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FRUIT QUALITY OF NEW BLUE HONEYSUCKLE BERRY CULTIVARS AFTER SHORT-TERM STORAGE UNDER DIFFERENT CONDITIONS

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ABSTRACT

Lonicera caerulea L. (blue honeysuckle) is an edible species cultivated for the health properties of its fruit; however, fresh fruit has a short shelf life after harvest. Therefore, the present study aimed to extend the post-harvest shelf life of fresh honeysuckle fruits under controlled storage conditions. The quality of three Canadian blue honeysuckle cultivars was assessed after 7 and 14 days of storage in a controlled atmosphere (20% CO_2 and 5% O_2) (CA), modified atmosphere (MAP) in Xtend bags and air atmosphere (AA). The duration of storage conditions significantly affected the quality traits of blue honeysuckle berries. Extended storage time (14 days) generally had a negative effect on the quality of the tested fruit, especially when stored in air atmosphere. The berries stored in a controlled atmosphere showed the best quality, as evidenced by the highest firmness, the lowest weight loss, and the smallest percentage of rotten berries. The effect of storage conditions on the value of parameters such as soluble solids (SSC), titratable acidity (TA) or the SSC/TA ratio were often not observed. The respiration rate of fruits was usually independent of both the cultivar and storage conditions. Compared to other cultivars, Boreal Beauty fruits were characterized by a lower content of SSC, higher TA and a lower SSC/TA ratio, and lower polyphenol content. Fruits of the Boreal Blizzard showed the highest susceptibility to rot.

Keywords: *Lonicera caerulea* L., controlled atmosphere, modified atmosphere, fruit shelf life, Xtend bags

INTRODUCTION

Lonicera caerulea L. (commonly known as blue honeysuckle, haskap or honeyberry) belong to the family *Caprifoliaceae* and comprises approx. 250 species of plants native to the Northern Hemisphere [Dziedzic et al. 2020]. Alongside actinidia and cherry silverberry, blue honeysuckle belongs to the group of lesser known berries with a high potential for health promotion [Szot and Lipa 2012, Bieniek et al. 2017, Krupa et al. 2022, Garg et al. 2023]. Blue honeysuckle is generally cultivated in northern regions due to its exceptional cold hardiness. Some reports suggest that blue honeysuckle flowers can tolerate temperatures as low as –8 °C while the entire plants can survive temperatures down to –40°C [Hummer et al. 2012, Gasic et al. 2018]. In addition to its adaptation to cold climates, blue honeysuckle is also valued for its early harvest time relative to other berry crops. Blue honeysuckles ripen earlier than raspberries, blueberries, and strawberries [Leisso et al. 2021a]. Honeysuckle berries are rich in biologically active compounds, which is why they are highly valued by conscious consumers and the processing industry [Kaczmarska et al. 2014,

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Wang et al. 2018]. In addition to their interesting taste, the berries are known for their high content of anthocyanins and vitamin C, which have strong anti-inflammatory and antioxidant effects [Celli et al. 2014] and antidiabetic effect [Łysiak and Szot 2023]. The sugar profile of these fruits is dominated by glucose and fructose, with smaller amounts of sucrose and sorbitol. They also contain other valuable elements and compounds such as calcium, magnesium, fiber, iridoids and polyunsaturated fatty acids [Kalisz et al. 2023]. Honeysuckle fruits are distinguished by their high antioxidant activity [Martinez-Romero et al. 2007, Gawroński et al. 2020, Orsavova et al. 2022]. Also contain physiologically active phytochemicals including flavonoids and phenolic acids, which can contribute to the prevention of chronic diseases [Ochmian et al. 2012, Khattab et al. 2015]. Blue honeysuckle fruits have also been associated with a variety of therapeutic effects, such as lowering blood pressure, reducing the risk of heart attack, preventing osteoporosis and anemia, alleviating hyperactivity in children therapeutic effects for malaria and gastrointestinal disorders, and slowing the aging process [Gawroński et al. 2020]. As a newly introduced species, it is of interest to breeders. Self-pollinating cultivars are sought, as this is the key to obtaining high yields with good quality fruit [Parveze et al. 2024]. One of the most important features of new cultivars is their qualitative assessment and storage capacity. Fruit ripening is an irreversible developmental process that involves numerous biochemical and physiological changes resulting in a fruit with favorable organoleptic properties [Mac Kenzie et al. 2018, Gołba et al. 2020]. Blue honeysuckle fruits are characterized by high metabolic activity, which manifests itself through a high respiratory coefficient and transpiration. In addition, the high production of ethylene and their sensitivity to this gas make it difficult to store the fruit for a long time [Martinez-Romero et al. 2007]. As with many species, long-term storage is only possible by harvesting the fruit at the appropriate ripeness stage and ensuring careful handling to avoid damage that can increase ethylene production and accelerate ageing and reduce firmness [Martinez--Romero et al. 2007, Krupa et. al. 2023].Weight loss is one of the main factors limiting the storage life of berries [Horvitz 2017, Gawroński et al. 2020]. Fresh honeysuckle berries have a short storage period [Gerbrandt et al. 2020], of 7–10 days [Leisso et al. 2021b]. However using modified atmosphere packaging (MAP), such as Xtend bags, it is possible to prolong the storage period of blue honeysuckle berries up to 28 days [Blinnikova et al. 2021]. The storage of berries under refrigerated conditions (from –1°C to +2°C) preserves their quality by slowing natural metabolic processes such as respiration and transpiration [Dziedzic et al. 2020]. Given the high water content of the fruits, it is important to ensure adequate relative humidity (90–95%) during storage [Harb and Streif 2004].Very good results are obtained by storing fruits under the conditions of a modified atmosphere. The gas composition is determined in such a way as to slow down chemical changes, although it cannot stop them, because only then can the high biological value of the fruit be maintained [Harb et al. 2014, Bodbodak and Moshfeghifar 2016]. Berries tolerate high levels of carbon dioxide, but must not exceed 20% concentration while the minimum oxygen content is 2% [Leisso et al. 2022].

The purpose of the study was to evaluate the effect of storage conditions for 7 and 14 days in a modified atmosphere (MAP) and a controlled atmosphere (CA) on the quality of blue honeysuckle fruits.

MATERIAL AND METHODS

The research material consisted of three new blue honeysuckle (*Lonicera caerulea* L.) cultivars namely the Boreal Beauty, Boreal Beast, and Boreal Blizzard obtained from the University of Saskatchewan.

The fruit was harvested in a commercial plantation located in the south of Poland, about 30 km from Kraków at an altitude of 315 meters above sea level (50°17'31"N, 20°06'59"E). The plantation was established in 2018, on heavy, loess soil with a pH of 7–7.8 and a humus content of 2%, from plants propagated using the *in vitro* method. The plants were planted at a spacing of 4 × 1 m.

Under the climatic conditions of southern Poland, tested cultivars of blue honeysuckle cultivars generally begin their growing season in the third decade of March. In 2021, from the beginning of vegetation to fruit harvesting, that is, on June 25, the average temperature was 11.4 °C, and the total precipitation was 239.0 mm. In the following year 2022, during the same period, the average temperature was 10.7 °C, and the total precipitation was 182.2 mm. The fruit was harvested on June 20.

The timing of harvesting is crucial to maintain high fruit quality during storage. The date of fruit harvest of each cultivar was determined on the basis of the color of the visual assessment of fruit (fully blue for all fruits) and the content of soluble solids (minimum 12.0%). This methodology is consistent with a study by Ochmian et al. [2012], who also collected blue honeysuckle fruits based on their color.

After delivery to the laboratory, the fruits were divided into three groups (four replicates, each containing about 300 g). All fruits were stored for 7 and 14 days at a temperature of 2 degrees Celsius (±0.5°C), using the following treatment:

1. Cold room (AA – air atmosphere) by keeping the relative humidity at 90–92%,
2. Controlled atmosphere cold room (20% CO_2 and 5% O_2) relative humidity as above,
3. Modified atmosphere pakages (MAP) in Xtend packaging (StePac L.A. Ltd. Johnson Mattey, Israel, USA)

The measurements and chemical analyses of the fruits were performed on a random sample with 40 fruits selected for each combination. Fruit firmness (N) was measured using a TA 500 Lloyd Texture Analyzer with a 6.35 mm diameter tip (AMETEK Test & Calibration Instruments; Fareham, Hampshire, United Kingdom). The soluble solid content SSC (°Brix) and the titratable acidity TA (% citric acid) were determined in the juice of blue honeysuckle berries, whose firmness had previously been measured.Soluble solids content was determined using an ATAGO PR 100 refractometer (ATAGO Co., Ltd.; Fukayashi, Saitama, Japan). Titratable acidity (TA) was determined by potentiometric titration at pH 8.1 with 0.1 N NaOH, using 5 mL of diluted juice in 100 ml of distilled water. Measurements were carried out using a CX 501 pH meter (ELMETRON; Zabrze, Poland) and then the soluble solids content to the titratable acidity ratio (SSC/TA). The fruit respiration rate (mg CO_2 kg^{-1} h^{-1}) was measured (using a sample of 25 blue honeysuckle berries from each combination) with an Air Tech 2500-P CO_2 analyzer(GAZEX; Warsaw, Poland). The polyphenol compounds in the extracts were determined on the reaction with the Folin–Ciocalteu reagent. The juice sample (0.25 mL) was mixed with 0.25 mL of 25% Na_2CO_3, 0.125 mL of the Folin–Ciocalteu reagent (Sigma–Aldrich, diluted twice with water prior to the analysis), 2.25 mL of water, and then incubated for 15 min. The absorbance was measured at 760 nm (JASCO V-530 UV–Vis spectrophotometer). The results were expressed as mg of gallic acid GAE per 100 mL. Furthermore, natural weight losses (%) were calculated based on the difference in fruit weight before and after storage and the percentage of fungal decay (%) was determined.

Data were analyzed using a two-way analysis of variance (ANOVA) implemented in Statistica software v. 13.3 (Tibco Software Inc., Palo Alto, CA, USA) with calculations conducted separately for each year and each date of fruits measurement and analysis (harvest, 7 and 14 day of storage). Values expressed as a percentages were transformed using the Bliss function ($y = \arcsin \sqrt{x}$). Tukey's HSD test was used to determine the significance of differences between mean values at a significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

The results of Leisso et al. [2021a] confirmed the involvement of ethylene in blue honeysuckle, but the evolution of CO_2 from detached fruits does not indicate classical climacteric ripening. These authors also suggest that determining the optimal harvest time for blue honeysuckle berries is challenging as the fruit darkens before reaching full maturity [Gerbrandt et al. 2020]. At harvest, depending on the cultivar, the ripeness stage and cultivation region, blue honeysuckle berries have a firmness ranging from 2.9 to 4.9 N [Dziedzic et al. 2020,Leisso et al. 2022], contain between 9.6 to 20.4°Brix SSC [Mac Kenzie et al. 2018, Dziedzic et al. 2020, Gerbrandt et al. 2020, Leisso et al. 2021a], with titratable acidity (TA) ranging from 1.8 to 4.4 % citric acid [Ochmian et al. 2012, Dziedzic et al. 2020, Gerbrandt et al. 2020, Leisso et al. 2021a], and the SSC/TA ratio ranging from 3.0 to high as 18.3 [Ochmian et al. 2012, Dziedzic et al. 2020, Gerbrandt et al. 2020, Leisso et al. 2021a]. Additionally blue honeysuckle berries were shown to have a high respiration rate, in the range of 208.8–310.8 mg CO_2 kg^{-1} h^{-1} [Dziedzic et al. 2020] or 1781.1–2463.4 nmol CO_2 kg^{-1} s^{-1} [Leisso et al. 2022]. According to Leisso et al. [2021a], the quality traits of the blue honeysuckle fruit at harvest showed significant variability in terms of SSC, TA, SSC/TA ratio and firmness of the flesh.

The values of the quality parameters evaluated directly after harvest depended on the cultivar (Tab. 1). Boreal Beauty berries were found to be distinguished, compared to other cultivars, were distinguished by the highest firmness and acid content (TA), while on the other hand, they had the lowest extract content (SSC) and the lowest SSC/TA ratio. Leisso et al. [2022] also obtained a lower SSC content in Boreal Beauty fruits compared to other cultivars. The lowest SSC/TA ratio observed in Boreal Beauty berries indicated that they were less ripe and less sweet compared to other fruits. In addition, in the first year of the study, the respiration rate of Boreal Beauty fruits was higher than that of the other cultivars.

Blue honeysuckle berries are distinguished by their high content of phenol compounds [Rupasinghe et al.

Table 1. Fruit quality of blue honeysuckle berries directly after harvest

Year	Cultivars	Fruit firmness (N)	Soluble Solids Content (°Brix)	Titratable Acidity (% Citric Acid)	Ratio SSC/TA	Respiration Rate (mg CO_2 kg^{-1} h^{-1})
2021	Boreal Beauty	2.1 ±0.80c*	12.1 ±0.40a	2.74 ±0.12c	4.4 ±0.42a	101.9 ±25.74b
	Boreal Beast	2.0 ±0.61b	13.4 ±0.33b	2.27 ±0.10b	5.9 ±0.40b	51.3 ±18.95a
	Boreal Blizzard	1.8 ±0.49a	13.6 ±0.17b	1.40 ±0.05a	9.9±0.46c	35.4 ±7.62a
2022	Boreal Beauty	2.1 ±0.50b	12.8 ±0.26a	2.62 ±0.04c	4.9±0.16a	95.0 ±20.78a
	Boreal Beast	1.5 ±0.30a	16.4±0.50c	2.32 ±0.06b	7.0 ±0.17b	120.9 ±36.76a
	Boreal Blizzard	1.5 ±0.38a	15.0 ±0.15b	1.57 ±0.03a	9.6 ±0.28c	104.0 ±41.57a

*Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.054$

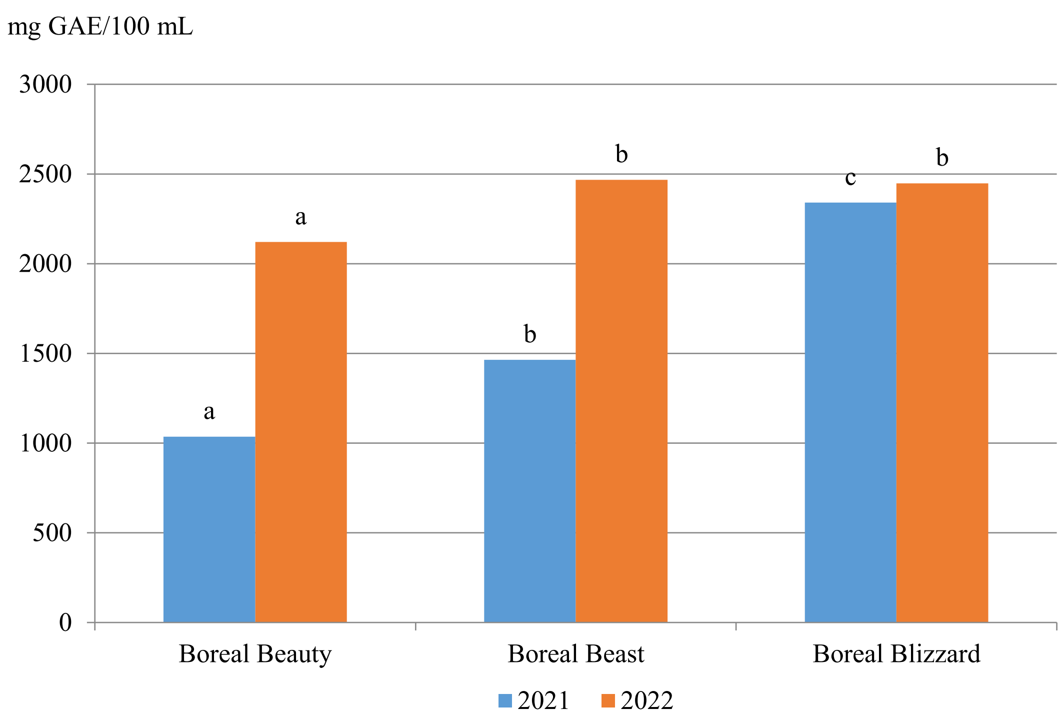

Fig. 1. Total polyphenol content (mg GAE/100 mL) of blue honeysuckle berries directly after harvest

2018]. According to Shevchuk et al. [2022], the Boreal group of cultivars has a higher polyphenol content compared to the other cultivars analyzed. The polyphenol content determined after harvest varied significantly by cultivar (Fig. 1). In the first year of the study, the Boreal Blizzard contained more polyphenols than berries of the other cultivars. In the following year, the polyphenol content of Boreal Blizzard fruits was higher compared to that determined in Boreal Beauty.

The interaction between experimental factors, such as variety and storage conditions, generally had a significant impact on the values of quality parameters (Tab. 2–5). Only the respiration rate of berries measured in 2021 after 7 days of storage (Tab. 2), and in 2022 after 14 days of storage (Tab. 5), was not influenced by the experimental factors. Firmness and weight loss are among the most important parameters that characterise the quality of berries after storage [Dziedzic et al. 2020]. Equally important components of fruit quality are the total content of soluble solids (SSC) and titratable acidity (TA) [Szot and Lipa 2012, Gerbrandt et al. 2020]. During storage, the firmness of blue honeysuckle berries gradually decreases [Mac Kenzie et al. 2018, Dziedzic et al. 2020, Leisso et al. 2021b, Leisso et al. 2022]. In the present study, at each date of measurement of the firmness of the fruit, the berries of a given cultivar stored under AA conditions consistently exhibited lower values compared to those

Table 2. Effect of cultivars and storage conditions on the quality of blue honeysuckle berries after 7 days of storage in 2021

Cultivars	Storage conditions	Fruit firmness (N)	Soluble Solids Content (°Brix)	Titratable acidity (% citric acid)	Ratio SSC/TA	Respiration rate (mg CO_2 kg^{-1} h^{-1})
Boreal Beauty	AA	1.5 ±0.12a*	10.8 ±0.10 b	2.24 ±0.04bc	4.8 ±0.11b	145.1 ±34.99a
	MAP	1.9 ±0.14 e	11.2 ±0.15 b	2.31 ±0.05 c	4.8 ±0.18b	104.8 ±29.40 a
	CA	2.0 ±0.15ef	10.1 ±0.16a	2.47±0.03 d	4.1 ±0.16a	117.5±49.61 a
Boreal Beast	AA	1.6 ±0.13bc	12.4 ±0.20 c	2.15 ±0.06 b	5.8 ±0.11 c	186.2 ±52.32a
	MAP	1.8 ±0.11d	13.8 ±0.14d	2.26 ±0.03bc	6.1 ±0.19c	102.4 ±14.22a
	CA	2.0 ±0.15 f	12.8 ±0.17c	2.25 ±0.04 bc	5.7 ±0.14c	149.6 ±29.01a
Boreal Blizzard	AA	1.5 ±0.14ab	13.8 ±0.21d	1.22 ±0.04 a	11.3 ±0.36 e	143.0 ±36.12a
	MAP	1.7 ±0.11cd	14.1 ±0.12d	1.25 ±0.05a	11.2 ±0.41de	107.9 ±25.43a
	CA	1.7 ±0.14cd	13.7 ±0.28d	1.29 ±0.06a	10.6 ±0.32 d	109.6 ±25.85a

*Means followed by the same letter within a column do not differ significantly at $p \leq 0.05$

Table 3. Effect of cultivars and storage conditions on the quality of blue honeysuckle berries after 14 days of storage in 2021

Cultivars	Storage conditions	Fruit firmness (N)	Soluble Solids Content (°Brix)	Titratable acidity (% citric acid)	Ratio SSC/TA	Respiration rate (mg CO_2 kg^{-1} h^{-1})
Boreal Beauty	AA	1.3 ±0.13a*	10.9 ±0.25b	2.52 ±0.05 c	4.3 ±0.18 a	159.7 ±48.83 bc
	MAP	1.6 ±0.10c	11.2 ±0.10b	2.67 ±0.08c	4.2 ±0.12a	123.2 ±18.97 abc
	CA	1.8 ±0.16d	10.3±0.15 a	2.60 ±0.09c	4.0 ±0.13a	120.3 ±23.89 abc
Boreal Beast	AA	1.4 ±0.12ab	15.1 ±0.26 ef	2.20 ±0.02b	6.9 ±0.22b	156.8 ±40.11 bc
	MAP	1.5 ±0.12bc	14.8 ±0.12de	2.24 ±0.04b	6.6±0.15 b	110.9 ±29.32 abc
	CA	1.9±0.15 d	15.6±0.10 f	2.25 ±0.09b	7.0 ±0.28b	49.8 ±14.66 a
Boreal Blizzard	AA	1.3 ±0.15 a	14.3 ±0.15cd	1.15 ±0.08a	12.4 ±0.32d	187.0 ±30.92c
	MAP	1.4 ±0.10ab	13.9 ±0.20c	1.21 ±0.05a	11.5 ±0.35cd	91.0 ±20.18abc
	CA	1.5 ±0.14bc	14.4 ±0.21cd	1.29 ±0.01a	11.2 ±0.18c	68.0 ±20.30ab

*Means followed by the same letter within a column do not differ significantly at $p \leq 0.05$

Table 4. Effect of cultivars and storage conditions on the quality of blue honeysuckle berries after 7 days of storage in 2022

Cultivars	Storage conditions	Fruit firmness (N)	Soluble Solids Content (°Brix)	Titratable acidity (% citric acid)	Ratio SSC/TA	Respiration rate (mg CO_2 kg^{-1} h^{-1})
Boreal Beauty	AA	1.4 ±0.11d*	12.1 ±0.17a	2.17 ±0.02b	5.6 ±0.35a	143.9 ±24.79a
	MAP	1.6 ±0.11e	12.1 ±0.32a	2.23 ±0.04b	5.4 ±0.17a	110.5 ±33.11a
	CA	1.8 ±0.14g	12.2 ±0.38a	2.22 ±0.08b	5.5 ±0.43a	81.8 ±11.55a
Boreal Beast	AA	1.3 ±0.12d	15.8 ±0.42cd	2.02 ±0.09b	7.8 ±0.44b	119.0 ±15.29a
	MAP	2.1 ±0.11h	15.8 ±0.50cd	2.13 ±0.03b	7.4 ±0.25b	69.4 ±13.63a
	CA	1.7 ±0.11f	16.1 ±0.42d	2,09 ±0.07b	7.8 ±0.27b	86.7 ±23.88a
Boreal Blizzard	AA	1.0 ±0.12a	14.4 ±0.21b	1.25 ±0.01a	11.5 ±0.13c	113.5 ±40.90a
	MAP	1.1 ±0.11b	14.7 ±0.31bc	1.26 ±0.03a	11.6 ±0.14c	104.9 ±48.70a
	CA	1.2 ±0.13c	14.1 ±0.40 b	1.30 ±0.07a	10.9 ±0.20 c	91.8 ±30.73a

*Means followed by the same letter within a column do not differ significantly at $p \leq 0.05$

Table 5. Effect of cultivars and storage conditions on the quality of blue honeysuckle berries after 14 days of storage in 2022

Cultivars	Storage conditions	Fruit firmness (N)	Soluble Solids Conten t (°Brix)	Titratable acidity (% citric acid)	Ratio SSC/TA	Respiration rate (mg CO_2 kg^{-1} h^{-1})
Boreal Beauty	AA	1.4 ±0.20b*	11.6 ±0.42a	2.11 ±0.03c	5.5 ±0.13a	148.0 ±41.46a
	MAP	1.6 ±0.10 cde	12.4 ±0.45a	2.32 ±0.06d	5.3 ±0.16a	112.1 ±25.19a
	CA	1.7 ±0.14ef	12.3 ±0.38a	2.30 ±0.01d	5.4 ±0.24a	64.6 ±16.12a
Boreal Beast	AA	1.6 ±0.12cde	15.5 ±0.16c	1.82 ±0.03b	8.5 ±015b	129.6 ±38.78a
	MAP	1.7 ±0.13ef	15.8 ±0.26c	1.91 ±0.01b	8.3 ±0.21b	107.5 ±31.93a
	CA	1.9 ±0.12f	15.9 ±0.28c	1.92 ±0.08b	8.3 ±0.24b	66.7 ±10.01a
Boreal Blizzard	AA	0.8 ±0.11a	14.0 ±0.21b	1.24 ±0.03a	11.3 ±0.12c	140.8 ±41.30a
	MAP	1.5 ±0.16bc	14.2 ±0.10 b	1.30 ±0.03a	10.9 ±0.16c	99.8 ±23.75a
	CA	1.6 ±0.20 cde	13.7 ±0.23b	1.30 ±0.02a	10.5 ±0.12c	69.8 ±18.39a

*Means followed by the same letter within a column do not differ significantly at $p \leq 0.05$

stored in CA and frequently also compared to the berries stored in MAP. Dziedzic et al. [2020] demonstrated that the firmness of blue honeysuckle berries stored under controlled atmosphere conditions was well preserved.

In both years of the study, the impact of cultivar on the soluble solids content (SSC) of the berry juice measured after storage was significant. The berries of the cultivar Boreal Beauty cultivar were shown to have a lower SSC content compared to the other cultivars. On the contrary, the storage conditions of the fruits did not always have a significant effect on the value of the described trait. The culture has previously shown a greater effect of cultivar than the storage conditions on the SSC content of blue honeysuckle berries by Dziedzic et al. [2020]. This relationship was recorded, among others, in 2021 for the cultivar Boreal Blizzard after 7 days of storage (Tab. 2), and in 2022 for the fruits of all studied blue honeysuckle cultivars after both 7 and 14 days of storage (Tabs 4, 5). According to Leisso et al. [2021b], the SSC content in blue honeysuckle berries remained relatively stable during the postharvest period. In our study, we observed a different relationship; in the first year, the SSC content of the berries during storage was generally higher than at harvest, while in the second year, it was lower.

The titratable acidity (TA) of blue honeysuckle berries decreases during storage [Mac Kenzie et al. 2018, Dziedzic et al. 2020, Leisso et al. 2021, Leisso et al. 2022]. Similarly to SSC, the TA of blue honeysuckle berries was significantly dependent on the cultivar. In general, regardless of storage conditions, the fruits of the Boreal Beauty had the highest TA values. In contrast, the lowest TA was observed for the Boreal Blizzard cultivar. On the other hand, the effect of storage conditions on the TA of the fruits was observed only in the Boreal Beauty. In 2021, after 7 days of storage, berries from CA exhibited higher TA values compared to those stored under MAP and AA conditions (Tab. 2). In the following year, after 14 days of storage, the berries from the CA and MAP treatments had a higher TA content than those stored in AA (Tab. 5). In the present study, we did not observe a significant decrease in TA during the storage of blue honeysuckle berries, similar to that reported by Leisso et al. [2021b].

The SSC/TA ratio increases during berry storage [Leisso et al. 2021b], which indicates favorable changes in consumer perception of the fruits [Harker et al. 2002, Jayasena and Cameron 2008]. Regardless of the storage conditions, the SSC/TA ratio for the cultivar Boreal Beauty was significantly lower at each time point compared to the values calculated for the remaining varieties. The highest value of the described trait was consistently observed in the fruits of the cultivar Boreal Blizzard fruit (Tabs 2–5). The low SSC/TA ratio associated with the cultivar Boreal Beauty was clearly associated with its lower perceived sweetness when consuming the berries, while the sweetest fruits had the cultivar Boreal Blizzard. The cultivar, in combination with fruit storage conditions, had a significant impact on the SSC/TA ratio only during the first year of the study (Tabs 2, 3). After 7 days of storage, the fruits of the cultivar Boreal Beauty stored under CA conditions exhibited a lower value of the described indicator compared to those of MAP and AA. For the cultivar Boreal Blizzard, the fruits stored in CA showed a lower value of the SSC/TA ratio compared to those stored in AA. This relationship was observed after both 7 and 14 days of storage.

Blue honeysuckle berries are characterized by a high respiration rate (Tabs 1–5). According to Dziedzic et al. [2020], blue honeysuckle berries are non-climacteric fruits, therefore, are not characterized by increased respiration.

Respiration is, however, necessary to meet the energy requirements necessary to maintain all metabolic processes. During this process, stored carbohydrates, lipids, and organic acids are broken down [Fonseca et al. 2002]. The present study demonstrated that the respiration rate of blue honeysuckle berries was generally not influenced by either the cultivar or the storage conditions. Leisso et al. [2022], on the other hand, suggested that the cultivar affected the CO_2 production. Only in 2021, after 14 days of storage, the value of this parameter depended on the interaction between cultivar and storage conditions (Tab. 3). The respiration rate of Boreal Beast fruits (49.8 mg CO_2 kg^{-1} h^{-1}) and Boreal Blizzard fruits (68.0 mg CO_2 kg^{-1} h^{-1}) fruits stored in CA was significantly lower compared to Boreal Blizzard fruits from the AA combination (187.0 mg CO_2 kg^{-1} h^{-1}). Fonseca et al. [2002] reported that respiration slowed due to reduced O_2 availability resulting from reduced overall metabolic activity. A beneficial effect of storing blue honeysuckle fruits in CA on the reduction of respiration rate was previously demonstrated by Dziedzic et al. [2020].

The polyphenol content of the blue honeysuckle berries decreased successively during storage (Figs 2 and 3). Polyphenols are sensitive to oxidative stress and enzymatic activity, which can lead to their degradation during storage [Zhang et al. 2021]. Fruits stored under CA and MAP conditions are slower to carry out metabolic processes, which is one of the factors in oxidative stress. The fruits of the tested cultivars stored under MAP and CA conditions generally contained more polyphenols compared to those under AA conditions. The content of polyphenols during storage is a species and cultivar feature that is largely influenced by the gas composition, especially the concentration of carbon dioxide [Khorshidi et al. 2011, Harb et al. 2014, Dziedzic et al. 2020]. A significant effect of storage conditions on the described trait was not shown only for the Boreal Beast cultivar in the first year of the study after 7 days of storage. On the other hand, after 14 days of storage, the same content of polyphenols was characterized by fruits of Boreal Beast and Boreal Blizzard cultivars with AA and MAP. This relationship was also noted in the second year of the study

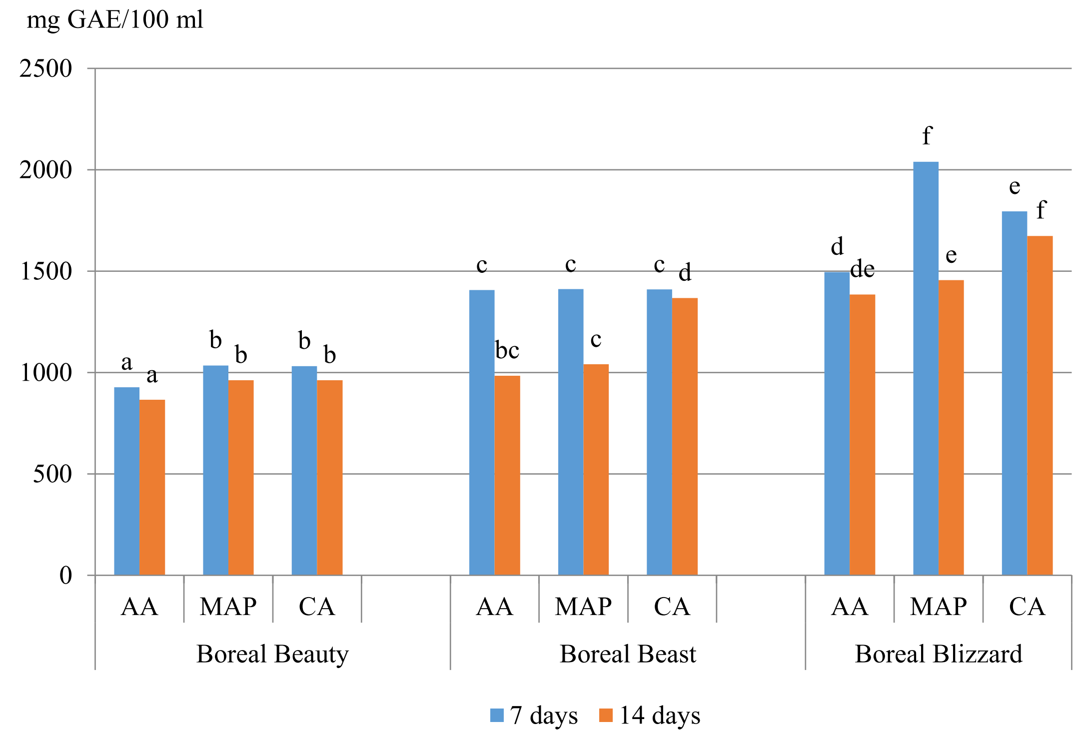

Fig. 2. Total polyphenol content (mg GAE/100 mL) of blue honeysuckle berries after 7 and 14 days of storage in 2021

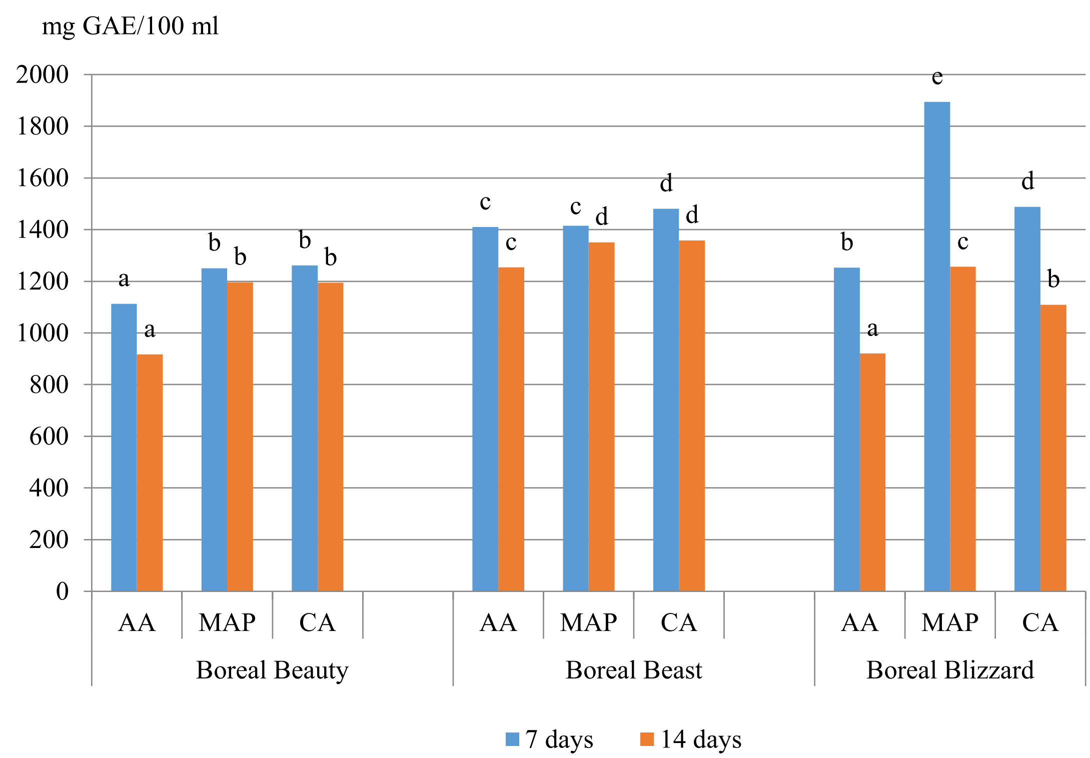

Fig. 3. Total polyphenol content (mg GAE/100 mL) of blue honeysuckle berries after 7 and 14 days of storage in 2022

for the Boreal Beast cultivar after 7 days of storage. Boreal Beauty fruits generally had a lower polyphenol content compared to Boreal Beast and Boreal Blizzard fruits determined after 7 and 14 days of storage. The exceptions to this rule were similar polyphenol content in Boreal Beauty fruit stored in MAP and CA and Boreal Beast fruit under AA conditions (2021 after 7 days of storage) and in 2022 after 14 days of storage in Boreal Beauty and Boreal Blizzard fruit stored in AA and CA.

The results obtained in our study showed that the weight losses of berries of all cultivars stored in CA were always lower compared to those measured in fruits from the AA environment. We have reported very similar relationships in our earlier study [Dziedzic et al. 2020]. The only exception was the weight loss of Boreal Beast fruits recorded in 2022 after 7 days of storage. For fruits stored in MAP bags, the parameter value of the discussed was often statistically the same as under fruits stored under AA conditions. However, Blinnikova et al. [2021] demonstrated that storage of blue honeysuckle berries in MAP reduced fruit weight loss by 1.5 times compared to storage under AA conditions. In addition to high respiration rates, blue honeysuckle fruits are also characterized by significant transpiration [Martinez-Romero et al. 2007], which can lead to substantial weight loss in stored berries (Figs 4–7).

Fruit decay during storage (Figs 4–7) is another source of loss and a limiting factor for the storage time of blue honeysuckle berries [Leisso et al. 2021]. The main pathogenic organism that causes the rotting of berries is grey mould (*Botrytis cinerea*) [Wan et al. 2021]. The value of this characteristic was significantly dependent on the interaction between the cultivar and storage conditions of fruit. The storage of berries in CA always resulted in a lower percentage of rotten fruit compared to AA. MAP conditions tended to limit fruit rot more effectively than AA. According to Blinnikova et al. [2021], the storage of blue honeysuckle berries in MAP bags significantly reduced the number of rotten fruits compared to the control (AA). In the present study, extending the storage period of Boreal Beauty fruits did not result in a higher percentage of rotten berries, compared to the other two cultivars. Additionally, it was found that the cultivar Boreal Blizzard was more susceptible to fruit rot.

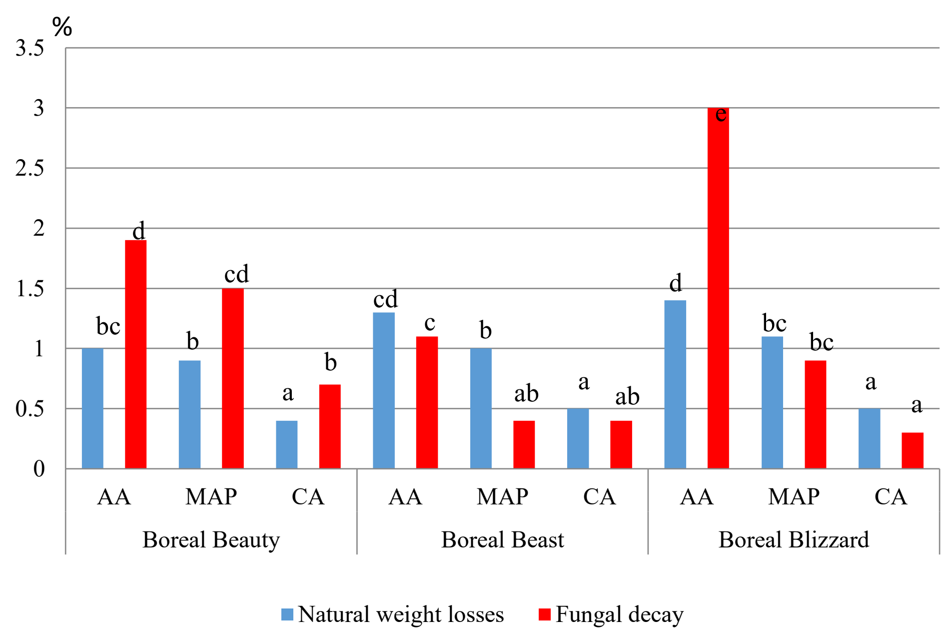

Fig. 4. Effect of cultivars and storage conditions on the natural weight losses (%) and fungal decay (%) of blue honeysuckle berries after 7 days of storage in 2021

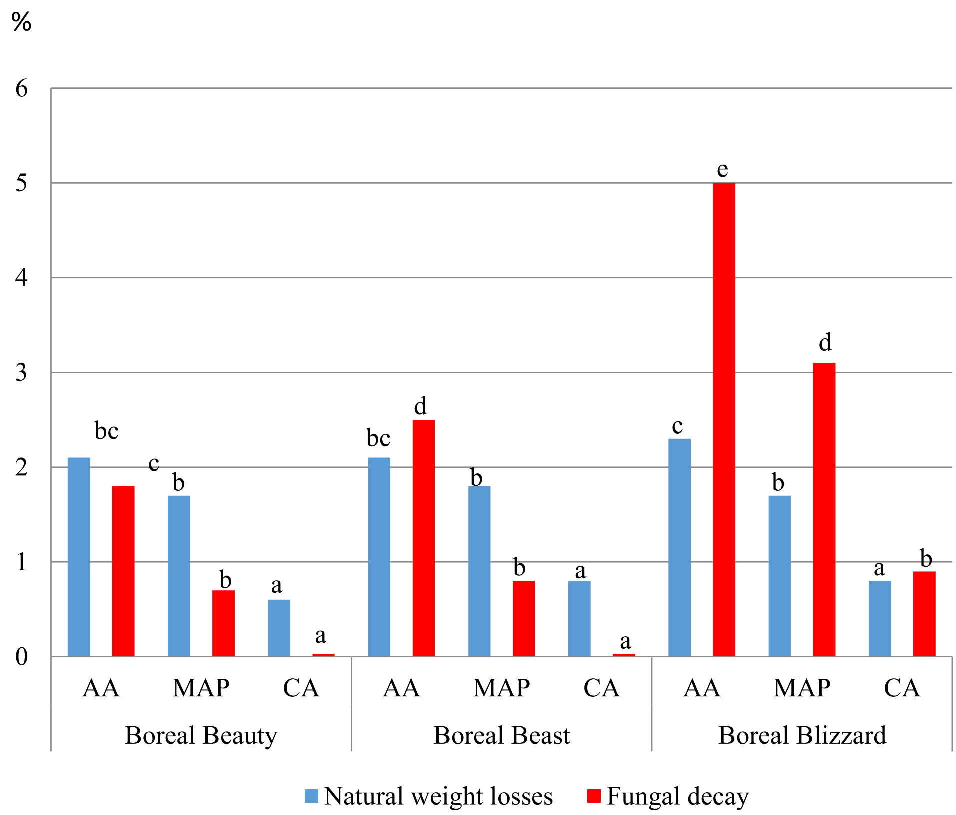

Fig. 5. Effect of cultivars and storage conditions on the natural weight losses (%) and fungal decay (%) of blue honeysuckle berries after 14 days of storage in 2021

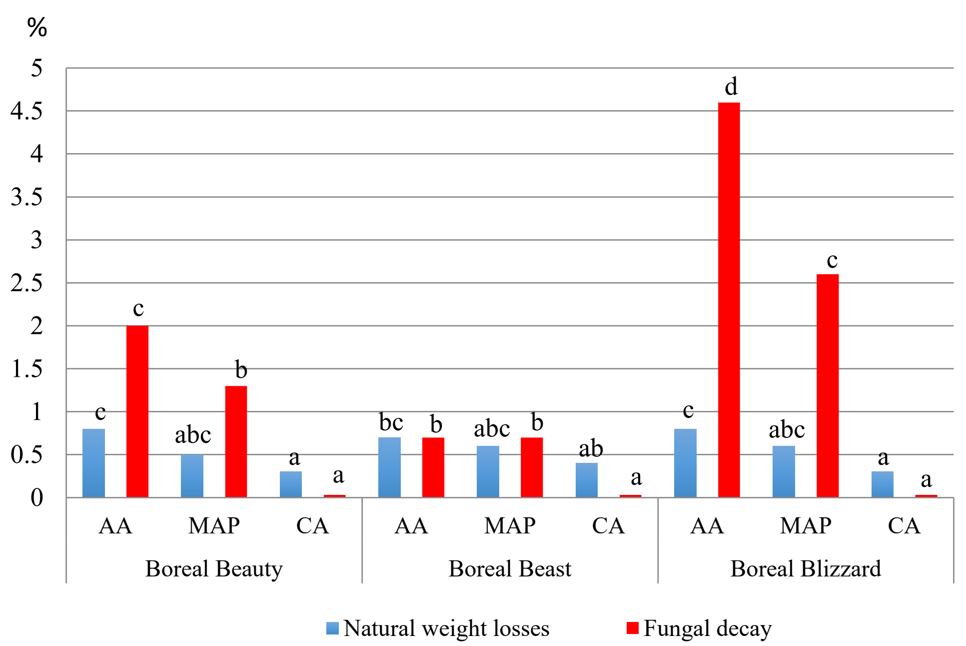

Fig. 6. Effect of cultivars and storage conditions on the natural weight losses (%) and fungal decay (%) of blue honeysuckle berries after 7 days of storage in 2022

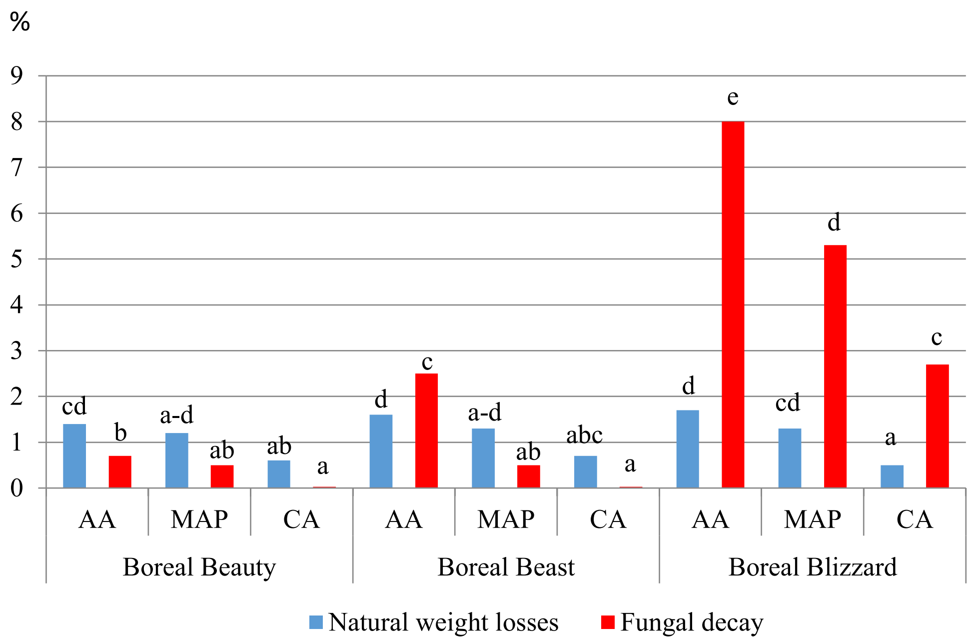

Fig. 7. Effect of cultivars and storage conditions on the natural weight losses (%) and fungal decay (%) of blue honeysuckle berries after 14 days of storage in 2022

CONCLUSIONS

Extended storage time (14 days) most often had a negative effect on the quality of the tested fruit, especially when stored in air atmosphere. Storing the berries in a controlled atmosphere guaranteed their best quality, as evidenced by the highest firmness, the lowest weight loss and the lowest percentage of rotten berries. The effect of storage conditions on the value of parameters such as soluble solids-SSC, titratable acidity-TA or the SSC/TA ratio were often not observed. The respiration rate of fruits was usually independent of both the cultivar and storage conditions. Compared to other cultivars, the fruit of the Boreal Beauty cultivar was characterized by a lower content of soluble substances SSC, a higher titratable acidity TA, and a lower SSC/TA ratio, and lower polyphenol content. The fruit of the Boreal Blizzard cultivar turned out to be the most susceptible to rot, therefore they can be stored longer (14 days) only in a controlled atmosphere. All storage conditions (AA, MAP and CA) ensure high quality of blue honeysuckle berries when stored for 7 days. However, when the storage period is extended to 14 days, only the CA conditions ensure the preservation of high fruits quality. Results of the presented research can be used in practice to create optimal conditions for short-term storage of blue honeysuckle berries and to ensure appropriate transport conditions for these fruits in order to maintain their high quality and shelf life.

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