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Precision cane meristem management can influence productivity and fruit quality of floricane red raspberry cultivars

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Abstract: In Bosnia and Herzegovina, the hedgerow system is the main raspberry growing system, which has no clearly-defined standards regarding plant density and fruit-bearing potential per meter of hedgerow. This study evaluates the effect of precision cane meristem management in growing major floricane red raspberry cultivars in Bosnia and Herzegovina. During 2015 and 2016, in Willamette, Meeker, and Tulameen, grown under the hedgerow system, mixed buds were selected on fruiting laterals with the fruit-bearing potential of 80, 100, and 120 well-developed and well-positioned mixed buds per meter of hedgerow. High stable yields were recorded under the medium load of 100 buds per meter of hedgerow. Yield ranged from 22.6 t/ha to 24.9 t/ha in Meeker and from 17.7 t/ha to 24.5 t/ha in Tulameen. The yield variation over the experimental years was somewhat higher in Willamette (10.4–21.8 t/ha). Fruit size was largest under the 100-bud load per meter of hedgerow. The biochemical characteristics of the fruit, expressed through vitamin C, phenol, flavonoid, and anthocyanin contents, and the antioxidant capacity, indicated differences among cultivars and the effect of the experimental year. The load of 100 mixed buds well-positioned on canes per meter of hedgerow was the optimum load of fruit-bearing potential. The reduction in bud numbers per meter of hedgerow led to a significant decrease in fruit yield, with no changes in fruit quality. Conversely, the increase in the number of buds per meter of hedgerow resulted in a decline in fruit quality, while not adversely affecting fruit yield.

Key words: raspberry, cane management, cultivar, yield, quality

1. Introduction

Horticulture plants have been recognized for their human health benefits. They have a high content of nonnutritive, nutritive, and bioactive compounds, such as flavonoids, phenolics, anthocyanins, phenolic acids, and as well as nutritive compounds, such as sugars, essential oils, carotenoids, vitamins, and minerals. Bioactive compounds from horticulture plants have potent antioxidant, anticancer, and antimutagenic, etc., properties (Ercisli et al., 2003; Dogan et al., 2014; Alp et al., 2016).

Raspberry (*Rubus idaeus* L.) is of high economic importance for Bosnia and Herzegovina (Mićić et al., 2015; Alibabić et al., 2018) given its positive biological and agronomic characteristics (Zorenc et al., 2016). Its quality is evidenced by high levels of nutritionally valuable compounds, such as phenols, flavonoids, anthocyanins, and vitamin C (Dai and Mumper, 2010). Although raspberry is believed to have originated in Turkey (Ercisli, 2004), its high production levels are generally obtained outside the gene center of origin (Eyduran and Agagoglu, 2006) and its immediate surroundings. Apart from Serbia, among Balkan countries, as one of the world's leading raspberry producers, Bosnia and Herzegovina (B&H) is gaining importance in raspberry production in Europe. Importantly, raspberries in B&H are produced on small farms (0.3 ha on average), which are specific to the country. According to official data on raspberry production in B&H for the period of 2015 to 2016, raspberry acreage increased by 57% (1.682–2.647 ha) and total production increased by 63% (13.631–22.160 t). Nevertheless, this increase is accompanied by the fact that growers are generally prone to increasing raspberry acreage rather than upgrading growing technology, which very often reduces the cost-effectiveness of production. Insufficient knowledge of raspberry growth and development biology and the consequential partial control of major physiological processes through cultural and cane management practices are the most common causes of reduced yields. The specificity of the biennial cycle of development in floricane raspberry cultivars and the need for precision cane management, by hand (Nenadić, 1986) or by chemical methods (Poledica et al., 2012), are made

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even more complex by the characteristics and position of adventitious buds that form new canes (Mićić et al., 2015). Cane density and the number of well-developed mixed buds per cane and hence the cane density per meter of hedgerow are determinants of fruit yield and quality. Cultivars should receive proper treatment adapted to local growing conditions (Stanisavljević et al., 2002; Skrovankova et al., 2015) in accordance with the cultivar specificity. A large number of studies on new raspberry cultivars have mostly relied on evaluating their vegetative and generative characteristics (Leposavić et al., 2013; Andrianjaka-Camps et al., 2016; Orzel et al, 2016; Alibabić et al., 2018). Few studies have analyzed the need for an optimum production system or the use of new or adapted cultural and cane management practices (Palonen et al., 2008; Glišić et al., 2009; Poledica et al., 2012), which could make a substantial contribution to high regular yields. It is a common practice among raspberry growers in B&H to retain a large number of canes for increased yields, without taking care of the quality of the buds retained on the canes, their position, biological potential, or competitive relationships with primocanes developing in the current growing season. This research evaluated the effect of the reduction of fruit bearing potential on the number and position of mixed buds on raspberry canes to determine the optimum crop load for high yields of good-quality fruit. At the same time, the objective of the study was to determine the contents of secondary metabolites in different cultivars (Meeker, Tulameen, and Willamette) and assess their antioxidant activity. The research is of practical importance in terms of establishing optimum cane density and providing recommendations about pruning, i.e. cutting back canes and removing mixed buds at the base of the cane.

2. Material and methods

This research was conducted in eastern Bosnia and Herzegovina, in a 0.5 ha commercial orchard (Municipality of Bratunac, Bjelovac site, Lat: 44 9 17.33097, Long: 19 23 44.49325, Altitude 219–230 m). The cultivar structure in the orchard was as follows: Willamette (about 60%), Meeker (about 20%), and Tulameen (about 20%). The orchard was established in 2010 in a hedgerow growing system with 2 wires placed at 120 and 180 cm above ground, respectively. The canes were secured to the wires with plastic-coated ties after dormancy, when the cut-back treatment was made. The initial plant density was 2.2 × 0.20 m for Willamette, and 2.7 × 0.25 m for both Meeker and Tulameen. The row space (1.2 m wide) was maintained fallow, whereas the interrow space was a mixture of native grasses maintained as grass mulch by regular mowing. The analysis of the effect of modeling the fruit-bearing potential was made during 2015 and 2016. The experiment, with different fruit-bearing potentials, involved 2 treatments and the control. The control was a load of 120 mixed buds per meter of hedgerow, i.e. the density of 9 canes per meter of hedgerow, each with 15 vital, well-developed buds (corresponding to the load of canes in ordinary production practice, indicated as c_{120} in Tables 1–3). For the fruit-bearing potential, 2 methods of reduction were used: a) retaining 100 mixed buds per meter of hedgerow, i.e. 10 canes with 10 buds per cane (Treatment 1, medium fruit-bearing potential, indicated as t_{100} in Tables 1–3) and b) keeping 80 buds per meter of hedgerow, i.e. 8 canes with 10 buds per cane (Treatment 2, low fruit-bearing potential, indicated as t_{80} in Tables 1–3). The other buds were manually removed before the onset of the growing season, ensuring that the buds of highest quality, i.e. ones positioned in the middle portion of the cane, were retained, while removing those at the base and tip of the cane. Each treatment was laid out in a randomized block design with 5 m of hedgerow in 5 replications. All of the canes were cut back to the same height of 200 cm, the standard in ordinary production practice. The number of fruiting laterals, number of fruits, and yield per cane were determined. The yield per meter of hedgerow in 2015 was analyzed from 12 June to 26 July for Willamette, 19 June to 15 August for Meeker, and 21 June to 30 July for Tulameen. In 2016, yield evaluations were made on the following dates: 4 June–25 July for Willamette, 14 June–29 July for Meeker, and 14 June–4 August for Tulameen. For each combination and replication, 50 fruits were sampled at the initial commercial maturity stage for the determination of the fruit weight (g), fruit length (cm), and fruit width (cm). Subsamples of the fresh fruits were stored at –20 °C for further analysis of the phenolic compounds and antioxidant capacity for all of the cultivars in both experimental years under the medium fruit-bearing potential treatment (t_{2-100}). Fruit samples were homogenized in a blender, and the pH of the obtained juice was measured using a standardized pH meter (Hanna pH 211, Hanna Instruments, Cluj, Romania) at room temperature. Titratable acidity (TA) was determined by titration with a solution of 0.1 M NaOH to an end point of 8.1, and expressed as percent of malic acid (Đurić et al., 2015). Fruit extracts were prepared according to the procedure described by Tehrani et al. (2011) and were used for the determination of the total phenols and flavonoids. Total phenol content (TPC) was determined using the Folin–Ciocalteu (FC) spectrophotometric (UV-VIS, Shimadzu 1240 mini; Shimadzu Corporation, Kyoto, Japan) method (Singleton and Rosi, 1965), and the results were expressed as milligrams of gallic acid equivalent (GAE) per 100 g fresh weight. Total flavonoid content was determined via the spectrophotometric method using aluminum chloride, as described by Tehrani et al. (2011), and the results were expressed as milligrams of catechin equivalent (CE) per 100 g fresh weight. All of

Table 1. Numbers of fruiting laterals and fruits per cane.

Year	Cultivar	Treatment	No. of fruiting laterals per cane			No. of fruits per cane		
			X ± SD			X ± SD		
2015	Meeker	$t_{1\text{-}80}$	9.58	±	1.89	220.10	±	83.58
		$t_{2\text{-}100}$	9.26	±	1.69	248.70	±	62.96
		$c_{\text{-}120}$	10.82	±	4.23	213.64	±	87.88
	Tulameen	$t_{1\text{-}80}$	8.70	±	2.32	184.30	±	47.01
		$t_{2\text{-}100}$	8.16	±	2.38	153.76	±	58.81
		$c_{\text{-}120}$	9.40	±	5.01	179.89	±	82.41
	Willamette	$t_{1\text{-}80}$	10.35	±	1.72	194.20	±	59.26
		$t_{2\text{-}100}$	10.20	±	1.57	172.45	±	57.02
		$c_{\text{-}120}$	14.89	±	5.63	223.93	±	90.93
2016	Meeker	$t_{1\text{-}80}$	8.93	±	0.94	167.63	±	33.44
		$t_{2\text{-}100}$	8.94	±	0.96	164.54	±	35.62
		$c_{\text{-}120}$	11.58	±	2.15	205.77	±	45.05
	Tulameen	$t_{1\text{-}80}$	8.98	±	1.10	202.10	±	31.47
		$t_{2\text{-}100}$	8.86	±	1.63	205.38	±	53.75
		$c_{\text{-}120}$	9.58	±	2.99	179.73	±	72.23
	Willamette	$t_{1\text{-}80}$	9.05	±	1.24	114.78	±	19.88
		$t_{2\text{-}100}$	8.95	±	0.96	107.65	±	19.39
		$c_{\text{-}120}$	12.69	±	3.74	158.21	±	52.46
F_{year}, LSD_{year}			-			-		
$F_{cultivar}$, $LSD_{cultivar}$			-			-		
$F_{density}$, $LSD_{density}$			-			-		
F_{Y*C}, LSD_{Y*C}			-			F = 10.3**, LSD = 14.2		
$F_{Y\times T}$, $LSD_{Y\times T}$			-			$F = 0.17^{ns}$		
$F_{C\times T}$, $LSD_{C\times T}$			-			F = 11.8**, LSD = 18.4		
$F_{Y\times C\times D}$, $LSD_{Y\times C\times D}$			F = 6.9**, LSD = 1.2			$F = 1.3^{ns}$		

* significant, ** highly significant, ns nonsignificant

the tests were performed in triplicate. The free radical scavenging ability of the fruit homogenate was measured using the method of Đurić et al. (2015), which includes quenching stable free 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals, and the antioxidant activity was expressed as the effective concentration (EC_{50}, mg fresh weight/mL), i.e. the concentration at which 50% of DPPH radicals were quenched. The standard AOAC (1990) 2,6-dichlorophenolindophenol method was used for the vitamin C content determination. The dry matter content was determined by drying at a temperature of 105 °C to a constant weight according to the standard AOAC (1990) method. The sample extraction and total anthocyanin content (TAC), which was quantified by the pH differential method, were performed using the procedure described by Natić et al. (2015). Measurements were done in triplicate and the results were expressed as milligrams of cyanidin-3-O-glucoside equivalents (C3GE) per 100 g frozen weight. Data were analyzed through general linear models with appropriate post hoc testing in cases of significant differences. The total effect of the applied treatments on the tested biochemical characteristics was presented and analyzed using principal components analysis. Statistical analysis and the graphical presentation were performed using IBM SPSS 22 statistical software.

3. Results

The mean monthly air temperatures during harvest were somewhat higher in 2016 than in 2015, as shown in Figure 1. The total precipitation in 2016 was 1285.8 mm, and it

Table 2. Fruit characteristics.

Year	Cultivar	Treatment	Fruit length (mm)			Fruit width (mm)			Fruit weight (g)		
			X ± SD			X ± SD			X ± SD		
2015	Meeker	$t_{1\text{-}80}$	23.31	±	1.38	21.93	±	1.21	4.46	±	0.49
		$t_{2\text{-}100}$	23.44	±	1.65	22.39	±	1.73	4.56	±	0.64
		$c_{\text{-}120}$	22.06	±	1.86	21.71	±	1.48	4.27	±	0.50
	Tulameen	$t_{1\text{-}80}$	26.65	±	1.90	23.34	±	1.12	5.50	±	0.51
		$t_{2\text{-}100}$	27.80	±	1.21	24.28	±	1.14	5.76	±	0.39
		$c_{\text{-}120}$	26.65	±	1.32	23.34	±	1.70	5.50	±	0.59
	Willamette	$t_{1\text{-}80}$	25.01	±	2.03	23.21	±	1.05	5.03	±	0.72
		$t_{2\text{-}100}$	27.48	±	1.73	25.39	±	0.94	5.49	±	0.43
		$c_{\text{-}120}$	26.31	±	2.03	24.57	±	1.05	5.10	±	0.72
2016	Meeker	$t_{1\text{-}80}$	21.35	±	1.32	19.99	±	1.63	4.08	±	0.57
		$t_{2\text{-}100}$	21.84	±	1.61	20.43	±	1.69	4.22	±	0.66
		$c_{\text{-}120}$	21.22	±	2.12	19.61	±	1.73	3.93	±	0.93
	Tulameen	$t_{1\text{-}80}$	27.32	±	1.26	21.89	±	1.17	5.68	±	0.40
		$t_{2\text{-}100}$	26.67	±	1.63	22.18	±	1.40	5.71	±	0.48
		$c_{\text{-}120}$	26.00	±	1.54	21.81	±	1.25	5.43	±	0.50
	Willamette	$t_{1\text{-}80}$	21.39	±	1.16	19.01	±	1.87	3.70	±	0.67
		$t_{2\text{-}100}$	22.30	±	2.06	19.68	±	1.78	3.79	±	0.88
		$c_{\text{-}120}$	20.38	±	2.13	18.70	±	1.45	3.21	±	0.72
F_{year}, LSD_{year}			-			-			-		
$F_{cultivar}$, $LSD_{cultivar}$			-			-			-		
$F_{density}$, $LSD_{density}$			-			-			F = 15**, LSD = 0.13		
$F_{Y \times C}$, $LSD_{Y \times C}$			-			F = 80**, LSD = 0.41			F = 54**, LSD = 0.18		
$F_{Y \times T}$, $LSD_{Y \times T}$			-			F = 3.6*, LSD = 0.41			$F = 0.1^{ns}$		
$F_{C \times T}$, $LSD_{C \times T}$			-			F = 2.4*, LSD = 0.51			$F = 0.6^{ns}$		
$F_{Y \times C \times D}$, $LSD_{Y \times C \times D}$			F = 4.5**, LSD = 0.86			$F=1.9^{ns}$			$F = 0.9^{ns}$		

* significant, ** highly significant, ^{ns} nonsignificant

was higher than in 2015 (1049.4 mm), particularly during the summer months (July and August) and, to some extent, in the first part of the growing season.

The analysis of the number of fruiting laterals per primary cane in the studied raspberry cultivars is shown in Table 1, which indicated a highly statistically significant interaction between the treatment and cultivar (P < 0.001), without a significant effect of the year of study (P = 0.129). Namely, in Meeker, the control yielded highly significantly (P < 0.001) more lateral branching per primary cane than the 2 treatments. In Tulameen, significantly more lateral branching was observed in the control than with Treatment 2 (P = 0.024). In Tulameen, Treatment 1 did not yield results that significantly differed from either the control or Treatment 2 (P > 0.199). In Willamette, the control yielded significantly (P < 0.001) more lateral branching on the primary canes than the 2 treatments. The analysis of the number of fruits showed a highly significant (P < 0.001) interaction of all of the studied factors. In Meeker, in 2015, Treatment 2 resulted in significantly (P = 0.017) more fruits than the control. In 2016, the control yielded a highly significant (P < 0.001) increase in the number of fruits than the 2 treatments. In Tulameen, in 2015, Treatment 2 resulted in a significantly (P < 0.043) lower number of fruits than Treatment 1 and the control. In 2016, the number of fruits was significantly higher with Treatments 1 and 2 than in the control (P < 0.020). In Willamette, in both years, the control yielded a significantly (P < 0.05) higher number of fruits compared to the 2 treatments.

Table 3. Yield per cane (g), per meter of hedgerow (kg) and per ha (t).

Year	Cultivar	Density	Yield per cane	Yield per meter of hedgerow	Yield per ha
			(g)	(g)	(t)
2015	Meeker	$t_{1\text{-}80}$	740.2 ± 26.7	5921.7	18.9
		$t_{2\text{-}100}$	765.5 ± 36.4	7655.4	24.5
		$c_{\text{-}120}$	729.8 ± 23.3	6568.1	21.1
	Tulameen	$t_{1\text{-}80}$	780.2 ± 39.7	6241.8	19.9
		$t_{2\text{-}100}$	708.5 ± 21.9	7085.3	22.6
		$c_{\text{-}120}$	791.5 ± 22.7	7123.7	22.8
	Willamette	$t_{1\text{-}80}$	735.2 ± 28.5	5881.4	18.8
		$t_{2\text{-}100}$	745.6 ± 21.2	7455.7	21.8
		$c_{\text{-}120}$	725.1 ± 23.1	6526.1	20.8
2016	Meeker	$t_{1\text{-}80}$	547.1 ± 18.6	4377.2	14.0
		$t_{2\text{-}100}$	555.5 ± 19.1	5554.9	17.7
		$c_{\text{-}120}$	646.9 ± 25.2	5822.5	18.6
	Tulameen	$t_{1\text{-}80}$	820.2 ± 34.2	6561.8	20.9
		$t_{2\text{-}100}$	780.1 ± 31.6	7801.0	24.9
		$c_{\text{-}120}$	760.3 ± 32.5	6842.5	21.8
	Willamette	$t_{1\text{-}80}$	339.8 ± 13.2	2718.1	8.7
		$t_{2\text{-}100}$	326.4 ± 17.6	3263.9	10.4
		$c_{\text{-}120}$	406.3 ± 15.3	3656.5	11.7

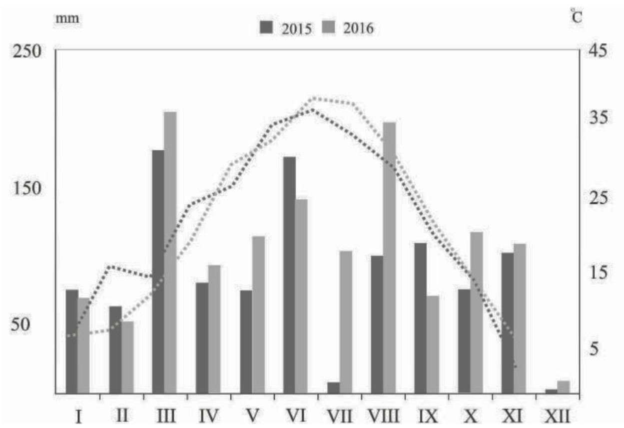

Figure 1. Mean monthly air temperatures and total precipitation for the experimental site.

Analysis of the fruit weight, as shown in Table 2, revealed no significant interaction between the studied factors regarding the treatment effects ($P > 0.112$). The heaviest fruits were produced with Treatment 2, which resulted in significantly higher fruit weight ($P = 0.004$) compared to Treatment 1.

The control yielded highly significantly ($P < 0.009$) smaller fruits than the 2 treatments. The analysis of fruit length and fruit width revealed highly significant ($P < 0.001$) and significant ($P < 0.048$) interactions of the studied factors, respectively. The yield per cane in the tested cultivars, as shown in Table 3, was rather uniform in 2015, whereas it was significantly higher in Tulameen than in Meeker and, particularly, Willamette, in 2016. The yield per meter of hedgerow and yield per unit area (ha) were dependent on the fruit-bearing potential of the canes, as well as the number of canes per meter of hedgerow and cane density. Yields were somewhat lower in Willamette in 2016.

The analysis of the phenols, flavonoids, and anthocyanins, as shown in Table 4, revealed a highly significant interaction of the studied factors ($P < 0.01$), indicating different cultivar responses in the different years of the study. The highest phenol, flavonoid, and anthocyanin contents were consistently measured in Meeker and Willamette, while Tulameen had the lowest levels. The opposite was found for antioxidant activity, expressed as EC_{50} (Table 3), in 2016, while in 2015, the cultivars followed the same pattern for EC_{50} as for the other biochemical characteristics.

Analysis of the titratable acidity, pH, dry matter, and vitamin C content, as shown in Table 5, indicated a highly significant ($P < 0.01$) interaction between the studied factors for vitamin C and titratable acidity, whereas the dry matter content was highly-significantly affected by the year and cultivar, with no significant interaction. There was no significant difference in the pH values. Highly significant vitamin C content was determined in Meeker and Willamette, for both years. The dry matter content was significantly higher in 2016, and highly-significant in Meeker. The highest acidity was measured in Tulameen and Willamette in 2016. These cultivars were also more acidic in 2015.

The principal components analysis presented in Figures 2 and 3 showed 2 distinct groups of cultivars along the second component, with the year of study as the grouping factor.

Acidity, dry matter content, pH, and vitamin C differed consistently between the years. Namely, in 2016, there was an increase in dry matter content, acidity, and vitamin C, and a decrease in pH, compared to 2015. The cultivars were also separated into groups along the first principal component. In both years, Tulameen was grouped separately from Meeker and Willamette. Generally in both years, Tulameen had lower flavonoid, phenol, anthocyanin, and vitamin C values. The grouping of

Table 4. Phenols, flavonoids, anthocyanins, and EC_{50} in the fruit of the analyzed cultivars.

Year	Cultivar	Phenols mg GAE/100 g fresh weight			Flavonoids mg CE/100 g fresh weight			Anthocyanins mg C3GE/100 g frozen weight			EC_{50} mg /mL
		X ± SD			X ± SD			X ± SD			X
2015	Meeker	2066.17	±	56.095	157.61	±	2.699	8.74	±	0.065	4.31
	Tulameen	1578.66	±	29.758	116.79	±	2.56	6.30	±	0.042	6.45
	Willamette	2254.11	±	34.517	204.42	±	1.645	11.63	±	0.040	4.92
2016	Meeker	2301.86	±	34.437	187.87	±	2.915	6.96	±	0.040	5.12
	Tulameen	1624.91	±	19.401	160.45	±	2.05	6.59	±	0.060	3.83
	Willamette	2102.79	±	41.758	165.49	±	10.104	8.99	±	0.734	4.62
F_{year}, LSD_{year}		-			-				-		-
$F_{cultivar}$, $LSD_{cultivar}$			-		-				-		-
$F_{interaction}$, $LSD_{inter.}$		F = 39.5**, LSD = 61.5			F = 134**, LSD = 7.6			F = 250**, LSD = 0.6			-

* significant, ** highly significant, ^{ns} nonsignificant

Table 5. Vitamin C, dry matter (DM), titratable aciditity (TA), and pH in the fruit of the analyzed cultivars.

Year	Cultivar	Vitamin C mg/100 g fresh weight			DM %			TA %			pH		
		X ± SD			X ± SD			X ± SD			X ± SD		
2015	Meeker	32.25	±	4.886	15.46	±	0.19	1.26	±	0.006	3.34	±	0.176
	Tulameen	30.12	±	1.846	14.80	±	0.284	1.46	±	0.006	3.19	±	0.142
	Willamette	36.52	±	1.846	14.12	±	0.183	1.80	±	0.006	3.16	±	0.01
2016	Meeker	47.18	±	3.199	17.45	±	0.376	1.69	±	0.006	3.16	±	0.047
	Tulameen	24.79	±	3.198	16.07	±	0.373	2.04	±	0.006	3.10	±	0.124
	Willamette	39.72	±	4.885	15.27	±	0.562	2.00	±	0.075	3.16	±	0.093
F_{year}, LSD_{year}		-			F = 78**				-		$F = 2.82^{ns}$		
$F_{cultivar}$, $LSD_{cultivar}$			-		F = 37**, LSD = 0.4				-		$F = 1.59^{ns}$		
$F_{interaction}$, $LSD_{inter.}$		F = 12**, LSD = 0.94			$F = 2.53^{ns}$			F = 55**, LSD = 0.5			$F = 1.01^{ns}$		

*significant, ** highly significant, ^{ns} nonsignificant

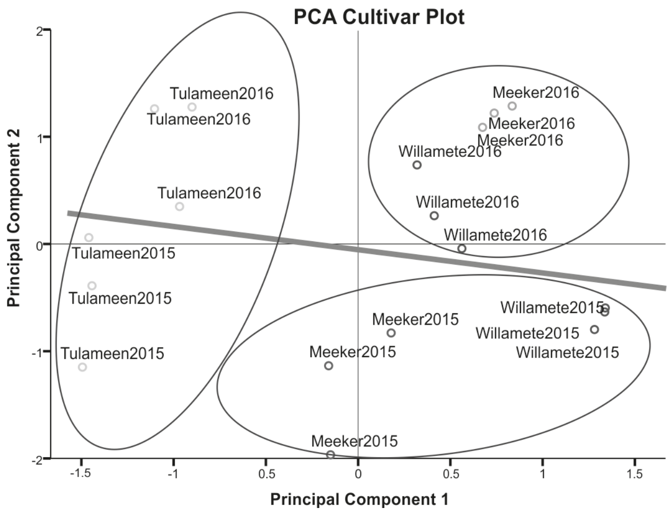

Figure 2. Principal components analysis (cultivar plot) of major biochemical characteristics of the fruit.

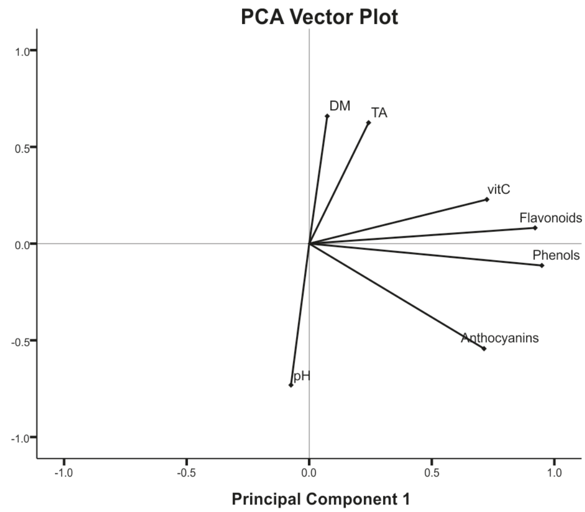

Figure 3. Principal components analysis (vector plot) of major biochemical characteristics of the fruit.

Meeker and Willamette in 2015 and 2016 was also notable. This grouping was along the second principal component, as a subgroup, with respect to years, as described above, and can be attributed to the influence of the year of study.

4. Discussion

Cultural and cane management practices in intensive raspberry orchards largely determine the quality of mixed buds that form fruiting laterals. The number of fruiting laterals per cane showed the high vitality and productivity of the retained buds, particularly when the number of buds was reduced to 10 buds per cane (Treatments 1 and 2). In 2015, in Treatments 1 and 2, each with 10 buds, Willamette produced a total of 10.35 and 10.20 fruiting laterals, respectively, as the result of activation of the bottom (secondary) serial bud on the node. During the research, all of the secondary fruiting laterals were recorded (data not shown); however, due to their low percent presence, they were not separately presented. The high percentage of fruiting lateral formation and secondary bud activation confirmed the importance and effect of the reduction of the number of buds per cane. The number of fruiting laterals is directly related to the length of the retained cane (Glišić et al., 2009; Poledica et al., 2012), although not always proportional. The increase in cane length (Glišić et al., 2009) is justified if it is accompanied by an increase in the number of high-quality mixed buds and, hence, the number of fruiting laterals. In ordinary production practice, buds in the bottom zone of the cane (below 50–60 cm) are quite often poorly differentiated or do not produce desired yields due to shade. The number of fruits per cane is directly associated with the number of fruiting laterals (Poledica et al., 2012), regardless of the cultivar specificity. The best fruit characteristics were obtained with Treatment 2, with a load of 100 buds, whereas both an increase and a decrease in the number of buds led to a reduction in fruit dimensions. The present results are consistent with the findings of studies conducted in regions with a long tradition of raspberry production (Glišić et al., 2009; Poledica et al., 2012), but are significantly higher than those of some other reports (Leposavić et al., 2013; Alibabić et al., 2018; Orzel et al., 2016). These differences were particularly pronounced in Willamette, in 2015, when the reduction in the fruit-bearing potential led to a significant increase in fruit size, which was not the case in 2016. This confirmed the fact that Willamette exhibits a very good response to optimum growing conditions (Stanisavljević, 2002), which opens up the possibility of modifying the existing production technology. Relatively large fruits were obtained in Meeker and, particularly, in Tulameen in both years. Precision cane management can contribute to achieving high fruit quality, not only for frozen raspberries, but also for the fresh market. This is of particular importance for Tulameen fruits, which are prone to an irreversible color change during freezing (personal communication with cold-storage specialists). Red raspberries are highly regarded for their antioxidant compounds, such as phenols, flavonoids, anthocyanins, and vitamin C. Their antioxidant activity is linked to their anticancer properties and the ability to prevent other oxidative stress-related diseases, such as inflammation and cardiovascular diseases (Andrianjaka-Camps et al., 2016). Consuming fresh, rather than processed, raspberries is recommended, since processing conditions, such as high temperatures, affect the content of secondary metabolites (Oancea and Calin, 2016). All 3 cultivars in both experimental years (Table 3) had extremely high total phenolic contents (1578.66–2301.86 mg GAE/100 g fresh weight), which is a result that has rarely been recorded in the literature (Pantelidis et al., 2007; De Ancos et al., 2000; Poledica et al., 2012; Orzel et al., 2016). Literature values for TPC are generally up to 500 mg GAE/100 g fresh weight (Milivojević et al., 2011; Alibabić et al., 2018). Many studies have shown that fruit characteristics are influenced by factors such as climate conditions, altitude, soil characteristics, ripeness at harvest time, irrigation and other cultural practices, and cultivar characteristics, which explain differences across experiments (Milivojević et al., 2011; Leposavić et al., 2013; Natić et al., 2015; Andrianjaka-Camps et al., 2016; Alibabić et al., 2018). The vitamin C content ranged from 24.79 to 47.18 mg/100 g fresh weight , and was comparable to the values in the literature (Poledica et al., 2012; Alibabić et al., 2018). The total flavonoid content, (116.79 to 204.42 mg CE/100 g fresh weight) compared to raspberries in Turkey (Sariburin et al., 2010), Brasil (Rios de Souza et al., 2014), and Serbia (Cetojević-Simin et al., 2015), was in the more than average range. However, interestingly, the total monomeric anthocyanin content was lower than values reported elsewhere (6.30 to 11.63 mg C3GE/100 g frozen weight) (Poledica et al., 2012; Alibabić et al., 2018). The dry matter content was higher in Meeker and Tulameen than in Willamette, in both experimental years, which is in accordance with the findings of Leposavić et al. (2013). Higher dry matter contents were obtained in 2016 for all of the cultivars, probably as the result of higher air temperatures in that year. All 3 cultivars had a narrow pH range in their fruit juice (3.1–3.34) and TA in the range of 1.26%–2.04%, which is consistent with the literature values (Milivojević et al., 2011; Poledica et al., 2012; Alibabić et al., 2018). Since the vitamin C and flavonoid contents were average and the TAC was even lower than in the literature, it can be assumed that the excellent antioxidant activity (EC_{50} in the range of 3.83–6.45 mg fresh weight/mL) mostly depended on high TPC.

In conclusion, precision cane meristem management, which is used to regulate fruit-bearing potential in floricane raspberry cultivars, affects their fruit characteristics and total yield. Reducing the number of mixed buds per meter of hedgerow to below 100 (80 buds) led to a substantial decline in crop yield, while increasing the number of buds to 120 did not result in substantial yield increases, but it did affect the fruit characteristics, given the more pronounced competitiveness. Willamette showed variations in these parameters. All of the tested cultivars had very high total phenol contents, which was strongly correlated with the excellent antioxidant activity expressed as the ability to quench free stable DPPH radicals. Therefore, the fruits of these cultivars are highly recommended for consumption, considering the well-known health benefits of phenolics and other antioxidant compounds. The results justified the use of precision cane management practices in raspberry orchards, particularly on small acreage. Regulating the fruit-bearing potential, vigor can have a positive effect on cultural practices used in the orchard (such as pest and disease management). Introducing new or old cultivars into new production areas calls for optimum cane management practices in accordance with growing conditions.

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