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ORIGINAL PAPER

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'KORDIA' SWEET CHERRY FRUIT QUALITY AS FUNCTION OF THE ROOTSTOCK AND STORAGE CONDITIONS

Jan Błaszczyk, Ewa Dziedzic

Department of Horticulture, Faculty of Biotechnology and Horticulture, University of Agriculture in Krakow

ABSTRACT

Sweet cherry fruit of the cultivar 'Kordia' derived from trees growing on the GiSelA 5®, Colt and Mazzard F12/1 rootstocks were harvested at the stage of consumption maturity and stored for three weeks in control atmosphere – CA (20% CO_2 and 3% O_2, RH 90%, 2 ±0.5°C), modified atmosphere packaging – MAP (2–4% CO_2, 13–18% O_2, 2°C ± 0.5°C) and air atmosphere – AA (RH 80%, 2 ±0.5°C). The rootstocks had a significant effect on all tested fruit quality parameters directly after harvest, except for respiration rate in the first year and fruit titratable acidity in the second year of the study. After sweet cherry storage, the influence of the rootstock on most of fruit quality parameters was proven. The GiSelA 5® rootstock contributed to the preservation of high firmness, high soluble solids content and high soluble solids content/titratable acidity (SSC/TA) ratio. MAP retained good fruit quality, although more favorable quality parameters were recorded after sweet cherry storage in CA, especially with regard to such features as fruit firmness, low respiration rate, small mass loss, low percentage of fungal diseases and good preservation of green color of the stem.

Key words: storability, fruit firmness, modified atmosphere, respiration rate, soluble solids content

INTRODUCTION

According to USDA (Foreign Agricultural Service/USDA) world cherry production is approximately 3.9 million t, and European Union sweet cherry production amount to about 703,000 t. Poland with an annual average production of about 50,000 t is among the top 20 countries. Climatic and environmental conditions in Poland favor the cultivation and production of sweet cherry fruit, although sometimes spring frost, low temperature and drought can cause a significant loss of fruit crop [Graczyk and Szwed 2020].

Most sweet cherries are consumed fresh, but sweet cherry fruit have a short harvest pe-riod and marketing window. The major losses in quality after harvest include moisture loss, softening, decay and stem browning. The most acceptable cultivars on the market are those whose fruit are large, shiny, and resistant to cracking after rainfall, with a high extract content and good taste [Schuster 2012]. Sweet cherries are highly perishable fruit (shelf-life of 7–14 days) and extremely difficult to handle after harvest [Padilla-Zakour et al. 2007]. Fruit contain little stored carbohydrate (starch) and are very susceptible to bruising leading to softening, changes in the sugar-acid ratio, desiccation and browning of the stem. Sweet cherry is charac-terized by a high transpiration rate, susceptibility to fungal diseases, acid degradation and sen-sitivity to physiological disorders such as pitting and bruising [Petracek et al. 2002, Bernalte et al. 2003, Alique et al. 2005].

Various technologies of post-harvest treatment of sweet cherries are being investigated to maintain good fruit quality in the post-harvest period and during fruit marketing [Chock-chaisawasdee et al. 2016]. The

jblaszczyk@urk.edu.pl

influence of factors such as high CO2 concentration and low temperature was investigated in order to limit fungal infections [Tian et al. 2001]. After packaging, sweet cherries are stored to maintain stems green and fruit fresher. The temperature recommended ranges from –0.5 to 2.5°C. In addition to the temperature of storage, humidity during this period is also very important because it affects sweet cherry quality and shelf life. Non-optimal humidity during storage contributes to water loss of cherries and their stems, thereby accelerating fruit decay. For this reason, the optimal storage humidity for cherries is between 90–95% [Chockchaisawasdee et al. 2016]. The application of a controlled atmosphere in combination with low temperature can be used to extend the shelf-life of sweet cherries by reducing fungal infections, preserving fruit firmness, titratable acidity and skin color [Chen et al. 1981, Patterson 1982, Kader 1997, Petracek et al. 2002, Remón et al. 2003, Crisosto et al. 2009, Habib et al. 2015].

Recently, modern MAP technology has been increasingly used for both fruit transport and short-term storage. MAP is defined as a technique of sealing actively respiring produce (fruit and vegetables) in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere [Mattheis and Fellmann 2000]. MAP packages with adequate gaseous permeability (i.e. 5–8% O_2 at 0°C) may be suitable for commercial applications to preserve the flavor without damaging the cherries due to fermentation, even with temperature fluctuations commonly occurring in commercial storage and transportation [Wang and Long 2014]. It is emphasized that cherries intended for storage in the MAP technology cannot be too mature and should be harvested in the early and intermediate ripening stage, because then the best quality is achieved after storage [Wargo et al. 2003]. MAP also reduces massloss and maintains fruit firmness, without affecting mold and yeast abundance. Moreover, this technology contributes to the maintenance of a higher level of antioxidant activity in the cherry fruit compared to the control treatment [Aglar et al. 2017, Guler et al. 2019].

The most common research related to the post-harvest preservation of fruit quality has concerned the assessment of the impact of storage conditions (temperature, atmosphere gas composition, air humidity) and cultivar of sweet cherries. On the other hand, the influence of the rootstock on which trees grow in the orchard is neglected and very rarely assessed, although it is known that the rootstock exerts a great impact on fruit physiology [Usenik et al. 2010, Balducci et al. 2019]. According to previous studies, the cultivar 'Kordia' has been particularly susceptible to the influence of rootstock on which the trees are grafted [Hajagos et al. 2012]. We showed in our previous experiments that fruit quality of the cv. 'Regina' after storage changed depending on the rootstock from which the fruit were obtained [Dziedzic et al. 2016, 2017, Dziedzic and Błaszczyk 2019].

The aim of the present research was to assess fruit quality of the sweet cherry cultivar 'Kordia' after short-term storage depending on storage conditions and rootstock on which the 'Kordia' sweet cherry trees were grown in the orchard.

MATERIAL AND METHODS

'Kordia'®, also known as 'Attika'® in the USA, belongs to one of the most widely cultivated cherry cultivars in Poland. It was bred in RPIB, Holouvosy, Czech Republic in 1981. 'Kordia' is self-sterile and belongs to Group VI (S3S6) of incompatibility. Good pollinators for 'Kordia' include 'Summit' (Group I), 'Regina' (Group II), 'Sunburst' (Group III) or 'Hedelfingen' (Group VII). It is a late-blooming cherry cultivar (in Poland blooms during the second week of April), however, it shows sensitivity to spring frosts. 'Kordia' is an attractive, large black cherry, and is popular in farmers markets. It bears good quality large heart-shaped fruit with juicy, dark red flesh that are very attractive commercially. The fruit is very firm with a good taste, it has a long stem and an elongated pit. 'Kordia' cherries are known to resist rain-crack and damage during transport or harvest [Long et al. 2008]. Because of high acid content, 'Kordia' fruit is especially useful for short-term cold storage [Hajagos et al. 2012].

Trees of the sweet cherry cultivar 'Kordia' were cultivated in the Experimental Station located near Krakow, Poland, 270 m above sea level (50°09' N, 19°56' E). Trees were planted on three rootstocks (GiSelA 5®, Colt and Mazzard F12/1 obtained from tissue culture) in 2003, with a spacing of 5 × 2.5 m. Weed control was maintained with herbicides in tree rows and grass between rows. Fertilization and chemical protection of trees was carried out according to the recommendation for commercial orchards. Trees were not additionally irrigated. Flowers were pollinated by honey bees with pollen of the cv. 'Regina'. Fruit with stems were harvested manually on June 13, 2018 and June 28, 2019, during the stage of commercial maturity, determined by skin color at using the Royal Horticultural Society Colour Charts (RHS, UK).

Atmospheric conditions influenced the different fruit harvest time in both years. The average temperature and the sum of the precipitation were recorded in April, May and June (in June, only until the day of fruit harvest). In 2018, the average temperature was 13.1, 6.6 and 17.9°C, respectively, and 9.7, 12.0 and 20.5°C in 2019 respectively. Total sum of precipitation in each month was recorded as followed: 18.0, 44.0 and 102.6 mm in 2018 year, and 89.2, 161.4 and 14.6 mm in 2019 year.

Immediately after harvest, fruit were transported to the laboratory (Department of Horticulture, University of Agriculture) and subjected to the first assessment in terms of firmness, soluble solid content (SSC), titratable acidity (TA), respiration rate and stem color. Random fruit samples (4 replicates, 0.5 kg each) from five trees from each rootstock combination were evaluated. Probe of 40 fruits from each combination was used for individual measure-ments.

Assessment of fruit quality directly after harvest

Fruit firmness was determining using a TA 500 Texture Analyzer (Lloyd Instruments Ltd., UK) equipped with an 8-mm tip; values were expressed in newtons (N). Fruit SSC was determined by a digital refractometer (PR-101, Atago, Tokyo, Japan) at 20°C and expressed as a percentage. Titratable acidity (TA) was determined by potentiometric titration to pH 8.1 with 0.1 N NaOH, up to pH 8.1 using 5 ml of diluted juice in 100 ml of distilled H_2O; the results were expressed as the percentage of malic acid. The SSC/TA ratio was also calculated. Respiration rate of fruit was determined from the CO_2 concentration using an Air Tech 2500P CO_2 analyzer and expressed in mg CO_2 kg^{-1} h^{-1}. The color of the fruit stem was estimated visually, according to the Royal Horticultural Society Color Chart (RHS, UK) and maintenance of green color was expressed as the percentage values.

Storage conditions

Fruit samples (4 replicates, 0.5 kg each) from each treatment (3 storage combinations × 3 root-stocks in 2018 and 2019) were stored in plastic containers for 3 weeks in three storage conditions: air atmosphere (AA) (RH 80%, 2 ±0.5°C), modified atmosphere packaging (MAP) polyethylene film bags (0.04 mm thick, 220–300 mm long for 0.5 kg fruit, at 2–4% CO_2 and 13–18% O_2, 2 ±0.5°C), and controlled atmosphere (CA) (20% CO_2 and 3% O_2, RH 90%, 2 ±0.5°C).

Assessment of fruit quality after storage

After storage, the following fruit parameters were investigated: fruit firmness, SSC, TA, SSC/TA ratio and respiration rate, according to the same methods as used after fruit harvest. The loss of fruit mass was recorded as a percentage by weighing the fruit in each condition before and after storage. Moreover, the occurrence of fungal rot and green stem maintenance were visually assessed and expressed as a percentage.

Statistical analysis

The experiment was conducted over two seasons. The data were analyzed using two-way analysis of variance (ANOVA) in Statistica software (StatSoft Inc., v.13.3, USA); calculations were conducted for each season separately. The values expressed as a percentage were transformed according to the Bliss function ($y = \arcsin \sqrt{x}$). Fisher's LSD test was used to determine the significance of differences between mean values at the level of significance at $p \leq 0.05$.

RESULTS

Data analysis in Table 1 shows that the rootstock had an impact on most of the examined fruit characteristics in both years of research directly after harvest as well as after sweet cherry storage.

The storage conditions influenced all traits in both years of the experiment, except for the soluble solids content in the first year. On the other hand, the interaction of the rootstock and cherry storage conditions had an effect on all fruit traits during two years of research.

Assessment of fruit quality after harvest

The type of rootstock had an impact on quality characteristics of the cultivar 'Kordia' cherries, determined directly after harvest (Tab. 2).

Table 1. *P* values obtained in the ANOVA for different rootstocks, storage conditions and their interaction variables in sweet cherry 'Kordia' recorded in years 2018–2019

Parameter	After fruit harvest		After storage period					
	rootstock		rootstock		storage conditions		rootstock × storage conditions	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Fruit firmness	0.0010	0.0007	0.0001	0.0039	0.0002	0.0001	0.0003	0.0034
Soluble solids content, SSC	0.0003	0.0108	0.0002	0.0001	NS	0.0114	0.0047	0.0047
Titratable acidity, TA	0.0012	NS	0.0042	NS	0.0015	0.0064	0.0116	0.0075
SSC/TA ratio	0.0049	0.0012	0.0002	0.0001	0.0242	0.0002	0.0053	0.0019
Respiration rate	NS	0.0078	NS	0.0244	0.0155	0.0032	0.0192	0.0175
Natural mass losses	–	–	NS	NS	0.0002	0.0001	0.0043	0.0002
Fungal decay	–	–	0.0001	NS	0.0001	0.0002	0.0079	0.0154

NS represents non-significance at $p \leq 0.05$

Table 2. Fruit quality of 'Kordia' sweet cherries directly after harvest as affected by rootstocks

Year	Rootstock	Fruit firmness (N)	Soluble solids content, SSC (%)	Titratable acidity, TA (%)	Ratio SSC/TA	Respiration rate (mg CO_2 kg^{-1} h^{-1})
2018	GiSelA 5®	12.8 ±2.04 c	15.7 ±0.36 b	0.78 ±0.06 a	20.2 ±0.52 b	34.7 ±0.94 a
	Colt	10.0 ±2.11 a	12.8 ±0.29 a	0.84 ±0.04 b	15.4 ±0.76 a	43.7 ±1.15 a
	Mazzard F12/1	10.4 ±2.23 b	12.7 ±0.34 a	0.93 ±0.02 c	13.8 ±0.43 a	43.3 ±1.49 a
2019	GiSelA 5®	10.6 ±1.98 c	17.5 ±0.78 c	0.94 ±0.07 a	18.6 ±1.06 b	42.0 ±0.21 a
	Colt	10.2 ±2.09 b	12.7 ±0.21 a	0.93 ±0.02 a	13.6 ±0.27 a	70.4 ±0.62 b
	Mazzard F12/1	9.9 ±1.74 a	14.1 ±0.36 b	0.95 ±0.01 a	14.8 ±0.41 a	48.2 ±0.86 a

Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$

Table 3. Fruit firmness (N) of 'Kordia' sweet cherries after storage as affected by rootstocks and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	10.2 ±2.47 d	10.6 ±3.02 e	11.8 ±1.86 f	10.9 ±0.83 c
	Colt	9.4 ±1.94 b	9.4 ±1.98 b	9.5 ±2.12 c	9.4 ±0.10 a
	Mazzard F12/1	9.2 ±2,02 a	9.3 ±2.11 ab	10.3 ±2.31 d	9.6 ±0.61 b
Storage means		9.6 ±0.53 a	9.7 ±0.57 b	10.5 ±1.17 c	
2019	GiSelA 5®	8.8 ±1.76 a	10.4 ±2.41 e	10.2 ±2.22 de	9.8 ±0.61 c
	Colt	9.0 ±2.04 ab	9.9 ±2.11 d	9.8 ±1.59 cd	9.6 ±0.49 b
	Mazzard F12/1	8.7 ±1.92 a	9.4 ±1.88 bc	9.5 ±2.01 bc	9.2 ±0.44 a
Storage means		8.8 ±0.55 a	9.9 ±0.50 b	9.8 ±0.86 b	

Means followed by the same letter, for each year, do not differ significantly at $p \leq 0.05$

AA – air atmosphere, MAP – modified atmosphere packaging, CA – controlled atmosphere

Table 4. Soluble solids content (%) of 'Kordia' sweet cherries after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	16.7 ±0.60 d	16.6 ±0.64 cd	16.6 ±0.65 cd	16.6 ±0.06 c
	Colt	14.3 ±0.32 ab	15.2 ±0.31 bc	14.5 ±0.31 ab	14.7 ±0.47 b
	Mazzard F12/1	13.6 ±0.10 a	13.1 ±1.06 a	13.4 ±0.17 a	13.4 ±0.25 a
Storage means		14.9 ±1.64 a	15.0 ±1.76 a	14.8 ±1.63 a	
2019	GiSelA 5®	17.9 ±0.12 d	17.4 ±0.10 d	17.8 ±0.49 d	17.7 ±0.26 b
	Colt	12.4 ±0.85 abc	11.9 ±0.36 ab	11.9 ±0.38 ab	12.1 ±0.29 a
	Mazzard F12/1	13.4 ±0.30 c	11.3 ±0.86 a	12.9 ±0.44 bc	12.5 ±1.10 a
Storage means		14.5 ±2.93 b	13.5 ±3.36 a	14.2 ±3.16 b	

Explanations – see Table 3

Table 5. Titratable acidity (%) as equivalent of malic acid of 'Kordia' sweet cherries after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	0.58 ±0.04 a	0.61 ±0.03 b	0.64 ±0.03 bcd	0.61 ±0.03 a
	Colt	0.62 ±0.01 bc	0.65 ±0.03 b–e	0.66 ±0.04 b–e	0.64 ±0.02 b
	Mazzard F12/1	0.67 ±0.03 cde	0.69 ±0.01 de	0.71 ±0.03 e	0.69 ±0.02 c
Storage means		0.63 ±0.04 a	0.65 ±0.04 ab	0.67 ±0.04 b	
2019	GiSelA 5®	0.58 ±0.02 a	0.65 ±0.03 ab	0.69 ±0.01 b	0.63 ±0.06 a
	Colt	0.63 ±0.02 ab	0.63 ±.03 ab	0.65 ±0.01 ab	0.64 ±0.01 a
	Mazzard F12/1	0.62 ±0.01 ab	0.69 ±0.01 b	0.69 ±0.02 b	0.67 ±0.04 a
Storage means		0.61 ±0.03 a	0.66 ±0.03 b	0.67 ±0.02 b	

Explanations – see Table 3

Table 6. Soluble solids to acids ratio (SSC/TA) of 'Kordia' sweet cherries after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	28.6 ±2.13 d	27.3 ±0.50 d	25.9 ±0.63 cd	27.3 ±1.35 c
	Colt	23.0 ±0.34 bc	23.5 ±0.44 bc	22.0 ±1.15 ab	22.9 ±0.76 b
	Mazzard F12/1	20.2 ±0.81 ab	18.9 ±1.47 a	19.0 ±0.92 a	19.4 ±0.72 a
Storage means		23.9 ±4.28 b	23.2 ±4.21 ab	22.3 ±3.46 a	
2019	GiSelA 5®	30.7 ±1.22 d	27.0 ±1.64 c	25.9 ±0.44 c	27.9 ±2.51 b
	Colt	19.7 ±2.11 b	18.8 ±1.11 ab	18.5 ±0.89 ab	19.0 ±0.62 a
	Mazzard F12/1	21.5 ±0.48 b	16.3 ±1.29 a	18.8 ±0.53 ab	18.9 ±2.60 a
Storage means		24.0 ±5.90 b	20.7 ±5.60 a	21.1 ±4.14 a	

Explanations – see Table 3

Table 7. Respiration rate (mg CO_2 kg^{-1} h^{-1}) of 'Kordia' sweet cherries after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	54.3 ±10.40 abc	29.7 ±6.38 ab	27.4 ±10.77 ab	37.1 ±14.91 a
	Colt	67.6 ±25.94 bc	54.1 ±2.81 abc	16.7 ±22.75 a	46.1 ±26.37 a
	Mazzard F12/1	72.0 ±7.90 c	49.1 ±15.72 abc	31.9 ±4.89 abc	50.9 ±20.12 a
Storage means		64.5 ±9.22 c	44.3 ±12.89 b	25.3 ±7.81 a	
2019	GiSelA 5®	79.1 ±14.17 c	74.2 ±14.39 abc	59.5 ±5.90 abc	71.0 ±10.20 b
	Colt	90.5 ±26.48 c	76.5 ±12.32 bc	53.6 ±11.82 abc	73.5 ±18.63 b
	Mazzard F12/1	86.6 ±11.99 c	34.4 ±13.78 a	36.9 ±5.82 ab	52.6 ±29.44 a
Storage means		85.4 ±5.79 b	61.7 ±23.27 a	50.0 ±11.72 a	

Explanations – see Table 3

Table 8. Natural mass losses (%) of 'Kordia' sweet cherries after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	4.4 e	1.2 bc	0.6 a	2.1 a
	Colt	4.3 e	1.3 c	0.7 ab	2.1 a
	Mazzard F12/1	3.7 d	1.4 c	0.7 ab	1.9 a
Storage means		4.1 c	1.3 b	0.7 a	
2019	GiSelA 5®	5.6 d	1.9 b	0.2 a	2.5 a
	Colt	4.1 c	2.3 b	0.4 a	2.2 a
	Mazzard F12/1	4.8 cd	2.1 b	0.2 a	2.4 a
Storage means		4.8 c	2.1 b	0.3 a	

Explanations – see Table 3

Table 9. Percent of 'Kordia' sweet cherries with fungal decay symptoms after storage as affected by rootstock and storage conditions

Year	Rootstock	Storage conditions			Rootstock means
		AA	MAP	CA	
2018	GiSelA 5®	7.6 e*	3.5 d	0.0 a	3.7 b
	Colt	2.4 c	1.1 b	0.0 a	1.2 a
	Mazzard F12/1	3.5 d	0.5 ab	0.5 ab	1.5 a
Storage means		4.5 c	1.7 b	0.2 a	
2019	GiSelA 5®	16.5 f	11.6 d	3.5 a	10.5 a
	Colt	14.5 e	12.2 d	3.6 a	10.1 a
	Mazzard F12/1	10.2 c	8.4 b	2.9 a	7.2 a
Storage means		13.7 c	10.7 b	3.4 a	

Explanations – see Table 3

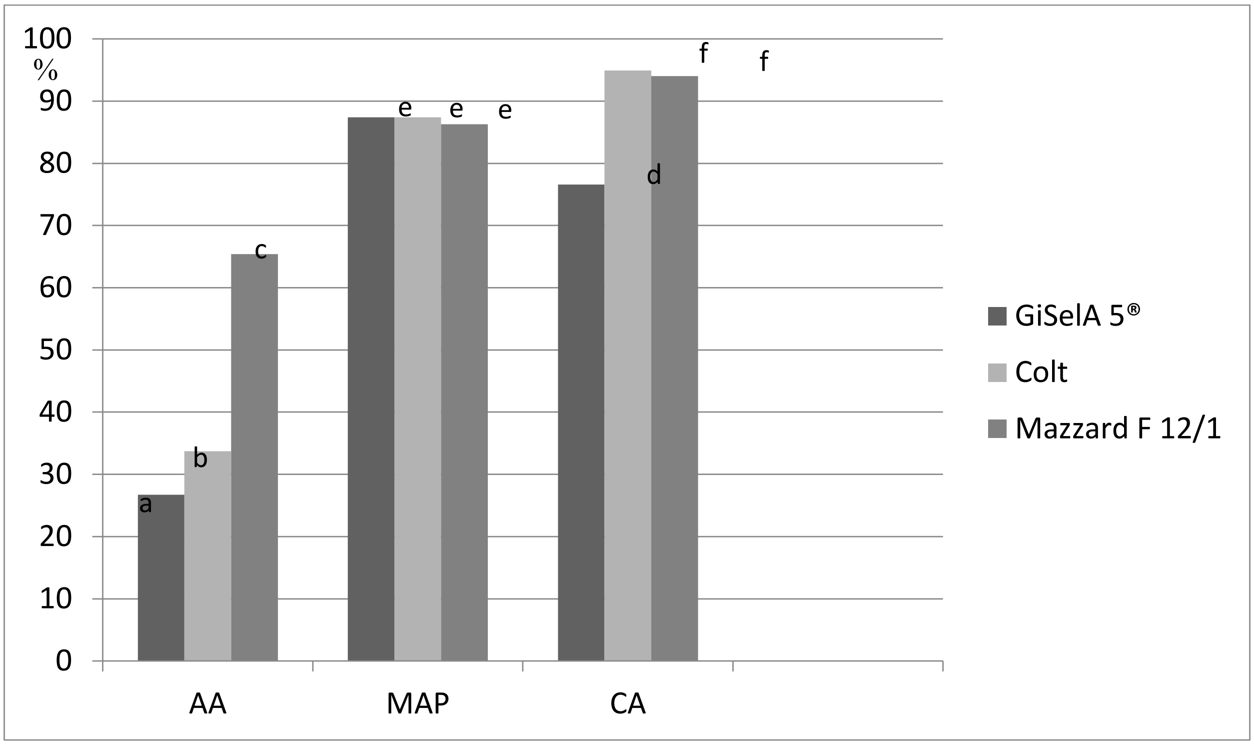

Fig. 1. Percentage of green peduncle of 'Kordia' sweet cherry fruit affected by rootstocks and storage conditions. Bars followed by the same letter are not significantly differ at $p \le 0.05$. AA – air atmosphere, MAP – modified atmosphere packaging, CA – controlled atmosphere

In both years of research, sweet cherries harvested from trees growing on the GiSelA 5® root-stock were characterized by higher fruit firmness (FF) and soluble solids content (SSC) as well as a higher value of the SSC/TA ratio compared to other fruit. Moreover, an effect of the root-stock on titratable acidity (TA) of cherries was recorded in the first year of research, and on fruit respiration rate in the second year (Tab. 2).

Assessment of fruit quality after storage

Experimental factors, i.e. the rootstock and storage conditions, as well as their interactions, usually influenced the values of cherry quality indices determined after their storage.

Sweet cherry firmness measured after storage depended on both the rootstock and storage conditions (Tab. 3). The fruit from trees growing on the GiSelA 5® rootstock had always the highest firmness (10.9 and 9.8 N, respectively). Cherries stored in the controlled CA atmosphere (10.5 and 9.8 N, respectively) and in MAP packages (9.7 and 9.9 N, respectively) had a higher value of the discussed trait than those from the air atmosphere AA (9.6 and 8.8 N, respectively).

The GiSelA 5® rootstock contributed to the higher SSC content in the fruit compared to the remaining rootstocks (16.6 and 17.7%, respectively) (Tab. 4). No effect of storage conditions on the SSC content in cherries was noted in the first year of research. In the following year, sweet cherries stored in the air (14.5%) and controlled atmosphere (14.2%) showed a higher SSC content than fruit from MAP packages (13.5%) (Tab. 4).

Differences in the effect of rootstock on titratable acidity (TA) of sweet cherries were found between the means only in the first year of the study (Tab. 5). The highest values of the described feature were determined in the fruit of trees growing on the Mazzard F12/1 rootstock (0.69%), and the lowest on GiSelA 5® (0.61%). Titratable acidity of cherries stored in the CA (0.67%) in the first year of the research was higher than that of cherries under AA conditions (0.63%). On the other hand, both fruit from the CA (0.67%) and MAP packages (0.66%) were characterized by higher titratable acidity in the following year than sweet cherries stored in air atmosphere conditions (0.61%).

Similarly as after harvest, stored cherries harvested from trees growing on the GiSelA 5® rootstock had a higher value of the SSC/TA ratio (27.3 and 27.9, in the first and the second year, respectively) compared to other fruit (Tab. 6). Cherries stored under AA conditions (23.9 and 24.0, respectively) exhibited a higher value of the discussed feature in comparison to fruit from the CA (22.3 and 21.1, respectively), and also to cherries stored in MAP packages (20.7) in the second year of the study.

Rootstock effected on respiration rate of sweet cherry trees was visible only in the second year of the study (Tab. 7). Fruit harvested from trees growing on the Mazzard F12/1 rootstock (52.6 mg CO_2 kg^{-1} h^{-1}) respired less intensively compared to sweet cherries from trees on GiSelA 5® (71.0 mg CO_2 kg^{-1} h^{-1}) and Colt (73.5 mg CO_2 kg^{-1} h^{-1}). An influence of storage conditions on the value of this feature was noted in both years of research. Sweet cherries stored in CA (25.3 and 50.0 mg CO_2 kg^{-1} $h^{-1,}$ respectively) were characterized by lower respiration rate than the fruit from the air atmosphere (64.5 and 85.4 mg CO_2 kg^{-1} h^{-1}, respectively) and MAP packages (44.3 mg CO_2 kg^{-1} h^{-1}), but only in the first year of research.

The type of rootstock did not have an effect on natural mass loss of sweet cherries determined after their storage (Tab. 8). However, the value of this trait was clearly influenced by storage conditions. The lowest mass losses were demonstrated for sweet cherries from the controlled CA atmosphere (0.7 and 0.3%, respectively), intermediate from MAP packages (1.3 and 2.1%, respectively), and the highest for fruit stored in the air atmosphere (4.1 and 4.8%, respectively).

Symptoms of brown rot (Monilia laxa) were observed after storage of 'Kordia' sweet cherry. The effect of rootstock on the occurrence of disease symptoms was visible only in the first year of the study, while it was found that a higher percentage of rotten cherries concerned the GiSelA 5® rootstock (3.7%) (Tab. 9). It was found that the fewest rotten fruit were among cherries stored in the CA (0.2 and 3.4%, respectively). The percentage of rotten fruit was the highest in sweet cherries stored in the AA condition (4.5 and 13.7%, respectively).

Fig. 1. Percentage of green peduncle of 'Kordia' sweet cherry fruit affected by rootstocks and storage conditions. Bars followed by the same letter are not significantly differ at $p \leq 0.05$. AA – air atmosphere, MAP – modified atmosphere packaging, CA – controlled atmosphere

One of the indicators of fruit quality after storage is the ability to maintain green color of the fruit stem. Fruit evaluation before storage showed that 100% of fruit had a green stem. After storage, change of this parameter was affected by both the rootstock on which the cherry trees grew in the orchard and fruit storage conditions (Fig. 1). Green color of the stem was preserved in the highest percentage in CA conditions for fruit from the Colt and Mazzard F12/1 rootstocks. AA conditions contributed to a high decrease in the percentage of green stems, especially for fruit from the GiSelA 5® and Colt rootstocks.

DISCUSSION

Sweet cherries belong to the group of non-climacteric fruit, they are harvested fully ripe for consumption, and therefore they can be stored for up to 5 weeks. Short-term storage of sweet cherries enables the continuous supply of these fruit, e.g. in periods when bad weather conditions reduce the supply of freshly harvested fruit; it allows for the stabilization of peaks in fruit supply and the extension of the sales season. The experimental results presented in this article are a continuation of our previous research on sweet cherries and are conducted due to the growing interest in new technologies of stone fruit storage. Relatively little information is available on the storage of cultivar 'Kordia' fruit, although some studies were conducted to assess the impact of MAP on fruit quality of this cultivar after a 6-week storage period [Çalhan et al. 2015]. A beneficial effect of this technology on fruit quality was observed, and it was found that MAP required several days for the atmosphere composition to stabilize in the bag, which meant that MAP technology was not suitable for very short fruit storage. These researchers also observed that preserving good fruit quality during storage was largely dependent on the stage of fruit maturation at which the cherries were harvested.

Our previous observations and experiments showed that not only the storage conditions affected fruit quality, but also the rootstock on which the tree grew in the orchard [Dziedzic et al. 2016, 2017, Dziedzic and Błaszczyk 2019]. This time, the study focused on the cultivar 'Kordia'. This cultivar is not a frequent object of research, despite the fact that its fruit has certain advantages during storage; these include high titratable acidity and firmness of the fruit. Our previous experiments with the cultivar 'Regina' showed that fruit titratable acidity after harvest was significantly lower [Dziedzic et al. 2016, 2017, Dziedzic and Błaszczyk 2019]. Firmness of 'Kordia' fruit is one of the highest, for comparison, the leading Turkish cultivar '0900 Ziraat' reaches values of this parameter at the level of 5–6 N [Guler et al. 2019]. According to Blazkova et al. [2002], firmness of sweet cherry fruit should not be less than 2 N for marketing them in markets.

Short-term storage of fruit is to maintain its high quality as dessert fruit. Research has demonstrated that fruit characteristics, which are of priority importance for their quality, changed many times and were primarily dependent on the examined factors and their interaction. After storage, the fruit from the dwarf rootstock GiSelA 5® were characterized by both high firm-ness and high SSC content. Our results were consistent with previous studies by other authors [Gonçalves et al. 2005, Usenik et al. 2010]. It was also observed that fruit retained their firmness better after storage in CA conditions, which was accompanied by lower losses in fruit mass compared to the other two storage conditions. The reason for such a phenomenon was lower water transpiration from the fruit and stem, therefore the fruit retained better firmness, and the stem preserved its green color. Brummel [2006] also indicated a reverse relationship between mass loss and firmness loss, and reported that increasing mass loss accelerated cell wall and membrane disintegration.

Fruit quality after storage largely depends on the quality at harvest. It is difficult to correctly determine the harvest date in the case of sweet cherry, which is a non-climacteric fruit, with a very low ethylene production during ripening [Gong et al. 2002]. The most frequently used indicators are: fruit size and skin color. Skin color depends on the anthocyanin content [Esti et al. 2002], which ranges from few mg 100 g in lightcolored to about 700 mg 100 g in dark cherries [Wang et al. 1997]. As skin color of the fruit darkens, postharvest life decreases. The SSC is also taken into account, and it is assumed that the content should not be less than 14%, as fruit with a lower SSC content are less acceptable to consumers. Sugar content in sweet cherries can be as high as 25% [Girard and Kopp 1998]. Of five sugars that may be present in sweet cherry fruit (glucose, sucrose, fructose, maltose and sorbitol), glucose and fructose constitute 90% [Usenik et al. 2008]. In the present experiment, only the fruit from the GiSelA 5® rootstock met this requirement directly after harvest, as SSC content in these fruit was 15.7 and 17.5% in the subsequent years of research, respectively, and it was significantly higher than SSC content in the fruit obtained from the Colt and Mazzard F12/1 rootstocks. This regularity for the fruit from the GiSelA 5® rootstock was also preserved in all combinations after fruit storage, with SSC reaching values higher than the recommended 14%. There have also been other reports indicating the beneficial effect of the GiSelA 5® rootstock on the value of this parameter [Kankaya et al. 2008].

The content of organic acids in fruit is another, often determined, fruit quality parameter. Among many acids present in sweet cherries, malic acid is the main one [Serrano et al. 2005], and its content varies between cultivars and ranges from 0.3 to 0.8% fresh fruit mass [McLellan and Padilla-Zakour 2004, Usenik et al. 2008]. In the current experiment, rootstock affected the level of titratable acidity of harvested fruit of the cultivar 'Kordia', and this relationship was also preserved after storage (only in the first year of the study). Fruit from the dwarf rootstock GiSelA 5® was characterized by lower titratable acidity compared to vigor-ously growing rootstocks. Cavalheiro et al. [2005] showed a similar relationship, namely the fruit of the cv. 'Summit' from the poorly growing Tabel-Edabriz rootstock contained less or-ganic acids than the fruit of the Prunus avium and CAB 11E rootstocks. High O2 and low CO2 percentage in AA conditions during 'Kordia' cherry storage significantly lowered organic acid contents in comparison to other combinations. The general decrease in acid content after the storage of sweet cherries resulted from the fact that organic acids were involved in the fruit respiration process [Wang and Long 2014, Wani et al. 2014]. CA and MAP conditions slowed down life processes of fruit, which in turn limited the decrease in titratable acidity compared to air atmosphere conditions. The interaction effect of the examined factors (root-stock and storage conditions) was strongly visible in both years of research.

The SSC/TA ratio is another parameter used in the evaluation of fruit quality. It is sometimes helpful in determining the optimal date of sweet cherry harvest, but it is also called the taste index used in sensory evaluations of cherry fruit as a sensory acceptability index of fruit taste. The value of this coefficient depends both on SSC and organic acid contents and represents equilibrium between them. The acceptable SSC/TA ratio for sweet cherries is at least 20, preferably higher [Kader 1999]. At the time of harvest, only fruit from the GiSelA 5® rootstock in the first year of the experiment met this requirement, while after storage, the SSC/TA ratio was 20–30 for most combinations and interactions of rootstock and storage conditions. This was mainly due to a significant reduction in fruit titratable acidity level.

Temperature during fruit harvest and storage is one of the main factors that affect postripening fruit metabolism. Hydrocooling of sweet cherries shortly after harvest (4 h) and then transporting fruit in cold flume water is widely recommended [Wang and Long 2015]. The optimum temperature for harvest and handling of sweet cherries is 10–20°C, while the opti-mum storage temperature is 0°C with an RH range of 90–95% [Bernalte et al. 1999, Çalhan et al. 2015]. In practice, the temperature of 2°C is often applied, as in the present or other studies [Wang and Long 2014, Dziedzic et al. 2016, 2017, Dziedzic and Błaszczyk 2019].

The effectiveness of MAP technology is determined in part by fruit quality at harvest [Mattheis and Fellman 2000]. Sweet cherry is better adapted to MAP technology since it is more tolerant to higher CO_2 concentrations than other stone fruit. MAP is generated through the natural process of respiration of the enclosed product, which reduces O_2 and increases CO_2 under restricted gas exchange through the film barrier [Beaudry and Lakakul 1995]. Optimal MAP conditions for sweet cherry are: 3–10% O_2 and 10–15% CO_2 at 0°C [Mitcham et al. 2002]. Scientific findings revealed many benefits of MAP technology: decreased respiration rate and delayed fruit maturation by changing the O_2 and CO_2 concentration ratio, delayed fruit color change and losses in fruit firmness and titratable acidity [Giacalone and Chiabrando 2013], preservation of green stem color [Remon et al. 2000, Kappel et al. 2002, Padilla-Zakour et al. 2004]. In addition, the newest findings confirmed the favorable effect of 10% CO_2 in MAP technology on fruit quality [Xing et al. 2020].

The discussed experiment proved the beneficial effect of MAP technology on most pa-rameters compared to air atmosphere conditions, and only on fruit firmness preservation, and SSC content compared to CA technology with 20% CO_2 concentration. CA conditions had a positive effect on the maintenance of fruit firmness, slower respiration of cherries, small losses in fruit weight, reduced occurrence of fungal diseases and better preservation of green color of the stem. In the experiment involving 'Regina' cultivar, 20% CO_2 concentration also contributed to better preservation of favorable fruit parameters compared to the combination with 10% CO_2 [Dziedzic and Błaszczyk 2019]. Wargo et al. [2003] studied the Hedelfingen and Lapins cultivars and demonstrated that MAP maintained fruit color and intensity, preserved green stem color, maintained fruit firmness, prevented water loss and shriveling and kept cherries in excellent condition during four weeks of storage. Moreover, recent studies showed that SSC, TA, total phenols and acceptability index SSC/TA were unaffected by the post-harvest MAP treatment [Miguel-Pintado et al. 2017]. Different CO_2 concentrations are sometimes used in CA technology [Cavalheiro et al. 2005, Goliaš et al. 2006]. One should be careful when choosing CO_2 concentration, as optimal concentration of carbon dioxide for sweet cherries ranges from 15 to 18%, however, concentrations above 20% may influence fruit taste by affecting aromatic compounds, similarly to berry species [Wang and Bunce 2004] sometimes an unpleasant taste may also appear after storing cherries in an atmosphere containing more than 10% CO_2 and up to 5% O_2 [Goliaš et al. 2007].

When stored at 0–5°C, sweet cherries show tolerance to very low oxygen concentrations (0.02% O_2 for 21–25 days) and can be stored at 0.5–1% O_2 and

20–40% CO_2 for several weeks [Golding et al. 2012]. The experiments carried out in CA at 10–30% CO_2 and 5–20% O_2 showed that firmness of sweet cherry fruit, vitamin C content and TA levels were effectively preserved without the development of unpleasant taste [Wang and Vestrheim 2002].

Metabolic activity e.g. respiration, aging or ethylene production occurs in fresh fruit. High respiration rate depletes energy reserves and accelerates aging processes, which result in a reduction in sweet taste and freshness. Cherries are highly perishable fruit with a respiration rate of 10–20 mg CO_2 kg^{-1} h^{-1} at 5°C, and are highly prone to surface pitting that leads to fruit rot during cold storage [Crisosto et al. 1993]. In our experiment, respiration rate of sweet cherry fruit of the cultivar ‘Kordia’ was dependent on storage conditions and interaction of experimental factors in both years of research, while rootstocks had an influence on this feature only in the second year of the study. Fruit from the Mazzard F12/1 rootstock, were characterized by low respiratory intensity both after harvest and storage. It was also observed that respiration rate was influenced by fruit physiological state in each year of the study. CA conditions with low O2 and elevated CO2 concentrations reduced fruit titratable acidity loss, which contributed to a higher SSC/TA ratio. A similar relationship was demonstrated by Harb et al. [2003] for the cv. ‘Regina’. The limiting effect of reduced oxygen concentration (to 10 %) on respiration rate of the cultivars Bing and Sweetheart was also proven in other studies [Wang and Long 2014].

Damages caused by fungal diseases are a frequent cause of fruit quantitative losses. We found that the overall percentage of infection observed was lower in the first year of the experiment, which could be related to weather conditions during fruit harvest. Rainfall and increased air humidity prior to fruit picking may favor the development of fungal spores and cause an increased development of infection during fruit storage. Storage conditions influenced the occurrence of diseases, but the effect of the rootstock was not found in the year of higher fruit rot intensity. We observed similar regularities in previous studies involving cultivar ‘Regina’ conducted in two year cycles [Dziedzic et al. 2016, Dziedzic and Błaszczyk 2019]. AA conditions always contributed to a high fruit percentage with symptoms of fungal diseases. CA conditions with high CO_2, more inhibited fruit decay than did MAP technology. It has long been observed that CO_2 concentrations above 20% and O_2 concentrations below 1% strongly reduce the incidence of infections in many fruit species [De Vries-Paterson et al. 1991]. Wilson et al. [1987] argued that fruit rot resistance in high CO2 storage was due to the production of high acetaldehyde and ethyl acetate levels in response to these conditions. Newer studies conducted both in CA and in vitro conditions confirmed the high sensitivity of the pathogen *Monilinia* to high, even up to 30% CO_2 concentrations [Tian et al. 2001].

Sweet cherries are harvested and stored with stems, whose preservation prevents the leakage of juice from the fruit flesh. Consumers attach great importance to the appearance of the stem when assessing sweet cherry freshness. During storage, stems transpire water and metabolic changes occur in them, manifested by tissue browning. However cherry stems have a much thinner epidermis and cuticle layer than the fruit, and thus they are very susceptible to water and carbon dioxide losses. Their resistance to water vapor transfer is much lower and can lose water up to eight-times faster than fruit [Linke et al. 2010]. Stem drying depends mainly on relative air humidity (RH) [Goliaš et al. 2006, 2007]. With an RH of 65% at 20°C, stems lose 60% of their mass within 6 h, while the loss of the mass at an RH of 95% is only 5%. Our results showed that the preservation of green color of the stem after fruit storage was dependent on both storage conditions and rootstock type. CA conditions and the Mazzard F12/1 rootstock had the most positive effect on green color preservation. Under air atmosphere conditions, there was a dramatic decrease in the percentage of green stems. According to Linke et al. [2010], low air humidity and atmosphere composition (high oxygen concentration) contributed to large water losses and subsequent damage to the photosynthetic appa-ratus, which resulted in chlorophyll degradation and, consequently, browning of the stem.

CONCLUSIONS

The rootstocks on which the ‘Kordia’ cherry trees grew had an effect on all fruit quality parameters measured directly after harvest, except for respiration rate in the first and fruit titratable acidity in the second year of the study. After 3-week storage of sweet cherries, the influence of rootstock was proven on most of fruit quality parameters. The GiSelA 5® rootstock contributed to the preservation of high firmness, high SSC content, and high SSC/TA ratio of the fruit. MAP conditions were conducive to maintaining good fruit quality, although more favorable quality parameters were recorded after sweet cherry storage in CA, especially with regard to such features as fruit firmness, low respiration rate, low massloss, low percentage of fungal diseases and good preservation of green color of the stem. The recorded significant impact of interactions of all parameters on fruit quality indicated the need for this type of research in order to broaden the knowledge.

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REFERENCES

Aglar, E., Ozturk, B., Guler, S.C., Karakaya, O., Uzun, S., Saracoglu, O. (2017). Effect of modified atmosphere packaging and 'Parka' treatments on fruit quality characteristics of sweet cherry fruits (*Prunus avium* L. '0900 Ziraat') during cold storage and shelf life. Sci. Hortic., 222, 162–168. https://doi.org/10.1016/j.scienta.2017.05.024

Alique, R., Zamorano, J.P., Martínez, M.A., Alonso, J. (2005). Effect of heat and cold treatments on respiratory metabolism and shelf-life of sweet cherry, type Picota cv 'Ambrunés'. Postharvest Biol. Technol., 35, 153–165, https://doi.org/10.1016/j.postharvbio.2004.07.003

Balducci, F., Capriotti, L., Mazzoni, L., Medori, I., Albanesi, A., Borraccini, G., Giampieri, F., Mezzetti, B., Capocasa, F. (2019). The rootstock effects on vigor, production and fruit quality in sweet cherry (*Prunus avium* L.). J. Berry Res., 9(2), 249–265, https://doi.org/10.3233/JBR-180345

Beaudry, R.M., Lakakul, R., (1995). Basic principle of modified atmosphere packing. Tree Fruit Postharvest J., 6, 7–13,

Bernalte, M.J., Hernández, M.T., Vidal-Aragón, M.C., Sabio, E. (1999). Physical, chemical, flavor and sensory characteristics of two sweet cherry varieties grown in 'Valle del Jerte' (Spain). J. Food Qual., 22, 403–416. https://doi.org/10.1111/j.1745-4557.1999.tb00173.x

Bernalte, M.J., Sabio, E., Hernandez, M.T., Gervasini, C. (2003). Influence of storage delay of 'Van' sweet cherry. Postharvest Biol. Technol., 28(3), 303–312. https://doi.org/10.1016/S0925-5214(02)00194-1

Blazkova, J., Hlusickova, I., Blazek, J. (2002). Fruit weight, firmness and soluble solid content during ripening of Karesova cv. sweet cherry. Hortic. Sci., 29, 92–98. https://doi.org/10.17221/4470-HORTSCI

Brummell, D.A. (2006). Cell wall disassembly in ripening fruit. Funct. Plant Biol., 33, 103–119. https://doi.org/10.1071/FP05234

Çalhan, Ö., Onursal, C.E., Güneyli, A., Eren, İ. (2015). Effect of harvest date on postharvest quality of 'Kordia' sweet cherry during MAP storage. Acta Hortic., 1071, 667–674. https://doi.org/10.17660/ActaHortic.2015.1071.88

Cavalheiro, J.T., Santos, A.A., Marques, R.I., Pirra, A., Silvestre, A. (2005). Rootstock and storage regime influence 'Summit' cherry quality. Acta Hortic., 682, 1179–1185. https://doi.org/10.17660/ActaHortic.2005.682.156

Chen, P.M., Mellenthin, W.M., Kelly, S.B., Facteau, T.J. (1981). Effects of low oxygen and temperature on quality retention of 'Bing' cherries during prolonged storage. J. Am. Soc. Hortic. Sci., 106, 533–535.

Chockchaisawasdee, S., Golding, J.B., Vuong, Q.V., Papoutsis, K., Stathopoulos, C.E. (2016). Sweet cherry: Composition, postharvest preservation, processing and trends for its future use. Trends Food Sci. Technol., 55, 72–83. https://doi.org/10.1016/j.tifs.2016.07.002

Crisosto, C.H., Garner, D., Doyle, J., Day, K.R. (1993). Relationship between fruit respiration, bruising susceptibility, and temperature in sweet cherries. Hortic. Sci., 28(2), 132–135. https://doi.org/10.21273/HORTSCI.28.2.132

Crisosto, C.H., Lurie, S., Retamales, J. (2009). Stone fruit. In: Modified and Controlled Atmospheres for the Storage, Transportation, and Packaging of Horticultural Commodi-ties, Yahia (ed.). CRC Press, Taylor & Francis Group, Boca Raton, FL, 287–315.

De Vries-Paterson, R.M., Jones, A.L., Cameron, A.C. (1991). Fungistatic effects of carbon dioxide in a package environment on the decay of Michigan sweet cherries by *Monilinia fructicola*. Plant Dis., 75, 943–946.

Dziedzic, E., Błaszczyk, J. (2019). Evaluation of sweet cherry fruit quality after short-term storage in relation to the rootstock. Hortic. Environ. Biotechnol., 60(6), 925–934. https://doi.org/10.1007/s13580-019-00184-y

Dziedzic, E., Błaszczyk, J., Kaczmarczyk, E. (2016). Influence of rootstocks and storage conditions on the quality of sweet cherry fruits 'Regina'. Acta Sci. Pol. Hortorum Cultus 15(5), 119–131. https://doi:org/10.2426/asphc2016.5.9

Dziedzic, E., Błaszczyk, J., Kaczmarczyk, E. (2017). Postharvest properties of sweet cherry fruit depending on rootstock and storage conditions. Folia Hortic., 29(2), 113–121. https://doi.org/10.1515/fhort-2017-0011

Esti, M., Cinquanta, L., Sinesio, F., Moneta, E., Mateo, M.D. (2002). Physicochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. Food Chem., 76(4), 399–405. https://doi.org/10.1016/S0308-8146(01)00231-X

Giacalone, G., Chiabrando, V. (2013). Modified atmosphere packaging of sweet cherries with biodegradable films. Int. Food Res. J., 20(3), 1263–1268.

Girard, B., Kopp, T.G. (1998). Physicochemical characteristics of selected sweet cherry cultivars. J. Agric. Food Chem., 46, 471–476. https://doi.org/10.1021/jf970646j

Golding, J.B., Jessup, A., Spohr, L., Daniels, D., Satyan, S., Pristijono, P., McGlasson, W.B. Jacas, J. (2012). Efficacy of a combination quarantine treatment at 3°C as a potential disinfestation treatment for Queensland Fruit Fly (*Bactrocera tryoni* (Froggatt)) in cherry fruit. Acta Hortic., 934, 343–346. https://doi.org/10.17660/ActaHortic.2012.934.43

Goliaš, J., Lacny, Z., Němcova, A., Čaněk, A. (2006). Release of anaerobic metabolites from intact sweet cherries stored in low oxygen atmospheres. Mitt. Klosterneuburg 56, 157–165.

Goliaš, J., Němcova, A. Čaněk, A., Kolenčiková, D. (2007). Storage of sweet cherry in low oxygen and high carbon dioxide atmospheres. Hortic. Sci., 34, 26–34. https://doi.org/10.17221/1843-HORTSCI

Gonçalves, B., Moutinho-Pereira, J., Santos, A., Silva, A.P., Bacelar, E., Correia, C., Rosa, E. (2005). Scionrootstock interaction affects the physiology and fruit quality of sweet cherry. Tree Physiol., 26, 93–104. https://doi.org/10.1093/treephys/26.1.93

Gong, Y.P., Fan, X.T., Mattheis, J.P. (2002). Response of 'Bing' and 'Rainier' sweet cherries to ethylene and 1-methylcyclopropene. J. Amer. Soc. Hortic. Sci., 127, 831–835. https://doi.org/10.21273/JASHS.127.5.831

Graczyk, D., Szwed, M. (2020). Changes in the Occurrence of Late Spring Frost in Poland. Agronomy, 10(11), 1835. https://doi.org/10.3390/agronomy10111835

Guler, S.K., Karakaya, O., Karakaya, M., Ozturk, B., Aglar, E., Yarılgac, T., Gün, S. (2019). Combined treatments of modified atmosphere packaging with aminoethoxyvinylglycine maintained fruit quality in sweet cherry throughout cold storage and shelf life. Acta Sci. Pol. Hortorum Cultus, 18(5), 13–26. https://doi.org/10.24326/asphc.2019.5.2

Habib, M., Bhat, M., Dar, B.N., Wani, A.A. (2015). Sweet Cherries from Farm to Table: A Review. Crit. Rev. Food Sci. Nutr., 57(8), 1638–1649. https://doi.org/10.1080/10408398.2015.1005831

Hajagos, A., Spornberger, A., Modl, P., Végvári, G. (2012). The effect of rootstocks on the development of fruit quality parameters of some sweet cherry (*Prunus avium* L.) cultivars, 'Regina' and 'Kordia', during the ripening process. Acta Univ. Sapientiae Agric. Environ., 4, 59–70.

Harb, J., Streif, J., Saquet, A. (2003). Impact of controlled atmosphere storage conditions on storability and consumer acceptability of sweet cherry 'Regina'. J. Hortic. Sci. Biotech-nol., 78, 574–579. https://doi.org/10.1080/14620316.2003.11511666

Kader, A.A. (1997). A summary of CA requirements and recommendations for fruits other than apples and pears. In: Proceedings of the 7th International Controlled Atmosphere Research Conference, vol. 3, Davis, CA, USA, 1–34.

Kader, A.A. (1999). Fruit maturity, ripening and quality relationships. Acta Hortic., 485, 203–208. https://doi.org/10.17660/ActaHortic.1999.485.27

Kankaya, A., Askin, M.A., Akinci-Yildrim, F., Balci, B., Alkan, T. (2008). Evaluation of some sweet cherry cultivars on GiSelA 5 and GiSelA 6 rootstocks in Baryamic, Turkey. Acta Hortic., 795, 221–225. https://doi.org/10.17660/ActaHortic.2008.795.30

Kappel, F., Toivonen, P., McKenzie, D.L., Stan, S. (2002). Storage characteristics of new sweet cherry cultivars. HortScience, 37(1), 139–143. https://doi.org/10.21273/HORTSCI.37.1.139

Linke, M., Herppich, W.B., Geyer, M. (2010). Green peduncles may indicate postharvest freshness of sweet cherry. Postharvest Biol. Technol., 58, 135–141. https://doi.org/10.1016/j.postharvbio.2010.05.014

Long, L.E., Núñez-Elisea, R., Cahn, H. (2008). Evaluation of sweet cherry cultivars and advanced selections adapted to the Pacific Northwest USA. Acta Hortic., 795, 255–260. https://doi.org/10.17660/ActaHortic.2008.795.34

Mattheis, J.P. Fellman, J.P. (2000). Impact of modified atmosphere packaging and controlled atmosphere on aroma, flavour and quality of horticultural commodities. HortTechnology, 10, 507–510. https://doi.org/10.21273/HORTTECH.10.3.507

McLellan, M.R., Padilla-Zakour, O.I. (2004). Sweet cherry and sour cherry processing. In: Processing fruits: Science and technology, Barrett, D.M., Somogyi, L.P., Ramaswamy, H.S. (eds.). CRC Press, Boca Raton, 497–508.

Miguel-Pintado, C., Resende, M., Rodrigues, I., Antunes, P. (2017). Improvement of ‘Sweet-heart’ cherry quality by modified atmosphere packaging (MAP). Acta Hortic. 1161, 549–554. https://doi.org/10.17660/ActaHortic.2017.1161.87

Mitcham, E.J., Crisosto, C.H., Kader, A.A. (2002). Produce facts. Sweet cherry. Recommendations for maintaining postharvest quality. Perishable Handled Newsl., 86, 15–16.

Padilla-Zakour, O.I., Tandon, K.S., Wargo, J. (2004). Quality of modified atmosphere packaging ‘Hedelfinden’ and ‘Lapins’ sweet cherry. HortTechnology, 14(3), 331–337. https://doi.org/10.21273/HORTTECH.14.3.0331

Padilla-Zakour, O.I., Ryona I., Cooley H.J., Robinson T.L., Osborne, J. Freer J. (2007). Shelf-life extension of sweet cherries by field management, post-harvest treatments, and modified atmosphere packaging. New York Fruit Quart., 15(2), 3–6.

Patterson, M.E., (1982). CA storage of cherries. In: Controlled Atmospheres for Storage and Transport of Perishable Agricultural Commodities, Richardson, D.G., Meheriuk, M., Blankenship, S. (eds.). Timber Press, Beaverton, OR, 149–154.

Petracek, P.D., Joles, D.W., Shirazi, A., Cameron, A.C. (2002). Modified atmosphere packaging of sweet cherry (*Prunus avium* L., cv. ‘Sams’) fruit: metabolic responses to oxygen, carbon dioxide, and temperature. Postharvest Biol. Technol., 24, 259–270. https://doi.org/10.1016/S0925-5214(01)00192-2

Remón, S., Ferrer, A., Marquina, P., Burgos, J., Oria, R. (2000). Use of modified atmospheres to prolong the postharvest life of Burlat cherries at two different degrees of ripeness. J. Sci. Food Agric., 80, 1545–1552. https://doi.org/10.1002/1097-0010(200008)80:10<1545::AID-JSFA680>3.0.CO;2-X

Remón, S., Marquina, P., Peiró, J.M., Oria, R. (2003). Storage potential of ‘Sweetheart’ cherry in controlled atmospheres. Acta Hortic., 600, 763–769. https://doi.org/10.17660/ActaHortic.2003.600.117

Schuster, M. (2012). Incompatible (S-) genotypes of sweet cherry cultivars (*Prunus avium* L.). Sci. Hortic., 148, 59–73. https://doi.org/10.1016/j.scienta.2012.09.012

Serrano, M., Guillén, F., Martínez-Romero, D., Castillo, S., Valero, D. (2005). Chemical constituents and antioxidant activity of sweet cherry at different ripening stages. J. Agric. Food Chem., 53, 2741–2745. https://doi.org/10.1021/jf0479160

Tian, S., Fan, Q., Xu, Y., Wang, Y., Jiang, A. (2001). Evaluation of the use of high CO_2 concentrations and cold storage to control *Monilinia fructicola* on sweet cherries. Postharvest Biol. Technol., 22, 53–60. https://doi.org/10.1016/S0925-5214(00)00177-0

USDA.https://www.fas.usda.gov/search?keyword=sweet+cherry+production. [date of access: 2022.5.10].

Usenik, V., Fajt, N., Mikulic-Petkovsek, M., Slatnar, A., Stampar, F., Veberic, R. (2010). Sweet cherry pomological and biochemical characteristics influenced by rootstock. J Agric. Food Chem., 58(8), 4928–4933. https://doi.org/10.1021/jf903755b

Usenik, V., Fabčič, J., Štampar, F. (2008). Sugars, organic acids, phenolic composition and antioxidant activity of sweet cherry (*Prunus avium* L.). Food Chem., 107, 185–192. https://doi.org/10.1016/j.foodchem.2007.08.004

Wang, S.Y., Bunce, J.A. (2004). Elevated carbon dioxide affects fruit flavor in field-grown strawberries (*Fragaria* × *ananassa* Duch). J. Sci. Food Agric., 84, 1464–1468. https://doi.org/10.1002/jsfa.1824

Wang, Y., Long, L.E. (2014). Respiration and quality responses of sweet cherry to different atmospheres during cold storage and shipping. Postharvest Biol. Technol., 92, 62–69. https://doi.org/10.1016/j.postharvbio.2014.01.003

Wang Y., Long L.E. (2015). Physiological and biochemical changes relating to postharvest splitting of sweet cherries affected by calcium application in hydrocooling water. Food Chem., 181, 241–247. https://doi.org/10.1016/j.foodchem.2015.02.100

Wang, H., Cao, G., Prior, R.L. (1997). Oxygen radical absorbing capacity of anthocyanins. J. Agric. Food Chem., 45, 304–309. https://doi.org/10.1021/jf960421t

Wang, L., Vestrheim, S. (2002). Controlled atmosphere storage of sweet cherries (*Prunus avium* L.). Acta Agric. Scand. B Soil Plant Sci., 52, 136–142. https://doi.org/10.1080/090647103100004825

Wani, A.A., Singh, P., Gul, K., Wani, M.H., Langowski, H.C. (2014). Sweet cherry (*Prunus avium*): Critical factors affecting the composition and shelf life. Food Packag. Shelf Life, 1(1), 86–99. https://doi.org/10.1016/j.fpsl.2014.01.005

Wargo, J.M., Padilla-Zakour, O.I., Tandon, K.S. (2003). Modified atmosphere packaging maintains sweet cherry quality after harvest. New York Fruit Quart., 11(2), 5–8.

Wilson, C.L., Franklin, J.D., Otto, B.E. (1987). Fruit volatiles inhibitory to *Monilinia fructicola* and *Botrytis cinerea*. Plant Dis., 71, 316–319.

Xing, S., Zhang, X., Gong, H. (2020). The effect of CO_2 concentration on sweet cherry preservation in modified atmosphere packaging. Czech J. Food Sci., 38(2), 103–108. https://doi.org/10.17221/255/2019-CJFS