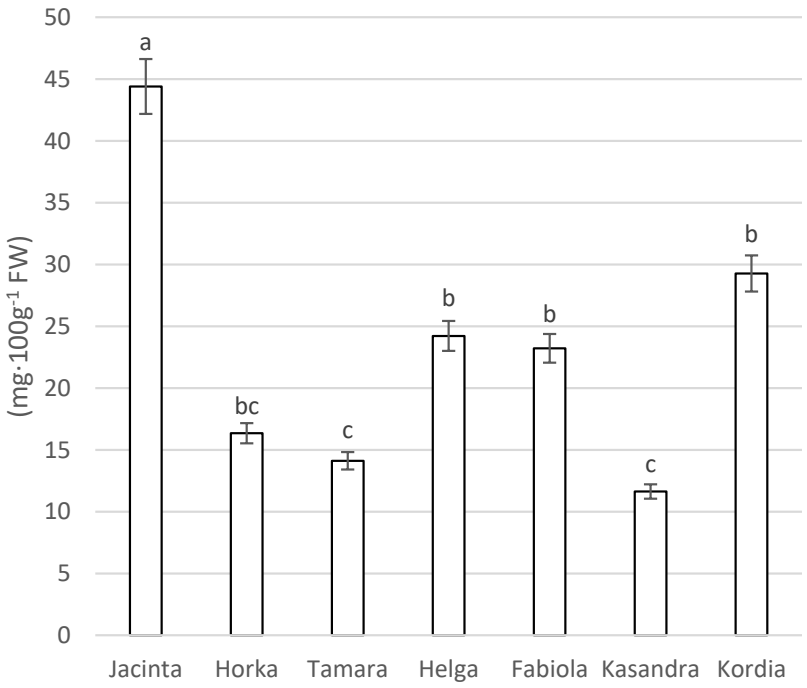


Figure 3. Flavonoid content, depending on cultivar. Values with different letters are significantly different.

3.3.3. Analysis of Anthocyanin Content

We demonstrated the presence of three basic anthocyanin compounds in the studied fruits: peonidin-3-rutinoside, cyanidin-3-rutinoside and cyanidin-3-galactoside.

According to the statistical analysis, their contents were determined by the cultivar (Figure 4a–c, respectively). The 'Jacinta' cultivar had the most anthocyanins of all the tested cultivars. For the peonidin-3-rutinoside content, Jacinta exceeded the other cultivars by almost six times. The content of this compound in the other cultivars did not exceed 2 mg·100 g^{-1} FW, while in 'Jacinta', it was almost 12 mg·100 g^{-1} FW (Figure 4a). Regarding cyanidin-3-rutinoside, 'Kasandra' (above 11 mg·100 g^{-1} FW) deserved attention in addition to 'Jacinta' (above 30 mg·100 g^{-1} FW) (Figure 4b). The content of this compound was three times lower compared to Jacinta; however, it was significantly higher compared to the other cultivars. We found the lowest content of the compound mentioned in the 'Tamara' cultivar (only approximately 3 mg·100 g^{-1} FW). Considering the content of cyanidin-3-galactoside, the cultivars 'Horka', 'Fabiola' and 'Kordia' (all approximately 5 mg·100 g^{-1} FW) had approximately half as much less of this compound compared to 'Jacinta' (above 10 mg·100 g^{-1} FW) (Figure 4c). We found the lowest content of cyanidin-3-galactoside (not exceeding 2 mg·100 g^{-1} FW) in the 'Tamara' and 'Helga' cultivars.

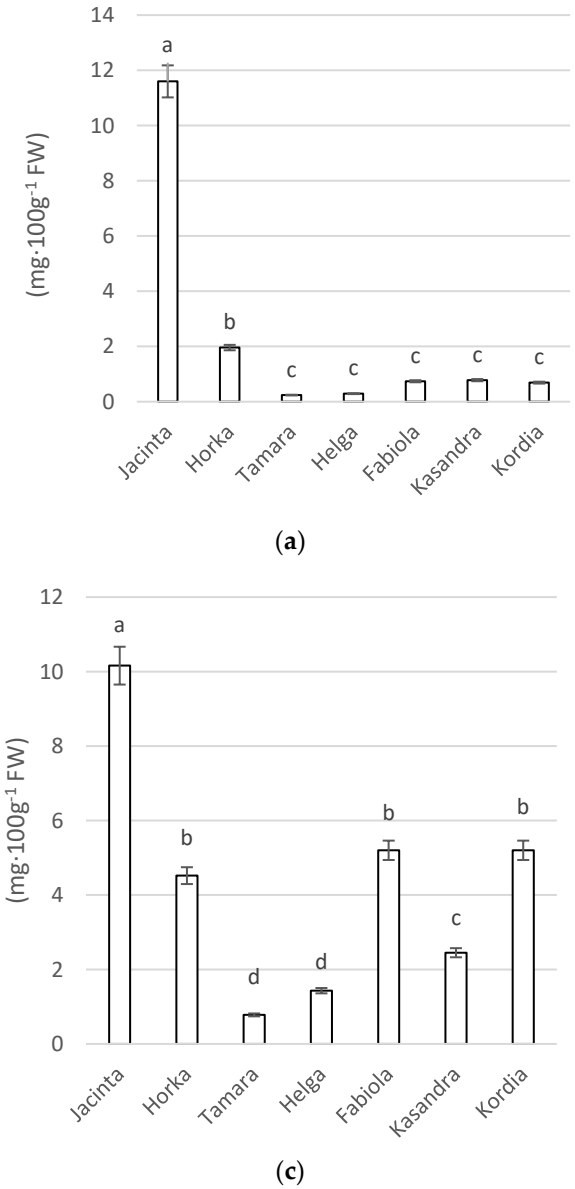


Figure 4. Contents of: (**a**) peonidin-3-rutinoside; (**b**) cyanidin-3-rutinoside; (**c**) cyanidin-3-galactoside, depending on cultivar. Values with different letters are significantly different.

3.3.4. Antioxidant Capacity

The antioxidant activity of the fruit depended on the cultivar (Figure 5). We found the highest value in the 'Jacinta' fruit (above 1µM Trolox·100 g^{-1} FW). High antioxidant capacity, although it was significantly lower compared with the 'Jacinta', was found in 'Kordia' fruit (less than 0.8 µM Trolox·100 g^{-1} FW). We also found the statistical lower value in the 'Fabiola' cultivar (approximately 0.7 µM Trolox·100 g^{-1} FW). 'Horka' and 'Tamara' had similar antioxidant activities (approximately 0.6 µM Trolox·100 g^{-1} FW). We found the lowest values of the discussed trait in the cultivars 'Helga' and 'Kasandra' (below 0.5 µM Trolox·100 g^{-1} FW).

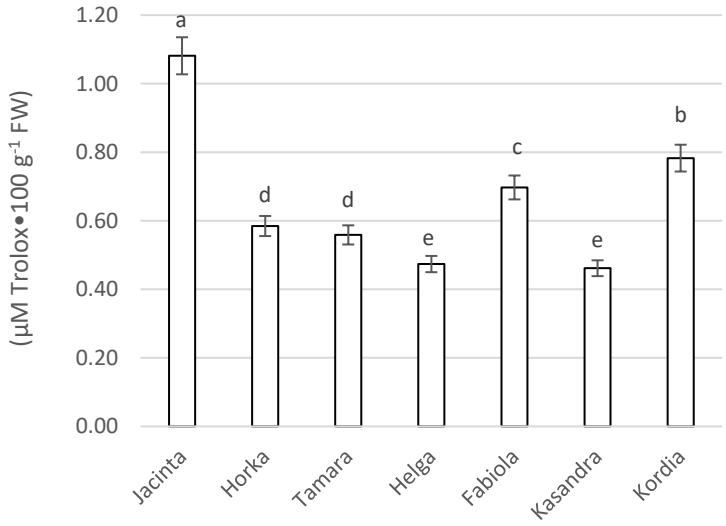


Figure 5. Antioxidant capacities, depending on cultivar. Values with different letters are significantly different.

3.4. Correlation Coefficient Values between Selected Parameters

We present the values of the correlation coefficients between the studied indicators of the physical and chemical qualities of the cherry fruits in Table 3. The calculations mainly prove the high correlation coefficients for the contents of biologically active compounds. The contents of polyphenols and flavonoids in sweet cherry fruit are strongly determined by the high content of cyanidin-3-galactoside, and to a slightly smaller extent, by the contents of peonidin-3-rutinoside and cyanidin-3-rutinoside. In turn, the antioxidant activity is highly correlated with the contents of all the health-promoting compounds tested in this experiment (polyphenols, flavonoids and anthocyanins), as evidenced by the high positive values of the correlation coefficients between the mentioned parameters.

We found positive correlation coefficients between the contents of most of the biologically active compounds and the fruit skin color, which is expressed by the *hue* component. The red color of the fruit is more strongly determined by peonidin-3-rutinoside ($r^2 = 0.60$) than by cyanidin-3-galactoside ($r^2 = 0.35$). Moreover, the other components of the skin color evaluation (*L** and Chroma*) are correlated with the contents of biologically active compounds, but in this case, we found a negative correlation. This means that, as the contents of peonidin-3-rutinoside and cyanidin-3-galactoside increase, the color of the skin of the sweet cherry fruits becomes darker, while at the same time, its saturation decreases. The decrease in the color saturation is determined, to a high degree, by cyanidin-3-galactoside ($r^2 = 0.56$).

Most of the evaluated parameters are correlated with the SSC of the fruit. An increase in the soluble solid content of the fruit results in an increase in the contents of polyphenols, flavonoids and anthocyanins, and it therefore determines the color of the fruit skin expressed by the *hue** index ($r^2 = 0.56$). Unfortunately, with the ripening of the fruit and the breakdown of polysaccharides into simple sugars, which is revealed by the increase in the SSC, we found a decrease in the fruit firmness, which we confirmed by the negative correlation between both indicators of the quality of the sweet cherry fruit.

All results presented represent a preliminary analysis of the research, which will continue in future years.

Table 3. Correlation coefficients between some analyzed parameters.

	Flavonoids	DPPH	Peonidin-3-rutinoside	Cyanidin-3-rutinoside	Cyanidin-3-galactoside	Color *hue*	Color *C*	Color *L**	Diameter	Weight	Firmness	SSC	Titration Acidity
Polyphenols	0.799 *	0.800 *	0.609 *	0.555 *	0.730 *	0.335	−0.480 *	−0.361	0.008	−0.002	−0.141	0.364	0.560 *
Flavonoids	-	0.871 *	0.774 *	0.731 *	0.810 *	0.463 *	−0.598 *	−0.234	0.048	0.091	−0.380	0.456 *	0.479 *
DPPH	-	-	0.847 *	0.767 *	0.925 *	0.611 *	−0.563 *	−0.492 *	0.410	0.417	−0.296	0.586 *	0.533 *
Peonidin-3-rutinoside	-	-	-	0.953 *	0.851 *	0.777 *	−0.464 *	−0.564 *	0.349	0.339	−0.721 *	0.757 *	0.609 *
Cyanidin-3-rutinoside	-	-	-	-	0.788 *	0.673 *	−0.397	−0.416	0.178	0.148	−0.813 *	0.637 *	0.511 *
Cyanidin-3-galactoside	-	-	-	-	-	0.591 *	−0.745 *	−0.482 *	0.392	0.371	−0.377	0.752 *	0.637 *
Color *hue*	-	-	-	-	-	-	−0.179	−0.720 *	0.510 *	0.496 *	−0.531 *	0.749 *	0.455 *
Color *C*	-	-	-	-	-	-	-	0.001	−0.048	−0.083	0.109	−0.609 *	−0.372
Color *L**	-	-	-	-	-	-	-	-	−0.650 *	−0.579 *	0.274	−0.669 *	−0.677 *
Diameter	-	-	-	-	-	-	-	-	-	0.974 *	0.042	0.462 *	0.283
Weight	-	-	-	-	-	-	-	-	-	-	0.078	0.430	0.188
Firmness	-	-	-	-	-	-	-	-	-	-	-	−0.501 *	−0.388
SSC	-	-	-	-	-	-	-	-	-	-	-	-	0.674 *

* Correlation coefficients, which are significant at $p = 0.01$, $n = 44$.

4. Discussion

The results obtained show the great diversity of sweet cherry cultivars, both in terms of fruit quality parameters and the content of bioactive compounds. These characteristics are not only strongly influenced by the environmental, meteorological and agrotechnical conditions, but also by the management of the orchard and the maturity stage [41,42].

In the opinion of scientists, the first basic quality characteristics in sweet cherries that consumers consider are the fruit diameter [43] and fruit color [9,44]. Whiting et al. [45], as well as Di Mateo [6], believe that the fruit size is the main feature of the fresh market sale classification of cherries. According to consumers, the highest-quality cherries should be dark red, large and sweet [46,47].

In the study, the fruit size was quite strongly correlated with the fruit weight. Such a relationship was also noted in the study of Bandi et al. [48]. The cultivars 'Horka', 'Jacinta', 'Tamara' and 'Fabiola' produced the largest fruits, and consequently, they were also the heaviest. The cultivars 'Kasandra' and 'Kordia' produced much smaller fruits, which were also lighter than the previously mentioned cultivars. 'Tamara' and 'Horka' were also characterized by impressive fruits in the experiment conducted by Vavra [49]. In contrast, in the same experiment, 'Kasandra' had substantially smaller fruits. The fruit size is mostly determined by the genetic factor. In addition, the fruit size can also be affected by many other factors, such as: the meteorological conditions, pollination and fertilization of the flowers, setting of the fruits, yielding, as well as some treatments carried out in the orchard, e.g., thinning, irrigation, fertilization, pruning and cultivation [50]. According to the research, although the large fruits also had quite large stones, the percentages of the stones in the flesh were higher in the smaller fruits.

As for the color of the fruit, full dark-red cherries have higher consumer acceptance than full bright-red cherries [51–53]. In the experiment, the cultivars with the darkest fruit were 'Jacinta' and 'Horka'. In addition, the Jacinta cultivar had the highest *hue* value and one of the lowest *C* values, which indicates that its fruit is not only among the darkest, but also the most luminous. As with the size of the fruit, the fruit color is also not only largely determined by the genetic characteristics of the cultivar, but it is also influenced by other factors (i.e., the climate in which the fruit ripens and maturity of the fruit) [21,54]. In our experiment, we also proved that the color intensity (*hue*) of the fruit was correlated with the size of the fruit (both in weight and diameter). Larger fruits tended to be more intensely colored. Usenik et al. [55] also noted such a correlation. They report that the more intensely colored fruit were larger and also had a higher sugar-to-acid ratio. Furthermore, they also found that the more intensely colored fruit had higher SSC and contained more sugars, anthocyanins and organic acids in relation to the less intensely colored fruit. In our experiment, we also obtained such a correlation between fruit color, as well as fruit size and SSC.

In addition to the size and color of the fruit, consumers also use the fruit firmness as an extremely relevant attribute when judging the acceptability of sweet cherries. Consumers prefer cherry fruits with high firmness [56–58]. Firm fruits keep well during marketing, have long shelf lives and are less susceptible to mechanical damage and crushing [7,59,60]. As with other traits, the firmness is not only largely dependent on the cultivar, but also on the cultivar conditions, fruit maturity and size of the fruit, which, in turn, are related to the volume of the yield. Therefore, the fruit firmness can often substantially vary among the testing seasons and locations of the experiment. For example, in Ballisterti et al.'s experiment [11], the firmness of different sweet cherry cultivars in Italy ranged from 3.2 N to as much as 27.0 N. In contrast, in a study by Szpadzik et al. [34], the firmness of some popular cherry cultivars growing under central Poland conditions was 5.7–8.7 N. In the presented experiment, the firmness of the tested cultivars ranged from 4.26 to 8.52 N. The 'Fabiola' and the 'Kordia' cultivars were substantially firmer than the other cultivars, while the 'Jacinta' cultivar had the lowest firmness.

Both the soluble solid content (SSC) and titration acidity (TA) are extremely important traits because the taste is largely determined by a balance between the sugar and the

acid contents [53,61]. According to Poll and Peterson [62], these two features are largely influenced by the weather conditions during the ripening of the fruit. During times of strong sunlight and high temperatures, the synthesis of the sugars in the fruit is increased. Palou et al. [63] state that the desired range for the marketing of high-quality sweet cherries is more than 14.0° Brix. In other works, researchers have shown large differences in the SSCs among cherry cultivars, ranging from 13.5 to 22.7%, as well as 11–25% [64]. In our study, the SSCs of the tested cultivars ranged from 13.30 in the 'Tamara' cultivar to 16.30 in the 'Jacinta' cultivar. In the Vavra experiment [49], these two cultivars had even higher SSCs than in the present experiment.

The ratio of SSC to TA in cherry fruit is one of the important criteria for the flavor formation. A high SSC-to-TA ratio is desired [58]. The 'Tamara', 'Helga', 'Fabiola' and 'Kasandra' cultivars had high ratios of extract content to titratable acidity in the present study, proving that they are among the tastiest of the cultivars discussed. Considering that consumers prefer sweet cherries [46,47], we assume that these cultivars will find acceptance among potential customers.

There is an increasing interest in food that is not only tasty and safe, but that also produces additional health benefits. Fruits contain high levels of antioxidant compounds, providing protection against cancer and heart diseases [16]. The strong nutraceutical effect of cherries is due to their high content of polyphenol groups, of which anthocyanins are the main group [21]. A characteristic aspect of red fruit ripening is the change in the initial green color to red, purple or black due to the anthocyanin accumulation and chlorophyll degradation [65]. The composition of the biochemical compounds in sweet cherry fruit depends on, among other things: the genetic characteristics of the cultivar [10,11,66–68]; the maturity [66,69–71]; the climatic conditions, and in particular, the difference between the day and night temperatures before harvest, as well as the intensity of light [72,73]; the rootstock [24]; the part of the fruit [74]; the geographic region in which the plant grows [75].

In the present experiment, we also compared the cultivars in terms of their contents of health-promoting compounds. In this respect, the cultivar distinguished by high contents of these compounds was 'Jacinta', which had high polyphenol and flavonoid contents and high antioxidant capacity, while 'Helga' had the lowest contents of these compounds. These results are confirmed in the study by Knapová and Bílková [76]. In both experiments, the cultivars had similar contents of polyphenols and flavonoids and similar antioxidant activities. Therefore, the 'Jacinta' cultivar is the most valuable in terms of the nutraceutical content, although it has the lowest firmness among the tested cultivars, which may create less consumer interest.

The composition and quantity of the phytochemicals in cherries strongly influence their antioxidant activities, as well as their quality characteristics. We could easily observe these relationships in the present study by analyzing the correlation between the different traits of the studied cultivars. Many researchers have confirmed that anthocyanins are mainly responsible for the high antioxidant capacity of cherries [25,68,70]. In our study, a correlation between the DPPH and high contents of flavonoids, polyphenols and anthocyanins was evident. Tomás-Barberán et al. [77] also proved these correlations. We also found that, of the anthocyanins present, cyanidin-3-galactoside was the most responsible for the high antioxidant activity of the fruit. Usenik et al.'s [55] study also found that, for the fruit of the 'Kordia' cultivar, the color was correlated with the chemical composition of the fruit, as well as the fruit size, although the correlation was weaker for the fruit size. We obtained similar results in our experiment, in which, in the case of the *hue*, we found a significant correlation with most of the bioactive compounds. We also noticed that fruit color is correlated with traits such as SSC and TA. Studies show that the more intense (darker) the color of the fruit, the higher the SSC and TA are. However, for the saturation (C^*) and color (L^*), we observed an inverse correlation (i.e., the more anthocyanins, the darker the fruit). Tomás-Barberán et al. [77] claimed that the increase in the fruit color intensity accompanies an increase in the bioactive compounds.

In the present experiment, we observed a substantial positive correlation between the bioactive compounds and SSC and TA. This correlation can be explained by the fact that anthocyanins are made up of sugar residues that are linked to aglycones, which are colored compounds from the anthocyanidin group. As the sugar content increases, the product (the sugar required for the synthesis of anthocyanins), and therefore the anthocyanin content, also increases. In the case of cherries, this process can even take place in the dark.

5. Conclusions

In this study, the studied sweet cherry cultivars ('Jacinta'; 'Horka'; 'Tamara'; 'Helga'; 'Fabiola'; 'Kasandra'; 'Kordia') had variability in the fruit quality parameters and biochemical attributes. At the current stage of the research, we confirmed 'Kordia', due to its high quality, is still one of the most valuable cultivars in Polish conditions. On the other hand, some promising cultivars have emerged. One of them, especially in terms of the health-promoting properties is 'Jacinta' (the highest contents of polyphenols and flavonoids and highest antioxidant activity). In addition, the fruits of this cultivar are characterized by fairly good quality parameters, but the disadvantage is the rather low firmness.

What is more, our research confirms the fact that darker cherries contain more bioactive compounds and have a higher antioxidant activity. This suggests that better-colored cherries could be more beneficial for human health. It is also worth noting that size of fruits as well as SSC and TA are also correlated with fruit color. Intensively colored fruit are larger and have higher SSC and TA.

However, further research is needed to confirm the results obtained.

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