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POSTHARVEST QUALITY OF SWEET CHERRY FRUITS AS AFFECTED BY BIOREGULATORS

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ABSTRACT

During the cold storage of sweet cherry, severe losses can occur due to the water loss, phytopathogenic fungi and physiological disorders. The aim of this research was to assess the effects of treatments with NAA (α-naphthaleneacetic acid), BA (6-benzyladenine), and GA_3 (gibberellic acid) on fruit quality at harvest and after 21 days of storage under two regimes, including 0°C, RH (relative humidity) 90% and 3°C, RH 70%, and after additional shelf life exposure. Sweet cherry cultivars – 'Summit', 'Kordia' and 'Regina' – were treated with bioregulators at the end of flowering. NAA significantly increased the fruit weight at harvest compared to the control in all cultivars assessed. BA stimulated the fruit growth in 'Kordia' and 'Regina', while it was ineffective in 'Summit'. GA_3 caused significant increase in fruit weight by 8.3% in 'Kordia' only. Moreover, BA and GA_3 induced a higher firmness of fruits at harvest. Weight loss of fruits during storage at 0°C, RH 90%, was increased with NAA and reduced with GA3 in 'Regina' only. BA and GA_3 reduced the weight loss of sweet cherry fruits stored at 3°C, RH 70%. Bioregulator treatments increased TA (titratable acidity) in fruits at harvest, while the effects on TA during storage were variable depending on the cultivar. 'Summit' had the highest sensitivity to storage fruit rot. BA and GA3 decreased the disease occurrence on fruits stored at 0°C in 'Summit' and 'Kordia'.

Key words: *Prunus avium* L., gibberellic acid, storage, shelf life, weight loss, fruit rot

INTRODUCTION

Sweet cherry fruits are very valuable on markets worldwide. For sweet cherry, fruit size is the most important attribute; small fruit size is one of the limiting factors for successful display of cherry fruits on the markets [Whiting et al. 2005]. Because of their highly perishable nature and short shelf life, the presence of sweet cherry fruits on the market is limited, and there is a need for extending postharvest life of the fruits by keeping them in a cold storage.

Keeping in mind that storage period of sweet cherry fruits is also limited, the adequate adjustment of storage conditions is of high importance. The quality of stored fruits depends on conditions in storage including: temperature, relative humidity and atmosphere composition, which affect physiological and biochemical processes in fruits [Sen et al. 2014]. Deterioration of fruit quality during storage under normal conditions is caused by water loss, phytopathogenic fungi and physiological disorders [Bal 2012].

Pre-harvest treatments with bioregulators exhibit positive effects on weight, size [Zhang and Whiting 2011] and internal quality of sweet cherry fruits at harvest [Canli et al. 2015]. The use of bioregulators on sweet cherry is not sufficiently tested, especially in re-

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lation with fruit quality and rot occurrence during and after storage period. The principal factors responsible for the decay of sweet cherry fruits are postharvest rots caused by several fungal species which further result in severe economic losses. Fungal infections can initiate fermentative metabolism leading to development of off-flavors due to ethanol and acetaldehyde formation [Esti et al. 2002]. The damage to sweet cherries caused by pathogenic fungi can be substantial, in particular in the case of longer storage periods [Conte et al. 2009]. *Monilinia* spp. and *Botrytis cinerea* are the most important causal agents of sweet cherry fruit rot [Feliziani et al. 2013]. Several other fungal species can cause significant losses as well: *Monilinia* species (*M. laxa*, *M. frutigena* and *M. fructicola*), *Pencillium expansum* (Blue mold), *Alternaria alternata* (Alternaria rot) and *Cladosporium* sp. (Cladosporium rot) [Romanazzi et al. 2009].

The higher firmness of sweet cherry fruits contributes to better quality preservation after harvest and reduces the development of fungal decay [Einhorn et al. 2013]. The use of gibberellic acid (GA_3) can delay fruit maturation, and thus help retention of fruit firmness [Ozkan et al. 2016]. It is well documented that 6-benzyladenine (BA) increases fruit firmness in sweet cherry [Canli et al. 2015] which may contribute to reduced rot occurrence during storage. It was previously reported that α-naphthaleneacetic acid (NAA) decreased fruit firmness in apple fruits [Milić et al. 2017a]. Decreased fruit firmness and increased soluble solids content (SSC) in fruits can increase the frequency of rot occurrence [Holb 2004]. Therefore, it was assumed that NAA pre-harvest treatment might reduce fruit firmness in sweet cherries at harvest and thus increase development of fungal decay in storage. The aim of this research was to assess the effects of pre-harvest treatments with NAA, BA, and GA_3 on fruit quality at harvest and after cold storage under different regimes in three sweet cherry cultivars. The occurrence of fungi causing fruit rot during storage was also monitored.

MATERIAL AND METHODS

Field trial

Sweet cherry cultivars, 'Summit', 'Kordia' and 'Regina', grafted on 'Gisela 5' (*P. cerasus* × *P. canescens*) rootstock were used in this study. The experiment was conducted during the growing season in 2017, at the Experimental field for fruit growing of the Faculty of Agriculture situated at Rimski Šančevi (45°20'N and 19°50'E, 80 m a.s.l.), Novi Sad, Serbia. Trees were planted in 2012 at the planting distance 4.0 × 1.5 m with 1666 trees ha^{-1}. All varieties were planted as two-years-old knip trees with a one-year-old feathered crown with 5 or more feathers. Standard cultural practices (irrigation, fertilization, winter and summer pruning, disease control) were implemented regularly during the experiment.

Each treatment was applied on a plot of five uniform, randomly chosen trees, with one single tree per replicate. Spraying was performed using backpack sprayer ("Stihl SR-420") until run-off, with the amount of solution of 3 L per plot. The commercial chemical bioregulators used in this trial were: Gerba 4LG, containing 4% active ingredient (a.i.) BA, Gibrelin containing 1.8% a.i. GA_3 and Dirager, containing 3.3% a.i. NAA ("L-Gobbi", Italy). The following bioregulator treatments were applied at 69 BBCH (end of flowering) [Meier 2001] at the rates of a.i. 100 mg L^{-1} BA, 200 mg L^{-1} GA_3, 20 mg L^{-1} NAA and an untreated control. Fruits were harvested at the commercial stage of maturity and the date of harvesting was determined based on the fruit color, according to the Centre Technique Interprofessionnel des Fruits et Legumes, Paris, France. Cherry color ranged between 4 and 5 for 'Summit', and 5 and 6 for 'Kordia' and 'Regina'. At harvest, fruit weight, SSC, TA and fruit firmness were measured. SSC in extracted juice was measured using a temperature compensated hand-held refractometer (Xin instruments, China) and TA was measured by titration of filtered juice with 0.1 NaOH to the pH 8.1. The amount of used NaOH was multiplied by 0.067, which is the correction factor for the dominant malic acid and the results were expressed as mg percentages (mg %). Fruit firmness was measured using a Fruit Texture Analyser, FTA-25 (Güss System, RSA) with an 8-mm probe and measured values were expressed in kg cm^{-2}.

Fruit storage and shelf life

Four replicates per treatment, each containing 30 fruits (120 in total per treatment), were placed in plastic containers and stored in cold storage

with the normal atmosphere (NA) under two air temperature and RH regimes: the first regime with air temperature 0°C, relative humidity 90%, and the second with air temperature 3°C, relative humidity 70%. Fruits were stored for 21 days. In order to determine weight loss (%) during storage period, the weight of each fruit was measured two times: after 21 days at NA storage (21 + 0) and after shelf life (21 + 3). 10 fruits were taken out from each replicate to determine SSC and TA after 21 + 0 days. The remaining fruits (20 in each replicate), were kept at 20°C for 3 days. After 21 + 3 days, fruits were classified into two categories according to the appearance: healthy and decayed, in order to calculate the percentage of decayed fruits. Fruit weight, SSC and TA content of remaining healthy fruits were measured after 21 + 3 days.

Rotten fruits were separated from the sample after 21 + 3 days and used for fungal pathogen isolation. The fruits were surface sterilized in 2% NaOCl for 1 min, and dried by placing cherries in a sterile air laminar flow cabinet for 1 h. Small plugs of the fruit tissue were cut from the edge of the lesion and placed on potato dextrose agar (PDA) plate followed by incubation at 25°C in darkness in a growth chamber until the colonies developed. The obtained isolates were identified based on morphological characteristics of colonies developed in PDA plates. After 7 days incubation on PDA plates at 23 ±1°C in dark, following features were determined: colony color, colony margin appearance, sporulation and conidia morphology. According to these features, isolates were identified as *Monilinia* sp., *Botrytis cinerea* or *Alternaria* sp. Isolates identified as *Monilinia* sp. formed creamy to yellow colonies with entire margins. Formed conidia were unicellular, hyaline, oval to lemon-shaped, produced in branched chains. Isolate identified as *Alternaria* sp. formed brown to grey, flat and circular colonies. Conidia were ellipsoidal to club-shaped, multicelled with 1–3 longitudinal and 2–10 transversal septa. Isolate identified as *Botrytis cinerea* formed grey colonies, and conidia were unicellular, ellipsoid, hyaline, formed on branched conidiophores. Described features of isolates are in accordance with the descriptions of these fungi found in literature [Hrustić 2013, Nagrale et al. 2013, Latorre et al. 2015].

Data analysis

The data were processed by factorial ANOVA using Software Statistica 13.3 (StatSoft Inc., Tulsa, OK, USA). Duncan's multiple range test was used to test significance of differences ($p \leq 0.05$) between mean values.

RESULTS AND DISCUSSION

Fruit weight and firmness at harvest

Effects of bioregulators on fruit weight and firmness were variable depending on a cultivar (Tab. 1). NAA treatment significantly increased fruit weight compared to the control at harvest in all cultivars assessed. It was previously found that the application of synthetic auxins increased fruit size in sweet cherry [Stern et al. 2007] and apple [Milić et al. 2017b] via direct stimulation of fruit cell enlargement. Auxin treatment caused some advanced fruit color development, while SSC and fruit firmness were unaffected [Zhang

Table 1. Fruit weight (g) and fruit firmness (kg cm^{-1}) of sweet cherry cultivars at harvest as affected by bioregulators

Treatment	Fruit weight (g)			Fruit firmness (kg cm^{-2})		
	'Summit'	'Kordia'	'Regina'	'Summit'	'Kordia'	'Regina'
Control	12.8 ^{b}	13.3 ^{b}	13.7 ^{b}	0.56 ^{b}	0.85 ^{b}	0.83 ^{b}
BA	12.8 ^{b}	14.4 ^{a}	15.4 ^{a}	0.59 ^{a}	0.94 ^{a}	0.90 ^{a}
GA_3	13.2 ^{ab}	14.4 ^{a}	13.4 ^{b}	0.58 ^{a}	0.93 ^{a}	0.86 ^{ab}
NAA	13.5 ^{a}	14.4 ^{a}	16.1 ^{a}	0.54 ^{b}	0.82 ^{b}	0.84 ^{b}

Mean values within the same column marked with the same letter do not significantly differ according to Duncan's multiple range test at $P < 0.05$

and Whiting 2011]. The advanced maturation in NAA treatment associated with decreased fruit firmness and increased SSC was also not observed in the present research.

The stimulating effect on fruit growth was observed in BA treatment in 'Kordia' and 'Regina' while it was ineffective in 'Summit'. Fruits from trees treated with BA had the higher firmness compared to the control (Tab. 1). According to Zhang and Whiting [2011], synthetic cytokinins applied at cell division stage significantly increased the share of cherry fruits with mass ≥10 g, fruit firmness by 10–30% and soluble solids content, but caused a delay of exocarp coloration. BA exhibited a direct effect in stimulating pericarp cell division in apple, resulting in increased fruit size at harvest [Milić et al. 2017b].

GA_3 caused the significant increase in fruit weight by 8.3% in 'Kordia' only. The significantly higher firmness was detected in GA_3 treated fruits in 'Summit' and 'Kordia' compared to the control (Tab. 1). Among three gibberellic acid isomers (GA_1, GA_3 and GA_{4+7}), GA_3 at 200 mg L^{-1} applied during the cell division stage was the most effective and improved final fruit weight by 15% [Zhang and Whiting 2011]. Cline and Trought [2007] examined the mode of action of GA_3, and found that GA_3 increased cell division rate and cell elongation thus positively affected fruit size in sweet cherry, but the effects were cultivar related. The same authors found an increase in fruit firmness in GA_3 treated fruits as well.

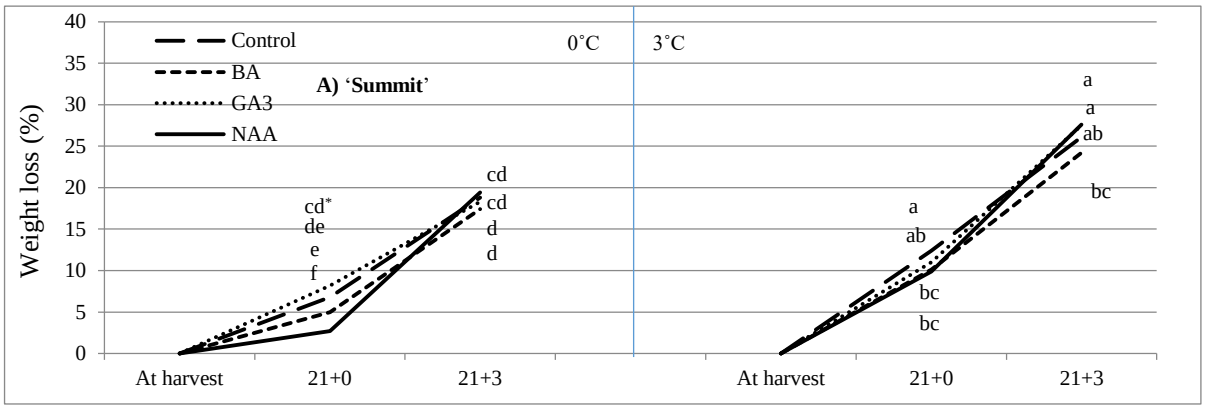
Weight loss during storage

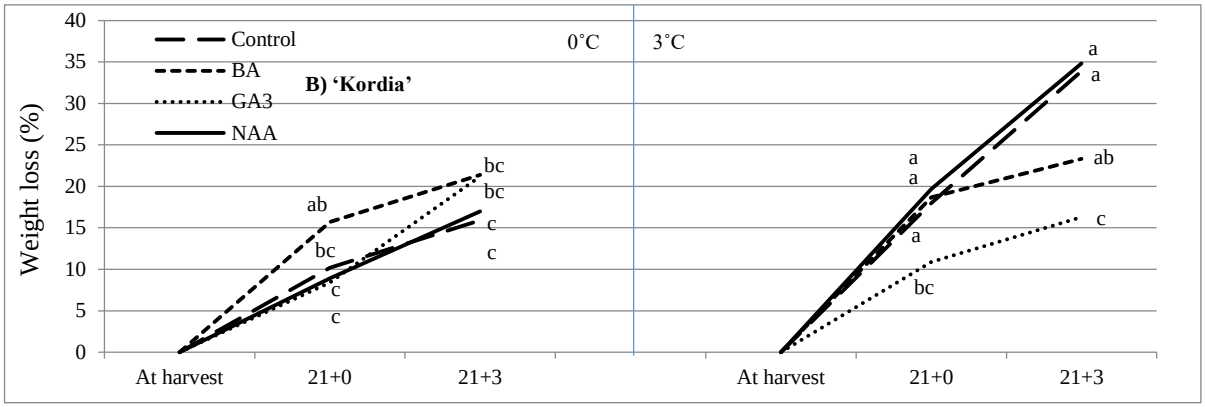
Weight loss of sweet cherry fruits after 21 days of storage in relation to pre-harvest bioregulator treatments is presented in Figure 1. In 'Summit', fruit weight loss after storage at 0°C, RH 90% and shelf life was smaller than at 3°C, RH 70%, for each of four treatments (Fig. 1a). The differences in fruit weight loss between two storage regimes were less pronounced in 'Kordia' and 'Regina'. In 'Kordia', a smaller weight loss at 0°C, RH 90% than at 3°C, RH 70% was detected in NAA and control treatment, while in 'Regina' in control treatment only. Weight loss during storage is mainly responsible for the degradation of cherry fruit quality and further increase in fruit susceptibility to fungal decay. Temperature regime is considered to be of high importance for good quality retention of fruits after harvest [Saltveit 2004] in a way that a higher temperature in NA storage induces a greater weight loss [Dziedzic et al. 2017]. A higher temperature increases transpiration rate in fruits, which further causes greater fruit weight reduction. On the other hand, an increased RH in storage reduces weight loss of sweet cherry fruits. Whitelock et al. [1994] stated that in peach fruit weight loss during storage period was related to water vapor pressure deficit and it can be controlled by lowering the temperature and increasing RH in storage. In the present research, pre-harvest treatments with GA_3 and BA diminished the effects of temperature and humidity during storage on fruit weight loss in 'Kordia' and 'Regina'.

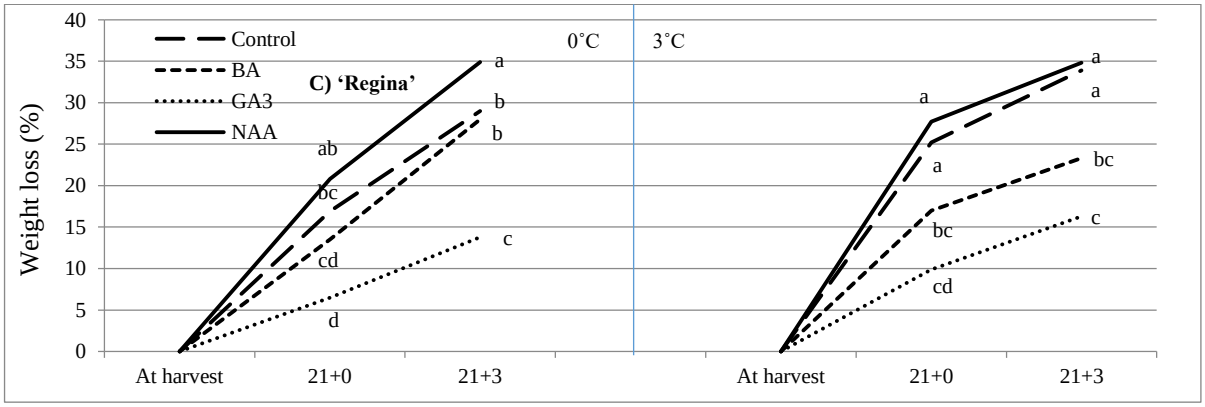
Weight loss of sweet cherry fruits during storage at 0°C, RH 90% was not affected by the bioregulator treatments in 'Summit' and 'Kordia' (Fig. 1a, b). Weight loss during storage at 0°C, RH 90% in 'Regina' was increased with NAA, while it was reduced in GA_3 treatment compared to the control (Fig. 1c). Althought pre-harvest GA_3 treatments increased fruit firmness at harvest, it did not significantly affect respiration rate or weight loss in sweet cherry cultivars during the storage at 0–1°C [Einhorn et al. 2013]. Most water transpires through the cuticle and its microcracks [Maguire et al. 1999]. Pre-harvest GA_3 application increased cuticle thickness, but the effects varied depending on a cultivar, which could result in different cultivar response to GA_3 regarding the weight loss [Demirsoy and Bilgener 2000]. In the present research, BA and GA_3 treatments significantly reduced weight loss during the storage at 3°C, RH 70%. Lowering the temperature and increasing humidity in storage, diminished the effects of bioregulator treatments on fruit weight loss during the storage and shelf life period.

SSC and TA at harvest and during storage

Although the differences were not always significant, in general SSC shows tendency to increase during storage at 3°C, RH 70% and shelf life period, while in most cases it was unaffected at 0°C, RH 90% (Tab. 2). However, some differences were observed regarding cultivar response to bioregulator treatments. In 'Summit' and 'Kordia', SSC increased significantly in fruits stored at 3°C, RH 70%, except for GA_3 treatment where it stayed unaffected by the end of the storage period and shelf life. On the other hand, in 'Regi-







*The means followed by the same letter do not differ significantly according to Duncan's multiple range test at $p < 0.05$ within the storage period for each cultivar

Fig. 1. Weight loss (%) at two storage regimes (0°C, RH 90% and 3°C, RH 70%) after 21 + 0 and 21 + 3 days in a) 'Summit', b) 'Kordia', c) 'Regina'

Table 2. SSC (%) of sweet cherry cultivars at harvest, after 21 + 0 and 21 + 3 under two different regimes (0°C, RH 90% and 3°C, RH 70%)

	Treatment	'Summit'		'Kordia'		'Regina'	
At harvest	control	16.8 $^{e–g}$		17.8 ^{d}		19.8 $^{d–j}$	
	BA	15.8 ^{g}		20.7 $^{b–d}$		18.2 $^{h–j}$	
	GA_3	18.4 $^{a–f}$		22.3 ^{a}		17.4 ^{j}	
	NAA	16.2 ^{fg}		19.7 $^{b–d}$		17.6 ^{ij}	
Storage conditions		0°C, RH 90%	3°C, RH 70%	0°C, RH 90%	3°C, RH 70%	0°C, RH 90%	3°C, RH 70%
21 + 0	control	17.4 $^{c–g}$	20. 3 ^{ab}	19.5 $^{b–d}$	22.1 ^{a}	20.0 $^{b–j}$	20.7 $^{a–h}$
	BA	18.0 $^{a–g}$	19.0 $^{a–e}$	20.5 $^{b–d}$	22.1 ^{a}	19.3 $^{e–j}$	21.1 $^{a–g}$
	GA_3	16.6 $^{e–g}$	17.7 $^{c–g}$	19.7 $^{b–d}$	21.4 $^{a–c}$	18.3 $^{g–j}$	20.4 $^{a–i}$
	NAA	17.1 $^{d–g}$	19.7 $^{a–d}$	21.4 $^{a–c}$	21.2 $^{a–c}$	21.8 $^{a–e}$	21.7 $^{a–f}$
21 + 3	control	18.7 $^{a–f}$	20.5 ^{a}	19.2 $^{b–d}$	22.5 ^{a}	20.0 $^{c–j}$	22.1 $^{a–e}$
	BA	17.1 $^{d–g}$	20.4 ^{a}	21.8 ^{ab}	22.8 ^{a}	19.8 $^{d–j}$	20.5 $^{a–i}$
	GA_3	19.1 $^{a–e}$	19.8 $^{a–c}$	22.2 ^{a}	22.4 ^{a}	18.8 $^{f–j}$	22.7 $^{a–c}$
	NAA	19.7 $^{a–d}$	20.3 ^{ab}	21.1 $^{a–c}$	22.4 ^{a}	19.2 $^{e–j}$	22.8 ^{ab}

The same letter do not differ significantly according to Duncan's multiple range test at $p < 0.05$ within a cultivar

Table 3. TA (%) of sweet cherry cultivars at harvest, after 21 + 0 and 21 + 3 under two different regimes (0°C, RH 90% and 3°C, RH 70%)

	Treatment	'Summit'		'Kordia'		'Regina'	
At harvest	control	0.42 ^{d*}		0.49 ^{de}		0.48 ^{c}	
	BA	0.43 ^{bc}		0.53 ^{c}		0.50 ^{b}	
	GA_3	0.43 ^{bc}		0.70 ^{a}		0.50 ^{b}	
	NAA	0.46 ^{a}		0.56 ^{b}		0.56 ^{a}	
Storage conditions		0°C, RH 90%	3°C, RH 70%	0°C, RH 90%	3°C, RH 70%	0°C, RH 90%	3°C, RH 70%
21 + 0	control	0.36 ^{h}	0.40 ^{de}	0.45 $^{f–h}$	0.37 ^{jk}	0.37 ^{fg}	0.37 ^{fg}
	BA	0.36 ^{h}	0.39 ^{ef}	0.38 ^{jk}	0.37 ^{jk}	0.38 ^{f}	0.49 ^{bc}
	GA_3	0.39 ^{ef}	0.41 ^{de}	0.37 ^{jk}	0.42 ^{ij}	0.34 ^{gh}	0.44 ^{d}
	NAA	0.41 ^{de}	0.41 ^{de}	0.44 $^{f–h}$	0.31 ^{e}	0.39 ^{e}	0.46 ^{cd}
21 + 3	control	0.31 ^{i}	0.35 ^{h}	0.42 ^{hi}	0.40 ^{ij}	0.34 ^{gh}	0.32 ^{ij}
	BA	0.32 ^{i}	0.37 ^{gh}	0.46 $^{e–g}$	0.41 ^{i}	0.39 ^{e}	0.31 ^{ij}
	GA_3	0.35 ^{h}	0.38 ^{fg}	0.47 ^{ef}	0.40 ^{ij}	0.29 ^{j}	0.37 ^{fg}
	NAA	0.36 ^{h}	0.37 ^{gh}	0.47 ^{ef}	0.42 ^{hi}	0.28 ^{j}	0.31 ^{ij}

The same letter do not differ significantly according to Duncan's multiple range test at $p < 0.05$ within a cultivar

Table 4. Causal agents of detected sweet cherry fruit rot (%) under two two different regimes (0°C, RH 90% and 3°C, RH 70%) after 21 + 3 days

Cultivar	Treatment	Causal agents of sweet cherry fruit rot (%) detected after NA storage					
		0°C, RH 90%			3°C, RH 70%		
		Monilinia spp.	*Botrytis cinerea*	*Alternaria* spp.	*Monilinia* spp.	*Botrytis cinerea*	*Alternaria* spp.
'Summit'	control	75	0	25	100	0	0
	BA	66.7	33.3	0	100	0	0
	GA_3	100	0	0	0	0	0
	NAA	100	0	0	80	0	20
'Kordia'	control	100	0	0	100	0	0
	BA	0	0	0	0	0	0
	GA_3	0	0	0	100	0	0
	NAA	100	0	0	0	0	0
'Regina'	control	75	25	0	100	0	0
	BA	100	0	0	100	0	0
	GA_3	75	0	25	100	0	0
	NAA	100	0	0	100	0	0

Table 5. p-values for ANOVA of the following experimental factors: cultivar, storage period, treatment and storage regime and their first order interactions

Factor	Weight (g)	SSC (%)	TA (%)	Rot occurrence (%)
Cultivar	0.000000	0.000000	0.000000	0.000000
Storage period	0.000000	0.000000	0.000000	–
Treatment	0.000000	0.976745	0.000000	0.000000
Storage regime	0.000000	0.000015	0.186703	0.000000
Cultivar × Storage period	0.000000	0.108740	0.000000	–
Cultivar × Treatment	0.000000	0.001543	0.000000	0.000000
Storage period × Treatment	0.001527	0.023548	0.000000	–
Cultivar × Storage regime	0.200695	0.567746	0.000000	0.000003
Storage period × Storage regime	0.000000	0.005202	0.005734	–
Treatment × Storage regime	0.327797	0.403935	0.000056	0.003202

Rot occurrence was measured after shelf life. Factor "storage period" not included in ANOVA for "rot occurrence

na' SSC did not increase in control treatment by the end of storage at 3°C, RH 70%. The increase in SSC in sweet cherry fruits is related to water loss during storage [Dziedzic et al. 2017] driven by a gradient of water vapor pressure. A higher temperature and lower humidity in NA storage induces a greater water loss, which, in the present research, resulted in the higher SSC increase in fruits stored at 3°C, RH 70% compared to 0°C, RH 90%.

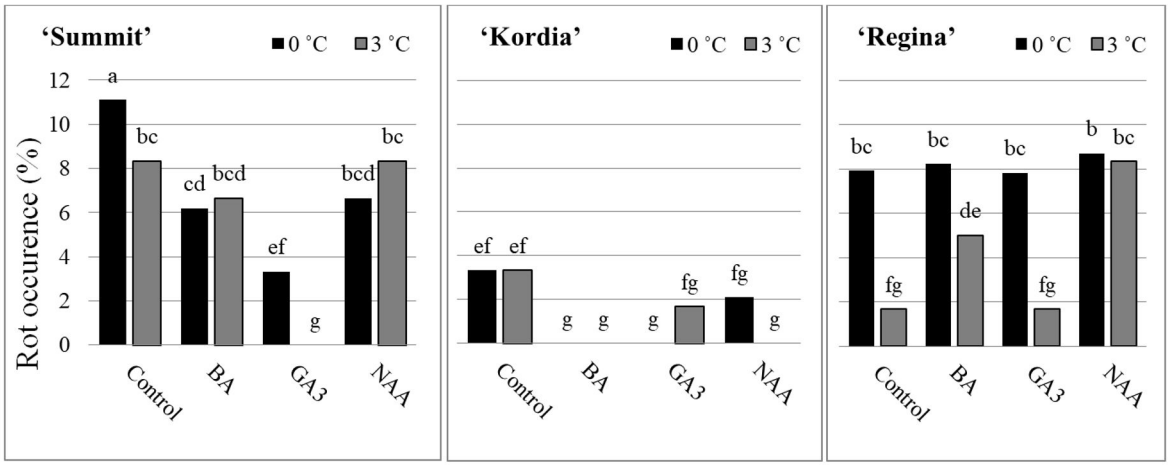
Previously reported effects of bioregulator treatments on SSC in sweet cherry fruits at harvest and after storage were very variable. According to calculated p values for the experimental factors, the effects of bioregulators on SSC in sweet cherry fruits at harvest and after storage were insignificant (Tab. 5). The similar was concluded by Zeman et al. [2013] who reported that GA3, NAA or their combination did not affect SCC of sweet cherry fruits. According to Canli et al. [2015], BA (50 ppm) increased SSC in fruits of '0900 Ziraat' at harvest, while $GA_{4/7}$ + BA (50 ppm) increased SSC at harvest and after NA storage. On the other hand, GA_3 can delay fruit maturation which can result in lower SSC in GA_3 treated fruits [Ozkan et al. 2016].

TA in sweet cherry fruits generally decreased during the cold storage both at 0°C, RH 90% and 3°C, RH 70%, and continued to decrease during 3 days shelf life (Tab. 3). The only exception was recorded in 'Kordia', where TA decrement ceased at shelf life regardless of the previous storage regime. TA decreases in fruits after harvest because organic acids are involved in respiration processes [Esti et al. 2002]. According to Dziedzic et al. [2016], the storage conditions significantly affected TA in fruits in a way that the higher TA was detected in fruits stored in CA storage at 2°C compared to fruits stored in NA storage at 8°C.

Bioregulator treatments increased acid content at harvest in three sweet cherry cultivars assessed (Tab. 3). Bioregulators had very variable, but significant effects on TA during the storage which depended on the cultivar (Tab. 5). Varietal differences in the response of fruits TA at harvest and after storage on bioregulator treatments were previously reported. Pre-harvest GA_3 application increased TA in fruits of 'Regina' and 'Sweetheart' at harvest while it was unaffected in '0900 Ziraat' [Ozkan et al. 2016]. However, considering other fruit quality parameters such as firmness, color, SSC, it was concluded that GA_3 treatments retarded fruit ripening in sweet cherry. On the other hand, GA_3 decreased TA in 'Lapins' at harvest, while after 4 weeks cold-storage it was unaffected compared to the control [Einhorn et al. 2013]. Moreover, respiration rates of fruits at harvest and after storage were not affected by GA_3 treatments, which might be the reason for diminishing the differences in TA among treatments after storage.

Fruit decay and rot occurrence during storage

Temperature regime and relative humidity in storage are important factors affecting decay of sweet cherry fruits. According to Bernalte et al. [1999], optimum storage temperature for sweet cherry is 0°C at RH 90–95%. Lowering fruit temperature immediately after harvest, results in firmer fruit with reduced decay after storage [Manganaris et al. 2007]. In the present research the highest sensitivity to fruit rot occurrence during the storage was recorded in 'Summit' (Fig. 2). According to Simon [2006] the cultivar sensitivity to fruits cracking has significant influence on fruit rot occurrence. Quero-García et al. [2017] also reported 'Summit' was the most sensitive cultivar compared to the other two. Dziedzic et al. [2016] reported higher disease occurrence on fruits stored in NA storage at 8°C in regard to fruits stored in NA at 0°C. In the present research, as shown in Figure 2, a higher occurrence of disease after storage and incubation at 20°C (21 + 3) was detected on fruits stored at 0°C, RH 90% compared to fruits stored at 3°C, RH 70% in control, in the case of 'Summit' and 'Regina', while for 'Kordia' no difference in rot occurrence was observed in relation to the storage temperature. The reason for differences registered for 'Summit' and 'Regina' might be a lower RH in NA storage at 3°C. High relative humidity in storage that is necessary for decreasing evaporation from fruits and peduncle may enhance the occurrence of fungal infection on fruits [Wani et al. 2014]. In 'Summit', BA, GA_3 and NAA caused a decrease in the occurrence of disease after 21 + 3 days at 0°C, RH 90% in comparison with control, while at 3°C, RH 70% only in treatment with GA_3 statistically significant decrease of disease occurrence was noticed. In 'Kordia' treatments with BA and GA_3 caused decrease of rot at 0°C, RH 90%, while at 3°C, RH 70% BA and NAA caused decrease of rot occurrence.



The same letter do not differ significantly according to Duncan's multiple range test at $p < 0.05$

Fig. 2. Rot occurrence (%) in two different regimes (0°C, RH 90% and 3°C, RH 70%) after 21 + 3 days in 'Summit', 'Kordia' and 'Regina'

Use of bioregulators did not result in decrease of rot in 'Regina' cultivar at 0°C, RH 90%, while at 3°C, RH 70% rot occurrence was significantly reduced in treatment with BA, while in treatment with NAA the occurrence of rot was favored and it was significantly higher compared to untreated control. Positive effect of BA and GA_3 might be related with fruits firmness. According to Andrews and Shulin [1995] GA_3 has positive influence on fruit firmness, reducing polygalacturonase and pectinmethylesterase enzyme activity, which degrade cell wall in sweet cherry fruits during storage. Salato et al. [2013] stated that fruit firmness is the main quality attribute of sweet cherry fruits and also one of the most important factors which have influence on disease occurrence during storage period. Similarly, Ghanni et al. [2011] found that pre-harvest treatments with calcium increased fruit firmness, and thus, occurrence of anthracnose and brown rot during storage was reduced. Up to now, there is no data about the impact of bioregulators applied during vegetation on fruit rot occurrence after storage, therefore these data could be an important base for the further testing.

According to data presented in Table 4 pathogens that caused rot of sweet cherry fruits in NA storage were *Monilinia* spp., *Botrytis cinerea* and *Alternaria* spp. The most frequently occurring pathogens were *Monilinia* spp., while *B. cinerea* and *Alternaria* spp. were registered on smaller number of fruits. In control on cultivars 'Summit' and 'Regina', it was noticed that *Monilinia* spp. occurred in lesser extent at 0°C, RH 90% compared to 3°C, RH 70%, where all rotten fruits were infected with *Monilinia*. It can be concluded that lower storage temperatures such as 0°C, inhibit development of *Monilinia* spp., which enables other causal agents with lower temperature requirements to cause fruit rot. Hrustić [2013] stated that 0°C *in vitro* conditions inhibited growth of *Monilinia* sp. isolates, and this is in agreement with findings in this paper. In 'Kordia', *Monilinia* spp. were causal agents of all registered rotten fruits regardless the storage temperature. Similarly, in 'Summit' in treatment with BA and in 'Regina' in treatment with GA_3, the lower occurrence of *Monilinia* spp. was observed. Therefore, it can be concluded that treatments with bioregulators have no effect on occurrence ratio of certain phytopathogenic fungi in the total number of rotten fruits, which primarily depends on the storage temperature, which is also in line with findings of Hrustić [2013].

Assuming that different experimental factors: cultivar, storage period, bioregulator treatment and storage regime simultaneously influenced fruit attributes, the significant interactions could be expected (Tab. 5). All main factors were significant for the average fruit weight, while the interactions "cultivar ×

storage regime" and "treatment × storage regime" were not. SSC was significantly affected by "cultivar", "storage period" and "storage regime", while the influence of "bioregulator treatment" was not significant. All main experimental factors and their interactions of first-order significantly influenced TA of fruits, except for the "storage regime". All experimental factors and their interactions were significant for fruit rot occurrence.

CONCLUSIONS

The study shows that the effects of bioregulators: BA, GA_3, and NAA on weight loss, SSC, TA and diseases caused by phytopathogenic fungi highly depended on varietal differences and on conditions during the storage. NAA was the most effective in increasing fruit weight at harvest, while, on the other hand, BA and GA_3 induced a higher firmness of fruits. A higher weight loss was recorded during the storage at 3°C, RH 70%, compared to fruits stored at 0°C RH 90%. BA and GA_3 reduced weight loss during the storage at 3°C, RH 70%. Lowering the temperature and increasing humidity in storage, diminished the effects of bioregulator treatments on fruit weight loss during the storage and shelf life period. Bioregulator treatments increased TA in fruits at harvest, while the effects on TA during storage were variable depending on the cultivar. 'Kordia' proved to be the most resistant cultivar to rot causal agents. Treatments with BA and GA_3 showed some inhibitory effect on disease development. *Monilinia* spp. was the most frequent disease of sweet cherry fruits in NA storage.

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