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Yield Performance and Physicochemical Properties of Selected Honey Berry (*Lonicera caerulea* L. var. *kamtschatica* Sevast.), Under Central Polish Conditions

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Abstract

Until recently, the blue honeysuckle (*Lonicera caerulea* L. var. *kamtschatica* Sevast.) was considered a niche species, but Poland is now one of the largest producers of this fruit in the world. The purpose of this study was to assess the yield, quality of the fruits, and the health promotion value of the fruits of selected honey berry cultivars grown under the conditions of central Poland. Six cultivars ('Morena', 'Vostorg', 'Honeybee', 'Wojtek', 'Boreal Beast', and 'Boreal Beauty') were evaluated for yield and physical fruit characteristics: average fruit weight (g), dry matter content (%), fruit shape, fruit colour (CIE lab), firmness (N), soluble solid content (°Brix), pH, titratable acidity (% citric acid), as well as biologically active compounds including polyphenols, flavonoids, anthocyanins, vitamin C, and antioxidant activity (DPPH+). The studies also determined the degree of correlation between different variables using Pearson's linear correlation coefficients. The highest yields were obtained for the 'Wojtek' and 'Boreal Beauty' cultivars, while in terms of health-promoting properties, the 'Morena' cultivar stood out, characterised by the darkest fruit colour, the highest content of polyphenols, anthocyanins, vitamin C, and the highest antioxidant activity. The correlation analysis showed relationships between the vitamin C content, antioxidant activity, and fruit colour and the accumulation of bioactive compounds. The differences observed among the cultivars tested indicated their different potential for use in the fresh consumption, food processing, and pharmaceutical industries.

Keywords: honey berry; yield; fruit quality; antioxidant activity; health-promoting value

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1. Introduction

The botanic species previously named 'blue honeysuckle' (*Lonicera caerulea* L. var. *kamtschatica* Sevast.) is now known as honey berry, and bred cultivars have been derived from this species. It is a plant species that belongs to the *Caprifoliaceae* family [1], which has gained increasing importance in Polish horticulture in recent years. This species originates in the cool regions of the northern hemisphere, including Siberia, the Far East, and Japan [2].

The honey berry is one of the first seasonal fruits in our climate zone—its fruits ripen earliest in the season, the first cultivars have berries ready for picking as early as at the end of May, even before strawberries and raspberries, and the peak of fruiting occurs in

June [3]. This creates an opportunity to extend the supply of fresh berries, and the market is very interested in this type of fruit, especially those from organic production. In addition, this species is not difficult to grow, the plant is highly resistant to disease, and it has low soil requirements. Although the species does not tolerate very heavy, clayey, or excessively light and sandy soils, it shows considerable tolerance to drought, making honey berry an attractive option for commercial cultivation [4]. In addition, the high tolerance to nutrient deficiencies makes these berries well-suited for organic and low-input farming. The shrubs are also highly winter resistant, capable of withstanding temperatures as low as −45 °C [2], and their buds and flowers demonstrate notable tolerance to spring frosts [5].

In recent years, honey berries have gained economic importance, especially in Central Europe and Poland, where cultivation is expanding steadily [6]. Honey berries are used not only as fresh fruit but also in the production of different products, dietary supplements, and natural cosmetics due to their high content of bioactive compounds and antioxidants [7]. The evaluation of the technological and functional quality of honey berries is extremely important for both producers and processors, as it determines their suitability for direct consumption and further industrial processing. This quality is based on many physicochemical and sensory characteristics that influence consumer acceptance and the efficiency of technological processes. In Poland, the number of commercial plantations has recently increased. In addition, new cultivars with improved fertility and fruit quality and a higher bioactive compound content have been developed in Poland. Honey berry is currently considered a crop with high market potential, not only for fresh fruit but also for preserves and functional products. In particular, Poland has successfully bred valuable honey berry cultivars with high-quality fruits. In our country, not only Polish cultivars but also Russian and Canadian ones have been planted in the large planting areas. New and valuable cultivars have completely changed the perception of honey berry, which until a dozen years ago was considered not very tasty or attractive. As the cultivation of honey berries in Poland and other European countries develops, the number of available cultivars is also growing. The differences between cultivars not only relate to the appearance and taste of the fruit but also to their nutritional value and use in processing [6]. Previous studies have shown significant differences in fruit weight, extract content, acidity, pH, firmness, and polyphenol levels [8]. It should be noted that individual honey berry cultivars should be treated differently according to their intended use. Foreign cultivars available on the Polish market originate from centres that have been selecting this species for many years, and they are still being improved in terms of their specific purpose. As Król-Dyrek [9] points out, Polish cultivars (e.g., ‘Wojtek’, but also ‘Zojka’) selected in the 1990s could not be treated as dessert cultivars due to a lower sugar content and a lower fruit weight compared to new Canadian and Russian cultivars. Their suitability for mechanical harvesting makes them suitable for industrial use. On the other hand, Canadian and Russian cultivars with large, firm, and tasty fruits—‘Aurora’, ‘Jugana’, ‘Vostorg’—seem promising and are recommended for the fresh fruit market. Other cultivars, such as ‘Indigo Gem’ and ‘Honeybee’, are suitable for industrial use, although they require appropriate cultivation techniques.

The research by Asănică et al. [1] indicated that the key quality parameters were the weight of the fruit, the firmness, the content of the extract, and acidity. Fruit weight is important to assess yield and commercial attractiveness, while the firmness determines the tolerance of the fruit to mechanical damage during harvesting, transport, and storage [10]. The firmness is measured as the force required to deform it, and a high value promotes shelf life and quality preservation.

The colour of the fruit is another important quality indicator, closely related to the anthocyanin content and the degree of ripeness. Celli et al. [11] and Raudone et al. [12] emphasised that spectrophotometric methods, especially the CIELab system, allowed an accurate colour assessment and were widely used in quality research. An intense, uniform navy-blue colour is a desirable feature that affects the visual appeal of the fruit.

The soluble solid content (measured in °Brix) and total acidity (citric acid equivalent) are basic indicators of the taste and sensory quality of the fruit [13]. Bieniek et al. [2] indicated that a high extract content, combined with moderate acidity, promoted a positive sensory evaluation and determined the taste of dessert fruits. These parameters are very important in the processing context, as they affect the quality of end products such as juices and jams [14].

However, the most important advantage of honey berry is its health-promoting properties. Honey berry belongs to a group of low-calorie foods, yet they are a rich source of carbohydrates and minerals, and they contain significant amounts of bioactive compounds with powerful health-promoting properties that improve the body and protect against many lifestyle diseases [2,15,16]. The anthocyanins, flavonoids, vitamin C, and phenolic acids present in the fruit regulate metabolic processes in the human body, deactivate oxygen free radicals, protect against oxidative stress and thus exhibit anticancer properties, and can counteract cell damage and the development of chronic diseases, such as cancer, diabetes, and cardiovascular diseases [15–18]. Celli et al. [11] emphasized that the natural antioxidants present in fruits had anti-inflammatory and anticancer properties and a beneficial effect on the cardiovascular system. Negreanu-Pirjol et al. [19] noted that honey berry had strong antioxidant properties, placing it in the group of so-called "superfoods". Particular attention is drawn to the high content of anthocyanins. Their concentration in fruits depends on many factors, such as the cultivar, growing conditions, climate, and degree of ripeness. According to research, the level of anthocyanins could reach 1300–1500 mg/100 g of dry matter, placing the honey berry at the forefront of the berries in terms of its content [7,15]. The fruit contains six different anthocyanins, the main being cyanidin-3-glucoside [20]. In addition to anthocyanins, these fruits are also rich in other polyphenols, such as flavonoids and phenolic acids, including chlorogenic, caffeic, and ferulic acids [17,21]. Honey berries are also distinguished by their high vitamin C content, which can range from 30 to 186 mg/100 g of dry weight [22], and in the case of fresh fruit, from 50 to 80 mg/100 g [3,16]. This vitamin is a well-known antioxidant that supports the immune system, has anti-inflammatory properties, and accelerates the body's regenerative processes.

The compounds mentioned above determine the remarkable health-promoting properties of honey berry. The results of the study by Cesonienė et al. [23] for evaluating 11 cultivars of honey berry, in terms of their content of bioactive compounds and their antioxidant and antibacterial properties, confirmed the high health benefits of the fruits. On the other hand, studies by Auzanneau et al. [24] and Zhang et al. [25] proved that the content of bioactive compounds and the level of antioxidant activity of the fruit vary depending on the cultivar and season. The antiviral, antibacterial, anti-inflammatory, and anticancer properties of honey berry further increased their use as natural medicinal preparations and dietary supplements [4,26,27]. They are used, among others, in dietary supplements, natural cosmetics, and functional products, due to their rich composition and health-promoting properties [2]. Ripe fruits are used not only in dietetics and medicine but also in the food industry—they are used to produce juices, jams, liqueurs, frozen foods, dried foods, or as a complement to desserts [17]. In addition, a natural red food colouring is obtained from honey berry [28].

The honey berry is a crop with a unique combination of botanical, ecological, and economic characteristics, which determine its growing role in horticulture and the food industry. High tolerance to harsh climatic conditions, early fruit ripening, and their nutritional value make honey berry an attractive raw material for both producers and consumers.

The growing interest in honey berries among growers and consumers means that there is a growing need for detailed research into the morphological and yield characteristics of cultivars and the physicochemical quality of their fruits. Knowledge of the chemical properties of the fruit, i.e., its sugar, organic acid, polyphenols, and anthocyanin content, is crucial from the point of view of its suitability for use in the food and processing industries [29].

The purpose of this study was to evaluate the fruit yield, quality, and health-promoting properties of various honey berries (*Lonicera caerulea* L.) grown in central Poland. Despite the increasing interest in honey berry as a functional fruit, limited data are available on the variation dependent on cultivars in bioactive compounds under Central European growing conditions. Therefore, this research aimed to identify differences between cultivars in terms of their agronomic performance, nutritional value, and content of bioactive compounds, relevant to health, providing useful information to growers, the food industry, and consumers.

2. Materials and Methods

This study was conducted in 2024. The research material consisted of six cultivars (cv./cvs.) of honey berry (*Lonicera caerulea* L. var. *kamtschatica* Sevast.) from different breeding programmes and countries: Canada—'Honeybee', 'Boreal Beast', and 'Boreal Beauty', Russia—'Vostorg', and Poland—'Morena' and 'Wojtek'. The field experiment was established at the Pomological Orchard in 2015 of the National Institute of Horticultural Research (InHort) in Skierniewice, located in the Łódź Voievodship, in central Poland (51°57′17″ N 20°09′30″ E 128 m a.s.l.). The following cultivars were selected for the assessment of fruit quality parameters based on their different ripening times: '**Morena**'—a very early cultivar, fruit ripeness at the turn of May and June, often considered one of the first to be ready for harvest under Polish climatic conditions; '**Vostorg**'—an early cultivar, fruiting just after 'Morena', with large and tasty fruits; '**Honeybee**'—a medium–early cultivar, with a compact bush habit and regular fruiting; '**Wojtek**'—a medium–early, popular Polish cultivar, ripening in the first half of June; '**Boreal Beast**'—a late cultivar, characterised by high yield potential and tolerance to fruit drop; '**Boreal Beauty**'—a very late cultivar, whose fruits reach full maturity in the second half of June, often even at the end of the month, which extends the harvest season.

The honey berry experiment was arranged in two rows, with three bushes per plot, in three repetitions. The plants were planted in rows with a planting density of 0.5 m between the bushes and 3.0 m between the rows (Scheme 1). This arrangement ensured that each plant had adequate access to light and air circulation, which limited the development of diseases and promoted uniform fruit ripening.

Scheme 1. The honey berry (*Lonicera caerulea* L.) experimental plantation in Skierniewice (S. Pluta).

The soil at the experimental site is class IV, characterized by a moderate nutrient content (medium reach) and an average water capacity. The year 2024 in the Skierniewice region was characterized by variable climatic conditions typical of the temperate zone. The average annual temperature fluctuated around 9.5 °C, with a clear division between a warm, dry summer and a cooler, wetter autumn and spring. Annual precipitation amounted to approximately 550 mm, with higher accumulation in the spring and autumn months, which ensured adequate soil moisture during key stages of plant development and fruit ripening and harvesting. The research year saw relatively high sunshine, with a monthly total of approximately 180–220 h of solar radiation, which was conducive to intensive fruit ripening. The wind in the experimental area was moderate, averaging 3–4 m/s [30].

Agrotechnical applications included standard practices typical for honey berry cultivation, with a particular emphasis on minimal protection of the plant against biotic and abiotic stresses. Basic protective measures were applied to reduce the pressure of weeds, pests, and diseases while minimizing the use of chemicals, in line with the sustainable agriculture strategy. The plants in the experiment were irrigated by an automatic drip irrigation system, distributed along the rows using appropriately spaced hoses. The system provided regular watering twice a day—in the morning and in the evening—for 1.5 h each, which ensured that the soil remained at the optimal moisture level necessary for the proper plant growth and yield. Additionally, a protective net on a special construction of wooden posts with wires was stretched over the field experiment to protect fruit from birds, which could cause significant crop losses.

The date of harvest of the fruits of each cultivar was determined on the basis of a visual evaluation of the fruits and soluble solids (minimum 13 °Brix) [8]. The different cultivars were harvested on the following dates: 'Morena'—May 20; 'Wojtek'—June 4; 'Vostorg'—June 4; 'Honeybee'—May 27; 'Boreal Beauty'—May 29; 'Boreal Beast'—June 6.

All physical parameters of the fruit and their instrumental quality were determined directly after harvest.

2.1. Tested Parameters and Methods Used

Laboratory tests of the fruits of tested cultivars were conducted at the Department of Horticultural Crop Breeding of the InHort in Skierniewice and the fruit physiology laboratory of the Horticultural Economics of the Warsaw University of Life Sciences, SGGW. For physical and instrumental tests, 60 fruits were collected from each cultivar and then divided into 3 equal replicates within each cultivar.

2.1.1. Yield and Physical Parameters of the Fruit

Yield—determined as the average weight of all fruits harvested from each bush of a given cultivar, with results expressed in kg/bush.

Weight of 100 fruits—calculated by weighing a random sample of 100 fruits from each replication of the tested cultivar on an Ohaus TP 2009 analytical balance (OHAUS Europe GmbH, Nänikon, Switzerland). The results were averaged and presented in grams.

Dry matter (DM) of the fruit was determined according to PN-90/A-75101/03 [31] using the drying method. Five grams of crushed fruit of each cultivar were weighed and dried in a laboratory dryer at 105 °C for 24 h until a constant weight was obtained. After being cooled in a desiccator, the samples were weighed again. The dry matter content was expressed as the percentage of the mass remaining after drying relative to the fresh sample mass.

Fruit dimensions and shape—the length and diameter of 30 randomly selected fruits were measured in three replicates for each cultivar. Measurements were taken using a precise Fanger Calipro electronic calliper (Polska, Kraków). The length was measured along the longitudinal axis of the fruit (from the stalk to the tip), while the diameter was measured at the widest point transversely to the axis of the fruit. On the basis of the data obtained, **the length-to-diameter ratio (L/D)** was calculated, which allows one to determine the shape of the fruit (elongated, oval, and spherical). It is assumed that a result closer to unity indicates fruit that is close to spherical in shape.

2.1.2. The External Colour of the Fruits

The external colour was evaluated using a Minolta CR-508i colourimeter (Minolta, Osaka, Japan), fitted with a 5 mm measurement head, under D65 illumination and a 10° standard observer. Calibration was performed with the manufacturer-provided white standard plate. Measurements were taken of 20 berries per replication, following the CIE Lab* colour space. In this system, L* represents lightness on a scale of 0 (black) to 100 (white), a* ranges from −60 (green) to +60 (red), and b* spans from −60 (blue) to +60 (yellow). Changes in colour were evaluated based on the L*, a*, and b* parameters. On the basis of the a* and b* values, the hue angle and chroma were calculated. The *hue* angle was determined using the formula $h^\circ = \tan^{-1}(b^*/a^*) + 180^\circ$, assuming that $a^* < 0$ and $b^* > 0$. The *hue* values correspond to positions on the colour wheel, where red, yellow, green, and blue are located at 0°, 60°, 120°, and 240°, respectively. Chroma, calculated as $C = \sqrt{(a^2 + b^2)}$, indicates the intensity or dullness of the fruit colour and is also known as colour saturation [32].

2.1.3. Fruit Quality Indicators (Instrumental Tests)

The firmness (FF) was assessed by measuring the maximum force needed to insert a 3 mm Magness-Taylor probe into the fruit to a depth of 3 mm. The measurement was carried out using an Instron 5542 test machine (Instron, High Wycombe, UK), and the results were reported in Newtons (N) [33]. The **soluble solid content (SSC)** in the fruit was measured using a refractometer (model PAL-1, Conbest, Kraków, Poland). **Titratable acidity (TA)** was determined according to the PN-EN 12147:2000 standard by titration with a 0.1 M sodium hydroxide (NaOH) solution until a pH of 8.1. Knowing the dilution and normality of the tested liquid, the acidity was converted to citric acid equivalents. The result was expressed as a percentage of citric acid [34]. The $\mathbf{pH_{KCl}}$ level was recorded using a pH meter (model CP-411, Elmetron, Zabrze, Poland).

2.1.4. Content of Biologically Active Compounds and Antioxidant Capacity

To analyse biologically active compounds, fruit samples were collected and stored at −80 °C until further analysis.

The total polyphenol concentration was determined using a Shimadzu UV-VIS 1280 (Shimadzu, Kyoto, Japan) spectrophotometer, following a spectrophotometric procedure based on the use of Folin–Ciocalteu reagent, according to the Waterhouse method [35]. For the analysis, 5 g of fruit flesh was ground in liquid nitrogen and extracted with 50 mL of pure methanol. Each extraction was performed twice, and the resulting extracts were combined in a 100 mL volumetric flask. From this, 1 mL of extract was transferred to a 50 mL volumetric flask, followed by the addition of 35 mL of distilled water, 2.5 mL of Folin–Ciocalteu reagent, and 7.5 mL of 10% sodium carbonate (Na_2CO_3). The mixture was diluted to volume with water and incubated at 25 ± 2 °C for 20 min. The absorbance was measured at 750 nm. Gallic acid was used as the standard, in concentrations of 0.00, 0.05, 0.15, 0.20, 0.25, and 0.30 g/L. The total polyphenol content was calculated using the formula $(105.89 \times \text{absorbance}^2 + 25.318 \times \text{absorbance})/\text{mass} \times 50$, and it was expressed as milligrams of gallic acid equivalent per 100 g of fresh weight (mg GAE·100 g^{-1} FW).

The total anthocyanin content in fruits was determined by spectrophotometry after extraction with acidified methanol. The berries were first frozen (−80 °C), then thawed and homogenised. From each sample, 2.5 g of crushed material was weighed and extracted twice using 25 mL of methanol acidified with 1% (*v*/*v*) hydrochloric acid (HCl). The extraction was carried out at room temperature for 30 min, and the samples were stirred vigorously each time. After extraction, the mixtures were centrifuged (10 min, 5000 rpm), and the supernatants from both extractions were combined. The absorbance of the extracts was measured using a UV-VIS spectrophotometer (Shimadzu UV-1280, Shimadzu, Kyoto, Japan) at wavelengths of 530 nm (for maximum anthocyanin absorption) and 657 nm. The total anthocyanin content was expressed as cyanidin-3-glucoside (C3G) equivalent and given in mg per 100 g of fresh weight (mg·100 g^{-1} FW) [36]

The total flavonoid content was measured according to a modified method described by Marinova et al. [37], also using the Shimadzu UV-VIS 1280 (Shimadzu, Kyoto, Japan) spectrophotometer at a wavelength of 510 nm. For this analysis, 2.5 g of fruit was ground in liquid nitrogen. Each sample was extracted twice with 25 mL of 80% methanol for 15 min. The supernatant was treated sequentially with distilled water, 5% sodium nitrite ($NaNO_2$), 10% aluminium chloride ($AlCl_3$), and 1 M sodium hydroxide (NaOH), with specified time intervals between additions. The flavonoid concentration was quantified on a calibration curve using quercetin, with standard concentrations of 0.00, 0.20, 0.60, 0.80, and 1.00 g/L. The results were reported as milligrams of quercetin equivalents per 100 grams of fresh weight (mg QE·100 g^{-1} FW).

The vitamin C content in a fruit juice sample was determined using an RQflex® 20 MilliporeSigma refractometer, Darmstadt, Germany. The method involved the reaction of vitamin C with the reagent 2,6-dichlorophenolindophenol (DCPIP), which undergoes discolouration in the presence of vitamin C. The refractometer measured the degree of change in colour in the sample by analysing light reflection, giving the ascorbic acid content in mg/L [38].

2.1.5. Evaluation of Antioxidant Activity

Antioxidant capacity was assessed following the procedure described by Saint Criq de Gaulejac et al. [39], using the synthetic radical DPPH (1,1-diphenyl-2-picrylhydrazyl; Sigma-Aldrich, Poznań, Poland). The antioxidant activity was expressed as milligrams of ascorbic acid equivalent per 100 g of fresh weight (mg AAE·100 g^{-1} FW).

2.2. Statistical Analysis

All data were statistically analysed using Statistica 13.3 (StatSoft Polska, Krakow, Poland) using one-way analysis of variance (ANOVA). To assess significant differences between group means, the Newman–Keuls post hoc test was applied ($p \leq 0.05$). Standard deviations are presented along with the results in tables and figures.

We also determined the degree of correlations between the different variables using Pearson's linear correlation coefficients.

3. Results

3.1. Yield and Physical Parameters of Fruit

Based on the measurements, significant differences were found between the tested honey berry (*Lonicera caerulea* L. var. *kamtschatica* Sevast) cultivars in terms of fruit yield and all physical parameters (Table 1). The highest yields were obtained for the cultivars 'Wojtek' and 'Boreal Beauty' (more than 2 kg/bush) and differed significantly from the remaining cultivars. The lowest fruit yields were harvested from bushes of the 'Morena', 'Vostorg', and 'Honeybee' (approx. 0.60 kg/bush).

Table 1. Yield and physical parameters of the fruit depending on the honey berry (*Lonicera caerulea* L.) cultivar.

Cultivar	Fruit Yield [kg/bush]		Weight of 100 Fruits [g]		Dry Matter (DM) [%]		Fruit Length (L) [mm]		Fruit Diameter (D) [mm]		L/D Ratio	
'Morena'	0.53	±0.06 C *	113.8	±10.6 D	16.4	±0.14 CD	19.86	±1.49 C	7.58	±0.61 C	2.60	±0.01 A
'Wojtek'	2.13	±0.25 A	157.8	±4.50 B	16.2	±0.28 D	21.33	±0.52 B	9.48	±0.18 B	2.24	±0.10 B
'Vostorg'	0.63	±0.12 C	141.6	±10.0 C	17.7	±0.35 B	24.50	±0.48 A	11.52	±0.15 A	2.18	±0.05 BC
'Honeybee'	0.67	±0.13 C	62.7	±6.10 E	18.3	±0.21 A	13.44	±1.44 E	6.62	±0.75 D	2.08	±0.05 C
'Boreal Beauty'	2.08	±0.32 A	151.7	±5.90 BC	16.9	±0.21 C	15.86	±0.76 D	11.48	±0.30 A	1.40	±0.02 D
'Boreal Beast'	1.40	±0.28 B	228.0	±10.4 A	17.1	±0.14 C	20.85	±2.04 B	9.24	±0.44 B	2.27	±0.12 B

* Values with different letters are significantly different within a column at $p \leq 0.05$.

'Boreal Beast' showed the greatest 100-fruit weight (over 200 g) among all the cultivars tested. The highest fruit weight was recorded for the cv. 'Honeybee' (more than 62 g/100 fruits). Fruit weights of other analysed cultivars ranged from 113.8 g to 157.8 g/100 berries and could be classified as medium-sized cultivars.

The dry matter content in the fruit was significantly the highest for 'Honeybee' (more than 18%) and the lowest for cvs. 'Wojtek' and 'Morena' (slightly above 16%). Fruits of the remaining three cvs. 'Boreal Beauty', 'Boreal Beast', and 'Vostorg' were mid reach in dry matter and contained from 16.9% to 17.7%.

On the basis of the measurements, it was found that the tested cultivars differed significantly in terms of shape and size as well as L/D ratio (Table 1).

The longest fruits among the tested cultivars were those of the 'Vostorg' (approx. 25 mm). The shortest fruits were observed for the cv. 'Honeybee'.

In terms of fruit diameter, the highest values were observed for the cultivars 'Vostorg' and 'Boreal Beauty' (for both cultivars above 11 mm), with no significant differences between them. The smallest fruit diameter was recorded for the cultivar 'Honeybee' (slightly larger than 6.5 mm), whose fruits differed statistically from those of the other cultivars.

When considering the length-to-width ratio (L/W) of the fruits of the tested cultivars, the highest value was found for the cv. 'Morena' (2.60), which indicated that the shape of the fruit of this cultivar was the most elongated. The lowest value of this ratio was recorded for the cv. 'Boreal Beauty' (1.40), which in turn indicated a more spherical fruit shape.

The results clearly highlight the morphological diversity of the fruits of the honey berry cultivars studied, which may affect their market value.

3.2. The External Fruit Colour

The analysis revealed significant cultivar-dependent differences for most of the colour indices measured in the CIELab colour space (Table 2). The L* value (lightness) ranged from approximately 29 for the cv. 'Morena' to 40 for the 'Wojtek'. This result showed that the 'Wojtek' berries were significantly lighter than the fruits of other cultivars, while the 'Morena' fruits were the darkest.

For the component 'a' (red–green hue), the highest value (3.48) was recorded for the cv. 'Morena', while the lowest (−0.75) was obtained for the cv. 'Wojtek'. The differences between cultivars were statistically significant.

The 'b' component (yellow–blue hue) took negative values in most cultivars, indicating the dominance of blue tones. Only the cv. 'Vostorg' had a positive value (1.47), which could indicate a shift in colour change towards yellow–green tones. The other cultivars tested were characterised by a blue–violet colour more typical of honey berries.

Chroma (C), that is, colour saturation, was highest for the cultivars 'Morena' and 'Boreal Beauty', respectively, 5.12 and 5.15, suggesting a more intense colour of the fruit of these cultivars. The lowest chromaticity was found for the cultivars 'Honeybee' and 'Vostorg'—2.77 and 2.96, respectively; these differences were statistically significant.

Table 2. The external fruit colour depends on the tested cultivars of honey berry (*Lonicera caerulea* L.).

Cultivar	L*		a		b		C		*h*	
'Morena'	28.9	±0.64 C *	3.48	±0.46 A	−2.66	±0.31 B	5.12	±0.40 A	284.1	±9.20 A
'Wojtek'	40.0	±0.60 A	−0.75	±0.32 E	−4.46	±0.20 B	4.53	±0.24 B	260.1	±4.30 A
'Vostorg'	32.5	±4.16 BC	0.47	±1.53 D	1.47	±2.78 A	2.96	±0.30 C	241.0	±7.05 A
'Honeybee'	33.0	±1.41 BC	0.09	±0.70 DE	−1.31	±1.00 B	2.77	±0.54 C	242.1	±11.06 A
'Boreal Beauty'	34.1	±2.04 B	2.15	±0.21 B	−4.13	±0.28 B	5.15	±0.20 A	284.7	±10.21 A
'Boreal Beast'	34.6	±1.45 B	1.39	±0.65 C	−3.00	±0.34 B	3.57	±0.05 B	291.5	±9.04 A

* Values with different letters are significantly different within a column at $p \leq 0.05$.

The $h°$ value ranged from approximately 241° ('Vostorg') to approximately 292° ('Boreal Beast'), which corresponded to violet–blue tones. Although no statistically significant differences were found between the cultivars for this parameter, there was a general tendency for the colour to change to purple in cultivars with higher $h°$.

3.3. Fruit Quality Indicators

Statistical analysis of collected data showed that the tested cultivars of honey berry differed significantly from each other for all quality characteristics of the fruit (Table 3).

Table 3. Honey berry (*Lonicera caerulea* L.) fruit quality indicators depending on the cultivar.

Cultivar	FF [N]		SSC [°Brix]		TA [%]		SSC/TA Ratio		pH_{KCl}	
'Morena'	0.28	±0.02 C *	16.5	±0.22 B	3.00	±0.01 A	5.50	±0.10 D	3.35	±0.03 C
'Wojtek'	1.00	±0.13 A	15.0	±0.64 D	2.22	±0.02 B	6.75	±0.28 CD	3.44	±0.04 BC
'Vostorg'	0.20	±0.04 D	16.8	±0.42 B	2.15	±0.05 C	7.81	±0.23 C	3.45	±0.07 BC
'Honeybee'	0.60	±0.01 B	16.6	±0.31 B	2.00	±0.01 D	8.30	±0.17 B	3.48	±0.05 B
'Boreal Beauty'	0.24	±0.05 D	15.5	±0.60 C	1.92	±0.02 E	8.07	±0.31 BC	3.45	±0.02 BC
'Boreal Beast'	0.58	±0.04 B	17.7	±0.91 A	1.10	±0.01 F	16.10	±0.84 A	3.77	±0.04 A

* Values with different letters are significantly different within a column at $p \leq 0.05$. FF—fruit firmness; SSC—soluble solid content; TA—titratable acidity; SSC/TA—soluble solid content to titratable acidity ratio.

On the basis of the tests, significant differences in the firmness of the fruit were concluded between the tested cultivars of honey berry (Table 3). The fruits of cultivar 'Wojtek' were characterised by the highest firmness value (1.00 N), significantly different from the other cultivars. The lowest results were obtained for the cvs. 'Vostorg' and 'Boreal Beauty', respectively (0.20 N and 0.24 N), which formed a homogeneous statistical group. The cultivars 'Honeybee' and 'Boreal Beast' obtained intermediate values (0.58–0.60 N) and also formed a separate group of significance.

Significant differences in soluble solid content (SSC) of fruits were found between the tested cultivars (Table 3). The highest value was recorded for the cv. 'Boreal Beast' (17.7 °Bx), which might suggest its high suitability for direct consumption. In contrast, the lowest extract content was found in the fruits of 'Wojtek' (15.0 °Bx). The fruits of cultivars 'Morena', 'Vostorg', 'Honeybee', and 'Boreal Beauty' were of the intermediate reach in this compound.

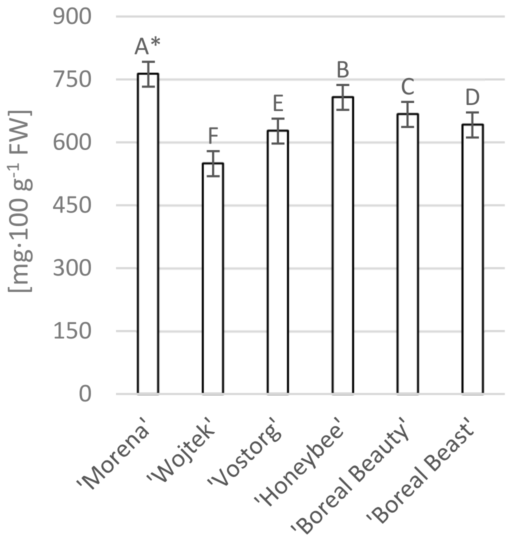
Differences between the tested honey berry cultivars were also observed in terms of titratable acidity (TA) (Table 3). The fruits of cv. 'Morena' showed the highest acidity—3%, significantly different from all other cultivars. The lowest acidity was recorded in the fruits of cv. 'Boreal Beast' (only 1.1%). The other cultivars occupied intermediate positions, clearly differing from each other.

After analysing the SSC-to-TA ratio, it was found that, similarly to SSC, the highest value was recorded for the cultivar 'Boreal Beast'—16.10, which indicated that fruits of this cultivar might be perceived by consumers as the sweetest (Table 3). In the other cultivars, the SSC-to-TA ratio was significantly lower, with one of the lowest values found in the cv. 'Morena'—5.5. The fruits of the 'Wojtek' cultivar had a slightly higher SSC/TA ratio—approximately 6.7

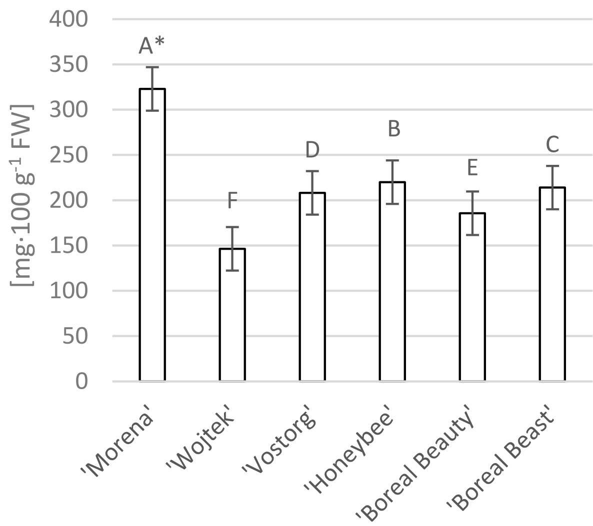
The fruits of the cultivars tested varied in terms of pH, although the variation range was relatively small (3.35–3.77) (Table 3). The lowest pH of the fruits was found for cv. 'Morena' (3.35) and the highest for 'Boreal Beast' (3.77), which was consistent with the results of the titratable acidity. The cultivars 'Wojtek', 'Vostorg', 'Honeybee', and 'Boreal Beauty' showed intermediate values, forming partially common statistical groups, which indicated smaller differences between them.

3.4. The Content of Biologically Active Compounds in the Fruit and the Antioxidant Activity of the Fruit

The analyses showed that the fruits of the honey berry cultivars differed significantly in terms of both the content of biologically active compounds and the antioxidant activity (Figure 1a–e). In general, it can be concluded that the fruits of the 'Morena' cultivar contained the most biologically active compounds. Its fruits contained significantly superior levels of total polyphenols (more than 760 mg·100 g^{-1} FW), total anthocyanins (over 320 mg·100 g^{-1} FW), total flavonoids (more than 1.7mg·100 g^{-1} FW), and vitamin C (over 173 mg·100 g^{-1} FW) (Figure 1a–d). In terms of vitamin C content alone, the cv. 'Morena' did not differ significantly from the cultivars 'Honeybee' and 'Boreal Beast'. Regarding the bioactive compounds, the 'Honeybee' fruit also had relatively high contents, although usually significantly lower than 'Morena' (total polyphenol content—more than 707 mg·100 g^{-1} FW, anthocyanin content—approximately 220 mg·100 g^{-1} FW, flavonoid content—approximately 0.4 mg·100 g^{-1} FW, vitamin C content—approximately 130 mg·100 g^{-1} FW). The lowest content of biologically active compounds was found in the fruits of cv. 'Wojtek'. Although this correlation was not statistically proven in every case (e.g., the flavonoid and vitamin C content in the fruits of this cultivar did not differ significantly from other cultivars, except for the cultivar 'Morena').

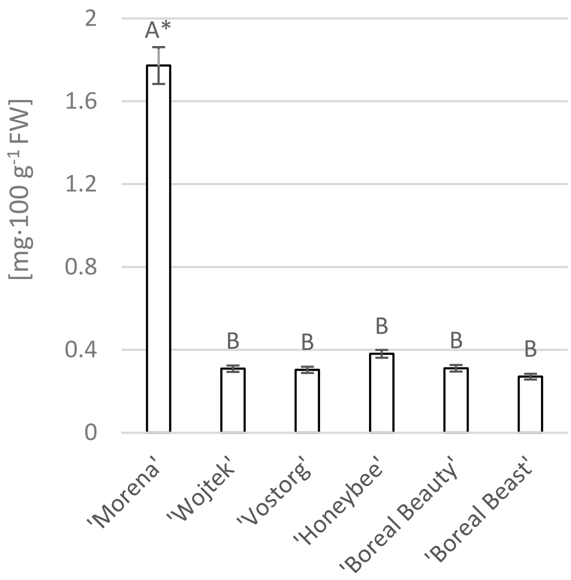


(**a**)

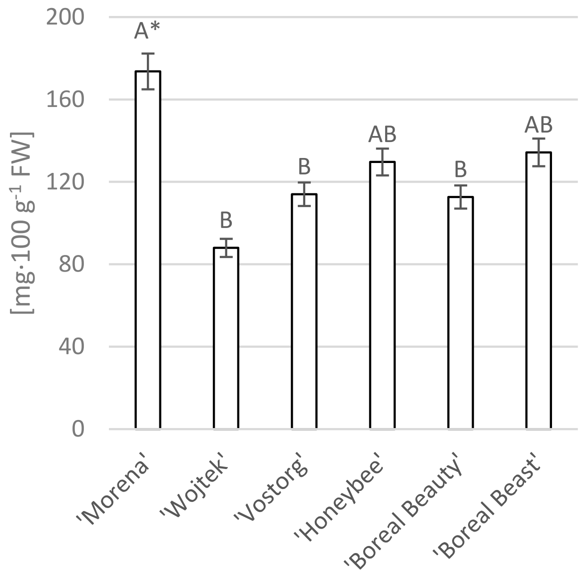


(**b**)

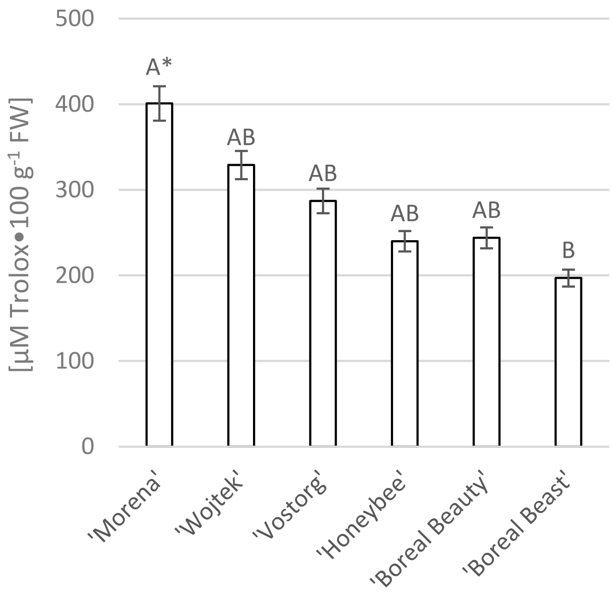
Figure 1. *Cont.*



(**c**)



(**d**)



(**e**)

Figure 1. Total polyphenol content (**a**), total anthocyanin content (**b**), total flavonoid content (**c**), vitamin C content (**d**), and antioxidant activity ($DPPH^+$) (**e**), depending on the cultivar. * Values marked with different letters differ significantly within a given characteristic at $p \leq 0.05$.

The smallest statistical variation was found in terms of antioxidant activity (Figure 1e). In this case, a significant difference was observed only between the cultivars 'Morena' and 'Boreal Beast', with antioxidant activity values slightly above 400 µM and around 200 µM Trolox·100 g^{-1} FW, respectively. However, no significant differences were found between the other cultivars tested and the 'Morena' or 'Boreal Beast'. The antioxidant potential of the fruits of the other cultivars ranged from approx. 330 µM Trolox 100 g^{-1} FW for the cv. 'Wojtek' to approximately 240 µM Trolox 100 g^{-1} FW for the cv. 'Honeybee'. It should be emphasized that the antioxidant activity of the 'Honeybee', whose fruits had a relatively high content of biologically active compounds, was one of the lowest among the tested cultivars.

3.5. Values of the Correlation Coefficients Between the Selected Parameters

Based on Pearson's correlation analysis, correlations were found between some of the physicochemical parameters of the honey berry (Figure 2). The results obtained indicated the presence of both statistically significant and insignificant correlations between the characteristics analysed. A significant positive correlation was found between the content of flavonoids and anthocyanins (r = 0.84, $p < 0.001$). The flavonoid content also significantly with the DPPH index (r = 0.73, $p < 0.001$), which could indicate a significant contribution of these compounds to the neutralisation of free radicals. A significant correlation was also shown between the contents of anthocyanins and polyphenols (r = 0.74, $p < 0.001$) and between anthocyanins and the DPPH index (r = 0.73, $p < 0.001$), confirming the high contribution of these phenolic compounds to antioxidant activity.

	FF	SSC	TA	Colour *L*	Colour a	Colour b	Colour C	Colour *hue*	Polyphenols	Anthocyanins	Flavonoids	Vitamin C
SSC	**−0.41***											
TA	−0.14	**−0.46***										
Colour L	**0.70***	−0.40	−0.31									
Colour a	**−0.56***	0.20	0.24	**−0.68***								
Colour b	−0.40	0.32	0.14	**−0.45***	0.01							
Colour C	−0.10	−0.35	0.33	0.04	**0.52***	**−0.63***						
Colour *hue*	−0.08	0.11	−0.18	0.09	0.40	−0.33	**0.48***					
Polyphenols	−0.30	−0.01	**0.49***	**−0.61***	**0.46***	0.29	−0.05	0.05				
Anthocyanins	**−0.51***	0.35	**0.52***	**−0.79***	**0.73***	0.32	0.17	0.21	**0.75***			
Flavonoids	−0.19	0.03	0.40	−0.29	0.35	0.04	0.17	0.29	0.33	**0.49***		
Vitamin C	**−0.41***	0.40	0.31	**−0.67***	**0.59***	0.20	0.09	0.30	**0.66***	**0.84***	**0.41***	
DPPH	−0.17	0.22	0.34	**−0.52***	**0.62***	0.13	0.24	0.03	**0.47***	**0.73***	0.20	**0.58***

1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00

Interpretation of values:
1.0—perfect positive linear correlation
0.7 to 0.9—strong positive correlation
0.4 to 0.6—moderate positive correlation
0.1 to 0.3—weak positive correlation
0—no correlation
−0.1 to −0.3—weak negative correlation
−0.4 to −0.6—moderate negative correlation
−0.7 to −0.9—strong negative correlation
−1.0—perfect negative linear correlation

* statistical significance of the correlation

Figure 2. Correlation coefficients between some analysed parameters.

In fruits, the vitamin C content showed a significant negative correlation with the colour brightness parameter (Colour L) (r = −0.67, $p < 0.001$), which might suggest that darker fruits contained more vitamin C (Figure 2). Furthermore, a moderate positive correlation was found between vitamin C and the Colour a parameter (r = 0.59, $p < 0.01$), suggesting a possible relationship between the intensity of the red colouring and the content of ascorbic acid. Relatively strong positive correlations were also observed between anthocyanin content and the total content of polyphenols, vitamin C, and flavonoids, as well as antioxidant activity (DPPH). The firmness parameter (FF) was significantly correlated with lightness—Colour L (r = 0.70, $p < 0.001$). A negative correlation between firmness and Colour a was also confirmed (r = −0.56, $p < 0.01$). For some parameters, i.e., SSC or colour *hue*, barely any significant correlations with the other characteristics were found. In these cases, the values of the correlation coefficient ranged below r < 0.3, which indicated a weak or no relationship.

4. Discussion

This study's results showed significant differences between honey berry (*Lonicera caerulea* L.) cultivars for most of the traits analysed.

We found considerable variation in fruit yield among the cultivars. It is known that yield is largely a genetic trait and depends on the cultivar, but is also influenced by environmental factors [14,16]. Higher yields were observed in Lonicera caerulea cultivars that have been frequently reported in the literature as having a high yield potential [1,2,11], confirming their importance for production. Fruit weight, size, and consequently its shape were also determined by the cultivar. It is natural that individual cultivars differ in these characteristics, as described by Dziedzic et al. [8]. According to these authors, cultivars with large fruits were more popular among consumers and therefore had a higher commercial value. In turn, cultivars with smaller fruits are often preferred for processing purposes [40]. In terms of the physical characteristics of the fruit, i.e., length and diameter, the results obtained are consistent with the description by Raudonė et al. [12]. These researchers pointed out that cultivars with longer fruits often had a smaller diameter, which contributed to their elongated shape. In the present study, the length-to-diameter ratio also indicated differences in fruit shape, which might be important for their intended use, e.g., for fresh consumption or processing. The most spherical fruits were those of the cv. 'Boreal Beauty', while the fruits of the other cultivars were more elongated in shape. Our results clearly highlighted the morphological diversity of the fruits of the studied honey berry cultivars, which could affect their market value. The results concerning the dry matter content of the fruits are consistent with the data presented by Gołba et al. [4], who emphasised that cultivars with a higher dry matter content had better storage and processing properties. According to some researchers, the dry matter content of the fruit also affected the level of bioactive substances [7], which was important in the context of the production of functional raw materials of honey berry.

The fruits also differed in terms of quality characteristics, i.e., firmness, soluble solid content, and titratable acidity. These are extremely important characteristics that greatly influence the overall quality of fruits of all berry species. The firmness is an essential quality indicator. It can indicate the marketability, shelf life, and susceptibility of the fruit to various types of damage. Therefore, this trait has been widely examined in previous research. According to Skupień et al. [22] and Ochmian et al. [3], honey berry fruits were characterised by relatively low firmness, and this feature depended mainly on the cultivar. The analyses carried out in our study confirmed the reports on the influence of the cultivar on the firmness of the fruit. In this experiment, the firmness of honey berry cultivars was similar to the results obtained by Senica et al. [41]. The authors also emphasised that firmness was an important indicator of the tolerance of the fruit to mechanical damage and its durability during transport and storage. These authors reported that honey berry cultivars with lower firmness of the fruit could be more susceptible to damage.

However, our results regarding the soluble solid content and the acidity of the honey berry fruit were consistent with the research of Dziedzic et al. [8], who showed that the cultivars differed in these characteristics, which definitely determined their taste and processing properties. Increased fruit acidity in certain cultivars could limit their appeal for fresh consumption, as indicated by Gołba et al. [4]. At the same time, lower acidity and a higher content of soluble solids in honey berry fruits indicated greater sweetness and better sensory properties, which was beneficial for consumers.

An analysis of honey berry fruit in terms of its health-promoting properties showed significant differences between the cultivars tested in terms of both the content of biologically active compounds and their antioxidant activity. The results of our analysis confirmed those reported earlier by Dziedzic et al. [8], who showed that honey berry cultivars varied in terms of their content of biologically active compounds, which affected their antioxidant potential.

The results of our analysis showed that the old Polish honey berry cultivar 'Morena' was distinguished among the tested genotypes, with the highest total content of polyphenols, anthocyanins, flavonoids, and vitamin C. The lowest concentrations of these compounds were observed in the fruits of the cv. 'Wojtek'. These results were reflected in the literature—Auzanneau et al. [24] showed that honey berry cultivars such as 'Morena' and 'Indigo Treat' were characterised by high polyphenol and anthocyanins and high antioxidant potential. These data confirmed that genetic differences between cultivars had a key impact on their health-promoting properties. However, it should be noted that despite such significant differences between tested cultivars in terms of bioactive compound content, the antioxidant activity of fruits in our studies did not differ between cultivars as significantly as the content of polyphenols, flavonoids, anthocyanins, or vitamin C. A significant difference was found only between the cv. 'Morena' (as its fruits were the richest in biologically active compounds) and 'Boreal Beast'. Other cultivars showed average results, which implies that higher levels of bioactive compounds do not always lead to proportionally higher antioxidant activity. In a study published by Česonienie et al. [23], the cultivar 'Morena' in terms of total polyphenol compounds and total anthocyanin was also among the cultivars with the highest antioxidant activity, although the range of this activity between honey berry cultivars was relatively small [12]. Regarding antioxidant activity, the literature showed that *Lonicera caerulea* cultivars with a high content of polyphenols and vitamin C also showed higher antioxidant activity. Similar relationships were also described by Negreanu-Pirjol et al. [19], who pointed out a significant correlation between the concentration of bioactive compounds and the antioxidant activity of fruits, which was not entirely consistent with the results obtained in our studies. However, it may be wondered why the 'Honeybee' cultivar, despite its relatively high total polyphenol content, did not show high antioxidant activity compared to other cultivars. Perhaps this is due to its genetic characteristics. According to some researchers, antioxidant activity can even differ two- to threefold between different cultivars [6,42]. In addition, it should also be taken into account that the Folin–Ciocalteu method, which was used in this study to analyse the total polyphenol content, combines many compounds of different structures. Not all phenols are equally effective antioxidants—simple phenolic acids, some glycosides, and proanthocyanidin polymers may have low activity in a given test, even though they increase the total polyphenol content. Therefore, a high polyphenol content does not always guarantee a high antioxidant activity [43].

However, when considering the results of Pearson's linear correlation, confirmation of these literature reports could be found. Although the results for antioxidant activity showed slight differences between the tested cultivars, there were quite strong positive correlations between the anthocyanin content and total polyphenols, flavonoids, vitamin C content, and antioxidant activity (DPPH). These results confirmed that anthocyanins, as the main phenolic component in honey berry fruits, significantly contributed to the antioxidant potential of the fruit, both through direct activity and accumulation with other bioactive compounds [23,44]. He et al. [45] indicated that the concentration of anthocyanins, polyphenols, and vitamin C strongly affected the antioxidant activity of the honey berry, showing a clear relationship with the DPPH value. Furthermore, a fairly strong correlation was also observed between the physicochemical characteristics and the colour of the honey berries studied. In our studies, a significant influence of colour parameters on the vitamin C content and fruit firmness was presented. A significant negative correlation was observed between the vitamin C content and colour lightness (L*) ($r = -0.67$, $p < 0.001$), suggesting that darker-coloured honey berries tend to have higher ascorbic acid concentrations. Although no specific examples that refer to this relationship were found in the literature, it was generally confirmed that fruits with more intense colouration contained higher levels of antioxidants, including anthocyanins and polyphenols [4]. Ochmian et al. [3] also noted that fruits harvested later become darker and softer, with a decrease in vitamin C content, which was consistent with our negative correlation between the Colour L and vitamin C content. Furthermore, the observed positive and moderate correlation between vitamin C and Colour a ($r = 0.59$, $p < 0.01$) suggested that fruits with a more intense red colour contained more ascorbic acid, which could mean that natural pigments, such as anthocyanins, also accumulated together with vitamin C [23]. Celli et al. [11] also emphasized the exceptionally high content of vitamin C and anthocyanins in honey berries, which supported the hypothesis that intensely coloured fruits were richer in antioxidants. In addition, in our study, fruit firmness (FF) showed a strong positive correlation with a light shade of the fruit—i.e., with Colour L ($r = 0.70$, $p < 0.001$)—and negatively correlated with the a* parameter ($r = -0.56$, $p < 0.01$). This indicated that lighter, less red fruits retained greater firmness—this was in agreement with previous observations, where the ripening of the honey berry led to a deterioration in firmness as the intensity of the colour increases and anthocyanins accumulate [3]. The literature indicated that the honey berry fruit content of vitamin C, anthocyanins, and other phenolic compounds was largely determined by genetic and environmental factors [46]. Finally, Pearson's linear correlation analysis showed the relative independence of selected quality parameters, i.e., SSC and hue. These parameters did not show significant correlations with other characteristics ($r < 0.3$), which could suggest their relative independence from other quality parameters of the tested honey berry cultivars.

The results of this study indicated significant diversity in the morphological, qualitative, and health-promoting characteristics of honey berry depending on the cultivar, as well as a significant correlation between the colour of the fruit and the vitamin C content, and between the content of biologically active compounds and the antioxidant activity. The high yield potential and attractive quality characteristics are common in cultivars recommended for commercial cultivation, while cultivars with a higher bioactive compound content could be used in the production of functional raw materials. The results of this study are consistent with previous findings, highlighting the need for a comprehensive evaluation of cultivars with respect to their physical, chemical, and health-promoting attributes.

5. Conclusions

Research conducted on the fruits of the honey berry (*Lonicera caerulea* L.) cultivars allows us to draw the following conclusions:

1. The honey berry cultivars studied are statistically significantly different in terms of the assessed yield characteristics, fruit weight, and their morphological traits, as well as contents of biologically active compounds.
2. Polish cv. 'Wojtek' and new Canadian cv. 'Boreal Beauty' yield well and produce large fruit, meaning they can be recommended for commercial cultivation in central Poland.
3. Among the cultivars tested, Polish cv. 'Morena' has the highest health benefits due to it having the highest content of polyphenols, anthocyanins, and vitamin C and the highest antioxidant activity.
4. The cv. 'Morena' is characterised by the darkest fruits with the highest content of biologically active compounds, which may confirm the common opinion that darker fruits have higher health-promoting properties.
5. The high positive correlation between flavonoids, anthocyanins, and polyphenols indicates their joint contribution to the antioxidant activity of the tested fruit samples, which emphasises their key role in neutralising free radicals.
6. Significant correlations between vitamin C content and fruit colour parameters suggest that darker and redder fruits may have a higher vitamin C content, which may be important for evaluating fruit quality and ripeness.

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