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Full Length Research Paper

Estimation of fruit weight by cane traits for various raspberries (*Rubus ideaus* L.) cultivars

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Raspberries are an important commercial fruit crop, widely grown in all temperate regions of the world. The raspberries contain significant amounts of polyphenol antioxidants such as anthocyanin pigments linked to potential health protection against several human diseases. The aim of this study was to estimate fruit weight by their cane traits (the number of canes, cane height, cane diameter, and cane yield) for Aksu Red, Canby, Heritage I, Heritage II, Holland Dwarf, Nuburg, Rubin, Summit, Tulameen, and Willamette cultivars grown in Central Anatolia region during 2002 - 2006. For this aim, average fruit weight (dependent variable) for each cultivar was estimated by independent variables such as the number of cane, cane height, cane diameter, and cane yield using Multiple Regression Analysis (MRA). The results clearly show that cultivars having the best fit (giving the best R^2 values and the lowest RMSE) in MRA were: Holland Dwarf (99.64%), followed by Heritage I (99.06%), Summit (98.6%) Aksu Red (92.82%), Willamette (92.68%), Heritage I (90.46%), Rubin (90.28%) and Canby (85.45%). Multiple Regression Modeling gave good results for these cultivars. However, R2 values of these cultivars were found higher (better fit) than those of Nuburg and Tulameen cultivars. It was concluded that the number of canes had significant negative effect on fruit weights of Heritage ($P < 0.05$) and Summit ($P < 0.001$) cultivars, but significant positive effect on only fruit weight of Rubin cultivar ($P < 0.05$). Cane height had significant positive effect on fruit weights of Aksu Red ($P < 0.001$), and Summit ($P < 0.001$) cultivars, while it had significant negative effect on fruit weights of Canby ($P < 0.05$) and Heritage I ($P < 0.05$). Cane diameter had significant positive effect on fruit weights of Aksu Red ($P < 0.001$), Heritage I ($P < 0.001$), and Tulameen ($P < 0.05$) cultivars. Cane yield had significant positive effect on fruit weights of Canby ($P < 0.05$), Heritage I ($P < 0.001$), Heritage II ($P < 0.05$), Holland Dwarf ($P < 0.001$), Summit ($P<0.001$) and Willamette ($P < 0.01$) cultivars, but significant negative effect on only fruit weight of Aksu Red cultivar ($P < 0.01$). The effects of cultivar, year, and cultivar by year interaction for fruit weight and all cane traits were statistically significant ($P < 0.001$). As a result, cane traits with the positive and negative effect on fruit weight for each cultivar might provide valuable clues for breeding proposes to improve fruit weight.

Key words: Raspberry, cane traits, fruit weight estimation, multiple regression analysis.

INTRODUCTION

The raspberries are the edible fruit of a number of plant species in the subgenus *Idaeobatus* of the genus *Rubus*. They are an important commercial fruit crop, widely grown in all temperate regions of the world. Many of the most crucial modern commercial red raspberry cultivars derive from hybrids between *Rubus idaeus* and *Rubus strigosus.* The black raspberry, *Rubus occidentalis*, is also rarely grown in the United States, providing fresh and frozen fruit along with jams, preserves, and other products (Agaoglu and Eyduran, 2006). Purple-fruited raspberries have been produced by horticultural hybridization of red and black raspberries, and have also been found in the wild in a few places where the American red and the black raspberries both grow in nature. Raspberries may be classified as summer- bearing (floricane

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Table 1. Monthly temperature and preciption in each year for Ankara (Ayaş) ecology.

Year		Month												
		Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Total**
2002	Precip. (mm)	39.6	9.3	23.8	102.7	29.6	41.9	42.9	12.2	31.7	25	41.3	29	429
	Temp. (°C)	-3.3	4.9	9.4	11.6	17.7	22.1	25.8	23.5	19.6	14.2	7.8	-0.2	12.8
2003	Precip. (mm)	51.6	43.7	6.9	61.7	27.3	17.7	7	39.1	1.1	65	0	0	321.1
	Temp. (°C)	5.6	0.6	4.2	10.7	20.6	24.1	24.9	25.8	19.3	14.9	8.1	2.5	13.4
2004	Precip. (mm)	77.9	20.1	39.5	37.3	18.6	25.8	4	22.3	9.3	44.2	22.9	0	321.9
	Temp. (°C)	1.2	2.3	7.8	12.7	17.1	21.4	25.7	24	20.9	15.5	7.8	2.7	13.3
2005	Precip. (mm)	29.7	48.2	68.4	62.7	27.5	47.6	18.7	1.8	4.8	15.9	43.9	17	386.2
	Temp. (°C)	3.6	3	6.8	12.5	17.6	20.9	26.3	26.6	20.3	12.2	7.1	3.6	13.4
2006	Precip. (mm)	60.9	84.7	43	14.1	13.3	9.2	39.1	0.3	82.8	19.9	17.5	1.8	386.6
	Temp. (°C)	-0.8	-0.4	8.1	14.3	18.1	23.1	24.7	28.7	19.5	14.9	6.3	1.3	13.2

State Meteorology Instute, Ankara 2006.

fruiting) or everbearing (fallbearing). Summer-bearing cultivars produce one crop in early summer (primocane), while everbearing cultivars can produce up to two crops a year; the first crop is being produced in the summer (floricane) and the second crop in the fall (primocane) (Gercekcioglu, 2008).

Raspberries include significant amounts of polyphenol antioxidants such as anthocyanin pigments associated to likely health protection against numerous human diseases. Preliminary medical research shows likely benefit of regularly consuming raspberries against inflammation, pain, cancer, cardiovascular disease, diabetes, allergies, age-related cognitive decline, and degeneration of eyesight with ageing. The leaves can be used fresh or dried in herbal and medicinal teas.

Several studies were conducted to improve various raspberry cultivars for breeding proposes (Finn et al., 2001a; Finn et al., 2001b; Finn et al., 2004; Kempler et al., 2005; Moore and Finn, 2007; Kempler et al., 2007). Numerous authors have studied adaptation of various raspberry cultivars in different locations (Jennings et al., 1990; Daubeny and Robertson, 1991; Cangi and İslam, 2003; Gercekcioglu et al., 2003; Kaplan et al., 2003; Kurt et al., 2003; Eyduran and Agaoglu, 2006; Eyduran et al., 2006; Atila et al., 2006; Eyduran et al., 2007; Gercekcioglu, 2008). However, there was no published information on estimation of fruit weight (g/berry) by cane traits of raspberry cultivars. Therefore, we aim to estimate average fruit weight (g/berry) by cane traits (number of canes, cane length, cane diameter, yield per plant) for each cultivar and determine the cane trait(s) with the positive and negative effect among these traits on fruit weight for different raspberry cultivars grown in Central Anatolia region for breeding proposes.

MATERIALS AND METHODS

The experiment was conducted using ten raspberry cultivars; Aksu Red, Canby, Heritage I, Heritage II, Holland Dwarf, Nuburg, Rubin, Summit, Tulameen, and Willamette Cultivars grown in Central Anatolia region during 2002 - 2006 grown in Central Anatolia (Ayaş Research and Application Farm of the Faculty of Agriculture, University of Ankara) during 2002 - 06, located at 32°52′ north, 39°56′ east. Its summers are hot and dry, but winters are cold and wet (Table 1).

The soil of experimental area is characterized by 1.4% total soil organic matter, 0.07% total salts, 56% soil saturation percentage, 7.5% lime ($CaCO_3$), 51.3 kg ha^{-1} phosphorus (P_2O_5), 1409.8 kg ha^{-1} potassium (K_2O) with soil pH of 7.2 in distilled water (1.5 v/v).

Agronomic observations were recorded for fruit weight, total acid, yield per plant, cane length, cane diameter of these raspberry cultivars. Two rows of each shrub plants set at 1.0 x 2.0 m spacing using randomized complete design. Raspberry was harvested in July during each year. Raspberries were weighed as fresh fruit; average fruit weights were calculated from 50-fruits sampled randomly from each of three plots of each cultivar. Number of canes, cane length, cane diameter, yield per plant, and fruit weight were determined as described by Eyduran et al. (2007).

Multiple Regression Analysis (MRA) is used to explain effects of independent variables on dependent variable. Model of MRA can be written as follows:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \in_i \quad i = 1, 2 \ldots n \qquad (1)$$

Where, Y, fruit weight as dependent variable; $X_1, X_2, \ldots, X_k$ are independent variables; namely, X_1: number of canes; X_2: cane height; X_3: cane diameter, and X_4: cane yield. $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are regression coefficients (slopes); namely, β_0: intercept; β_1: the regression of fruit weight on number of canes; β_2: the regression of fruit weight on cane height; β_3: the regression of fruit weight on cane diameter, and β_4: the regression of fruit weight on cane yield and, $\in_i$ random error. [Eq.1] can be rewritten as

$$Y = X\beta + \varepsilon$$

in matrix notation where X, design matrix; β, coefficients vector of regression coefficients, and $\in$, vector of random error. Regression coefficients can be estimated by Ordinary Least Square (OLS)

Table 2. Descriptive statistics of some pomological traits in raspberry.

Variable	N	Mean	Standard error	Minimum	Maximum
Number of canes	150	28.29	1.50	10.00	90.50
Cane Height (cm)	150	124.29	2.68	71.00	198.80
Cane Diameter (mm)	150	9.52	0.14	6.00	14.30
Cane Yield (g)	150	56.16	1.71	16.60	106.00
Fruit Weight (g)	150	1.79	0.05	0.61	3.04

Table 3. Probabilities of significance for analyses of variance of pomological traits in raspberry.

Trait	Cultivar	Year	Cultivar x Year interaction	Determination coefficient (R^2)
Number of canes	***	***	***	99.2
Cane Height (cm)	***	***	***	99.8
Cane Diameter (mm)	***	***	***	96.0
Cane Yield (g)	***	***	***	99.4
Fruit Weight (g)	***	***	***	99.7

*: P < 0.05; **: P < 0.01; ***: P < 0.001.

Method. The method is based on minimizing $\sum_{i=1}^{n} e_i^2 = Y - \hat{Y}$, difference between observed Y values with predicted $\hat{Y}_i$ values. $\hat{\beta} = (X'X)^{-1}(X'Y)$ is solved by using OLS then $\beta_0, \beta_1, \beta_2 ... \beta_k$ are calculated (Duzgunes et al., 1983; Sokal and Rohlf, 1996; Eyduran et al., 2005). Determination Coefficient and Root of Mean Square Error (RMSE) were used to determine effectiveness of Multiple Regression Model. The most suitable Multiple Regression Model must be the highest determination coefficient, but the lowest RMSE value. Multiple Regression Analyses were performed using REG procedure of SAS program. For all traits, GLM (General Linear Model) procedure of SAS computer software was used for testing hypotheses on cultivar, year, and their interaction in factorial design (SAS, 2006).

RESULTS AND DISCUSSION

Descriptive statistics of pomological traits

Descriptive statistics of some traits such as fruit weight, number of canes, cane height, cane diameter, and cane yield for ten raspberry cultivars grown in Central Anatolia are presented in Table 2. As shown in Table 2, average number of canes for these Raspberry cultivars was calculated as 28.29 g and number of canes ranged from 10 to 90.50; average cane height for the raspberry cultivars was estimated as 124.29 cm and cane height ranged from 71 to 198.8 cm; average cane diameter for the raspberry cultivars was determined as 9.52 mm and cane diameter ranged from 6.0 to 14.30 mm; and average cane yield for these cultivars was estimated as 56.16 and cane yield ranged from 16.60 to 106 (g). Average fruit weight for the cultivars was found as 1.79 g and fruit weight ranged from 0.61 to 3.04 g.

ANOVA results of pomological traits

The effects of cultivar, year, and cultivar by year interaction were tested by ANOVA at Factorial Design. Probabilities of significance for analyses of variance of pomological traits in raspberry are summarized in Table 3. When Table 3 was taken into consideration, the effects of cultivar, year, and cultivar by year interaction for pomological traits were found to be statistically significant (P < 0.001). Determination coefficients of pomological traits such as number of canes, cane height, cane diameter, cane yield, and fruit weight were estimated as 99. 2, 99.8, 96.0, 99.4, and 99.7% respectively. This means that most of total variations of these traits were explained by cultivar, year, and cultivar by year interaction.

Descriptive statistics of pomological traits for each raspberry cultivar

Table 4 presents descriptive statistics of pomological traits for the each raspberry cultivar. According to Table 4, cultivar with the highest fruit weight was Willamette (2.77 g), followed by Tulameen (2.32 g), Canby (2.04 g), Heritage II (1.82 g), Heritage I (1.70 g), Nuburg (1.70 g), Aksu Red (1.66 g), Holland Dwarf (1.53 g), Rubin (1.31 g), and Summit Cultivars (1.00 g) (LSD value at comparison of fruit weight averages of two cultivars: 0.02507).

As seen from Table 4, the raspberry cultivar with the highest number of canes was obtained from Willamette (73.96), followed by Heritage II (47.48), Tulameen (30.34), Holland Dwarf (21.60), Summit (21.48), Heritage I (20.61), Nuburg (19.22), Aksu Red (17.88), Rubin (17.02), Canby (13.32), with the lowest number of canes

Table 4. Descriptive statistics of some pomological traits for ten raspberry cultivar.

Cultivar	N	Mean	Std Error	Minimum	Maximum
Aksu Red Cultivar					
Number of canes	15	17.88	0.52	15.20	20.50
Cane Height (cm)	15	152.22	6.23	125.20	190.80
Cane Diameter (mm)	15	10.52	0.22	9.30	11.80
Cane Yield (g)	15	59.80	3.18	47.30	90.50
Fruit Weight (g)	15	1.66	0.07	1.13	1.84
Canby Cultivar					
Number of canes	15	13.32	0.50	10.00	15.70
Cane Height (cm)	15	143.98	9.13	99.40	178.80
Cane Diameter (mm)	15	8.24	0.41	6.00	10.90
Cane Yield (g)	15	51.14	3.21	29.70	64.20
Fruit Weight (g)	15	2.04	0.08	1.40	2.30
Heritage I Cultivar					
Number of canes	15	20.61	1.50	15.00	30.40
Cane Height (cm)	15	110.03	1.59	100.10	116.50
Cane Diameter (mm)	15	9.18	0.22	7.70	10.40
Cane Yield (g)	15	53.24	3.42	42.60	78.50
Fruit Weight (g)	15	1.70	0.07	1.22	1.96
Heritage II Cultivar					
Number of canes	15	47.48	2.16	32.20	55.90
Cane Height (cm)	15	115.06	3.19	98.10	133.30
Cane Diameter (mm)	15	10.24	0.30	8.50	11.80
Cane Yield (g)	15	65.74	2.80	45.50	82.80
Fruit Weight (g)	15	1.82	0.05	1.52	2.05
Holland Dwarf Cultivar					
Number of canes	15	21.60	0.64	17.40	25.10
Cane Height (cm)	15	98.38	4.04	80.40	120.20
Cane Diameter (mm)	15	8.94	0.52	6.00	12.00
Cane Yield (g)	15	44.06	2.93	22.40	52.80
Fruit Weight (g)	15	1.53	0.07	1.01	1.84
Nuburg Cultivar					
Number of canes	15	19.22	0.90	13.20	23.70
Cane Height (cm)	15	106.74	4.48	85.10	140.00
Cane Diameter (mm)	15	8.22	0.22	7.20	9.50
Cane Yield (g)	15	34.58	2.44	24.60	49.20
Fruit Weight (g)	15	1.70	0.06	1.31	1.99
Rubin Cultivar					
Number of canes	15	17.02	0.82	12.00	20.90
Cane Height (cm)	15	129.54	8.00	95.10	165.50
Cane Diameter (mm)	15	11.96	0.42	9.70	14.30
Cane Yield (g)	15	38.66	2.94	25.20	55.80
Fruit Weight (g)	15	1.31	0.08	0.70	1.60
Summit Cultivar					
Number of canes	15	21.48	0.44	19.00	24.00
Cane Height (cm)	15	85.24	2.57	71.00	98.80
Cane Diameter (mm)	15	8.44	0.21	7.20	9.70
Cane Yield (g)	15	48.06	4.34	16.60	65.50
Fruit Weight (g)	15	1.00	0.06	0.61	1.24

Table 4. Contd.

Tulamen Cultivar					
Number of canes	15	30.34	1.23	20.00	40.00
Cane Height (cm)	15	127.74	4.41	105.40	152.60
Cane Diameter (mm)	15	8.26	0.15	7.40	9.20
Cane Yield (g)	15	70.60	2.77	60.00	88.80
Fruit Weight (g)	15	2.32	0.09	1.55	2.54
Willamette Cultivar					
Number of canes	15	73.96	1.91	62.80	90.50
Cane Height (cm)	15	173.99	6.53	134.40	198.80
Cane Diameter (mm)	15	11.18	0.22	9.30	12.40
Cane Yield (g)	15	95.76	3.58	70.60	106.00
Fruit Weight (g)	15	2.77	0.12	1.87	3.04

(LSD value at comparison of number of canes averages of two cultivars: 1.483).

According to Table 4, the raspberry cultivar with the highest cane height was taken from Willamette (173.99 cm), followed by Aksu Red (152.22 cm), Canby (143.98 cm), Rubin (129.54 cm), Tulameen (127.74 cm), Heritage II (115.06 cm), Heritage I (110.03 cm), Nuburg (106.74 cm), Holland Dwarf (98.38 cm), and Summit (85.24 cm) cultivars (LSD value at comparison of cane height averages of two cultivars: 1.46).

It is clear in Table 4 that, the raspberry cultivar with the highest cane diameter was taken from Rubin (11.96 mm), followed by Willamette (11.18 mm), Aksu Red (10.52 mm), Heritage II (10.24 mm), Heritage I (9.18 mm), Holland Dwarf (8.94 mm), Summit (8.44 mm), Tulameen (8.26 mm) Canby (8.24 mm), and Nuburg (8.22 mm), with the lowest cane diameter (LSD value at comparison of cane diameter averages of two cultivars: 0.3072).

It is demonstrated clearly in Table 4 that, the raspberry cultivar with the highest cane yield (yield per plant) was recorded in Willamette (95.76 g), followed by Tulameen (70.60 g), Heritage II (65.74 g), Aksu Red (59.80 g), Heritage I (53.24 g), Canby (51.14 g), Summit (48.06 g) Holland Dwarf (44.06 g), Rubin (38.66 g), and Nuburg (34.58 g), with the lowest cane yield (LSD value at comparison of cane yield averages of two cultivars: 1.46).

In an earlier study of cv. Tulameen, Daubeny and Anderson (1991) noted that it was this cultivar that matured late and become tough, with the long-conical shape, bright red color and the fruit weight of 5.38 g. This result was found to be higher than that in the present paper (2.32 g).

Our findings on fruit weights of Heritage cultivars were lower than those reported by Finn et al. (2004), who found as 2.3 (g/berry) for Heritage cultivar. In previous studies of Tulameen and Willamette cultivars, Moore and Finn (2007) found 4.17 (g/berry) and 3.10 (g/berry) for 1997 harvest season, along with 3.64 (g/berry) and 2.7 (g/berry) for 1998 harvest season. Their results on Tulameen cultivar were higher than ours, but that of Willamette cultivar was partly consistent with our finding. The result of the fruit weight (4.4 g) of Tulameen cultivar reported by Kempler et al. (2007) was higher than that of our study.

Our findings on fruit weights of Willamette and Tulameen cultivars were lesser compared to those of Finn et al. (2001b), who found 3.22 g for Willamette cultivar and 4.04 g for Tulameen cultivar, and Kempler et al. (2005), who determined it as 4.8 g in Tulameen cultivar and 3.7 g in Willamette cultivar. The fruit weight of Willamette cultivar in this study was found lower than that of Finn et al. (2001a), who observed 3.1 g for the cultivar.

Previous evaluations in Turkey demonstrated that cv. Tulameen, Willamette, Heritage, Summit and Canby attained fruit weight of 2.87 to 4.40 g, 1.31 to 3.20 g, 1.54 to 1.80 g, 1.06 to 2.09 g and 3.30 g, respectively (Gercekcioglu et al., 2003; Cangi and Islam, 2003; Kaplan et al., 2003). The fruit weight of all cultivars in the present study are lesser compared to the fruit weight of these cultivars in earlier studies under Turkish conditions. In an investigation carried out under Giresun (Turkey) conditions, cane diameter in Rubin, Summit, Tulameen, Willamette, Canby and Heritage were determined as 9.7, 9.2, 10.2, 9.8, 10.5 and 9.8 mm respectively (Kurt et al., 2003). However, in our study, cane diameter in Rubin cultivar was found to be 11.96 mm, in Summit cultivar 8.44 mm, in Tulameen cultivar 9.18 mm, in Heritage I cultivar 8.26 mm, and 10.24 mm in Heritage II cultivar. When we compare the results of the same study which was carried out under Giresun conditions, cane height was found to be 140 cm in Summit, 215 cm in Canby, 240 cm in Tulameen and 220 cm in Willamette (Kurt et al., 2003). But in our study, cane height was found to be 85.24 cm in Summit, 143.98 cm in Canby, 127.74 cm in Tulameen and 173.99 cm in Willamette.

From the results of this study, we can obviously observe that soil and ecological conditions had a great

Table 5. Parameter results (±SE), R^2, and RMSE values from multiple regression analyses for ten raspberry cultivars.

Cultivar	β_0	β_1	β_2	β_3	β_4	R^2 (%)	RMSE
Aksu Red	-2.3212*** (0.371)	-0.04226 ns (0.0199)	0.0085*** (0.0011)	0.3922*** (0.055)	-0.01134** (0.0026)	92.82	0.08624
Canby	0.9459* (0.40121)	-0.037363ns (0.0669)	-0.006424* (0.0025)	0.0897ns (0.0492)	0.0347* (0.0114)	85.45	0.14648
Heritage I	-0.09135ns (0.288)	-0.0280* (0.0095)	-0.006* (0.0026)	0.212039*** (0.0202)	0.02034*** (0.0043)	99.06	0.02938
Heritage II	0.5404* (0.2113)	0.01044ns (0.005)	0.002565ns (0.0048)	-0.00953ns (0.05)	0.008920* (0.0034)	90.46	0.06658
Holland Dwarf	0.6297** (0.1504)	-0.0073ns (0.0108)	-0.002ns (0.002)	0.006ns (0.009)	0.0272*** (0.001)	99.64	0.01988
Nuburg	1.452ns (0.807)	0.0745ns (0.0406)	-0.0096ns (0.006)	-0.0483ns (0.1035)	0.0070ns (0.0066)	67.32	0.16873
Rubin	-1.3199ns (1.5023)	0.288327* (0.127)	-0.03153 ns (0.0284)	0.253ns (0.359)	-0.0314ns (0.0245)	90.28	0.1163
Summit	0.5952*** (0.125)	-0.039*** (0.0075)	0.0123*** (0.002)	-0.029ns (0.018)	0.0091*** (0.0010)	98.60	0.03083
Tulameen	-2.588* (1.184)	0.0173ns (0.0175)	-0.0242ns (0.0125)	1.15233* (0.412)	-0.029ns (0.018)	65.22	0.24532
Willamette	0.808ns (0.598)	-0.00723ns (0.0102)	-0.0084ns (0.0052)	-0.07666ns (0.05)	0.0503** (0.011)	92.68	0.14785

*: P< 0.05; **: P < 0.01; ***: P < 0.001; ns: non-significant.
β_0: intercept; β_1: the regression of fruit weight on number of canes; β_2: the regression of fruit weight on cane height; β_3: the regression of fruit weight on cane diameter, and β_4: the regression of fruit weight on cane yield.

influence on the growth of these plants.

Multiple regression modeling for each raspberry cultivar

Parameter estimates ($\pm$ SE), R^2 (%), and RMSE values from Multiple Regression Analyses (MRA's) for each raspberry cultivar are given in Table 5. By using MRA, our main concern in the present paper was to estimate average fruit weight by cane traits (number of canes, cane length, cane diameter, yield per plant) for each cultivar.

Aksu Red cultivar

As seen from in Table 5, determination coefficient for Aksu Red raspberry cultivar was found to be 92.82%. This means that 92.82% of total variation of fruit weight was explained by cane traits such as number of canes, cane height, cane diameter, and cane yield. Although the regression of fruit weight on number of canes was non-significant, the regressions of fruit weight on cane height ($P < 0.001$), cane diameter ($P < 0.001$), and cane yield ($P < 0.01$) were found to be significant. The regression of fruit weight on cane height for Aksu Red was found as 0.0085 ($P < 0.001$), which means that we expect 0.0085 g increase in fruit weight with increasing 1 cm in cane height, holding X1, X3, and X4 constants. The regression of fruit weight on cane diameter for Aksu Red was 0.3922 ($P < 0.001$), which means that we expect 0.3922 g increase in fruit weight with increasing 1 mm in cane diameter, holding X1, X2, and X4 constants. The regression of fruit weight on cane yield for Aksu Red cultivar was found as: –0.01134 ($P < 0.01$), which means that we expect 0.01134 g decrease in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants. It could be said that multiple regression modeling was found to be more sufficient to explain total variation of fruit weight of the cultivar.

Canby cultivar

As seen from in Table 5, determination coefficient for Canby raspberry cultivar was estimated as 85.45%. This means that 85.45% of total variation of its fruit weight was explained by the cane traits studied. The regressions of fruit weight on number of canes and cane diameter were non-significant, but the regressions of fruit weight on cane height ($P < 0.05$) and cane yield ($P < 0.05$) were found to be significant. The regression of fruit weight on

cane height for Canby Red cultivar was found as -0.006424 ($P < 0.05$). This value means that we expect 0.006424 g decrease in fruit weight with increasing 1 cm in cane height, holding X1, X3, and X4 constants. The regression of fruit weight on cane yield for Canby cultivar was calculated as: 0.0347 ($P < 0.05$). This means that we expect 0.0347 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants. It could be suggested that multiple regression modeling was more sufficient to explain total variation of fruit weight of the cultivar.

Heritage I cultivar

It is clear in Table 5 that coefficient of determination for Heritage I raspberry cultivar was estimated as 99.06%. This means that 99.06% of total variation of its fruit weight was explained by all cane traits studied. The regressions of fruit weight on number of canes ($P < 0.05$), cane height ($P < 0.05$), cane diameter ($P < 0.001$) and cane yield ($P < 0.001$) were significant (Table 5). The regression of fruit weight on number of canes for Heritage I cultivar was -0.028 ($P < 0.05$), which means that we expect 0.028 g decrease in fruit weight with increasing 1 unit in number of canes, holding X2, X3, and X4 constants. The regression of fruit weight on cane height for Heritage I cultivar was estimated as: -0.006 ($P < 0.05$), which means that we expect 0.006 g decrease in fruit weight for each 1 cm increase in cane height, holding X1, X3, and X4 constants. The regression of fruit weight on cane diameter for Heritage I cultivar was estimated as: approximately 0.21204 ($P < 0.001$), which means that we expect 0.21204 g increase in fruit weight for each 1 mm increase in cane diameter, holding X1, X2, and X4 constants. The regression of fruit weight on cane yield for Heritage I cultivar was estimated as: approximately 0.02034 ($P < 0.001$), which means that we expect 0.02034 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants. Multiple regression modeling explained almost 100% of total variation of fruit weight of the cultivar.

Heritage II cultivar

It is clear in Table 5 that coefficient of determination for Heritage II raspberry cultivar was estimated as 90.46%. This means that 90.46% of total variation of its fruit weight was explained by all cane traits. That is, multiple regression modeling was found more sufficient. The regression of fruit weight on only cane yield among cane traits studied was significant ($P < 0.05$), which means that we expect 0.00892 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants.

Holland Dwarf cultivar

Coefficient of determination for Holland Dwarf raspberry cultivar was estimated as 99.64%, which means that 99.64% of total variation of its fruit weight was explained by all cane traits. In other words, multiple regression modeling could be said to be more sufficient. The regression of fruit weight on only cane yield among cane traits studied was significant ($P < 0.001$), which means that we expect 0.0272 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants.

Nuburg cultivar

Coefficient of determination for Nuburg cultivar was estimated as 67.32%. Nearly two-third of total variation of its fruit weight was explained by all cane traits. However, all the regression coefficients were non-significant (Table 5).

Rubin cultivar

Determination coefficient for Rubin cultivar was estimated as 90.28% which means that 90.28% of total variation of its fruit weight was explained by all cane traits. It is demonstrated clearly that multiple regression modeling was more sufficient to explain total variation of fruit weight of the cultivar. The regression of fruit weight on number of canes was found significant, but other coefficients were non-significant (Table 5). Multiple regression modeling was more enough to explain total variation of fruit weight of the cultivar. The regression of fruit weight on number of canes for Rubin cultivar was found as 0.2883 ($P < 0.05$), which means that we expect 0.2883 g increase in fruit weight with increasing 1 unit in number of canes, holding X2, X3, and X4 constants.

Summit cultivar

Determination coefficient for Summit cultivar was estimated as 98.6% which means that 98.6% of total variation of its fruit weight was explained by all cane traits studied (Table 5). The regressions of fruit weight on number of canes ($P < 0.001$), cane height ($P < 0.001$), and cane yield ($P < 0.001$) were significant, but the regression of fruit weight on cane diameter was non-significant. The regression of fruit weight on number of canes for the cultivar was -0.039 ($P < 0.001$), which means that we expect 0.039 g decrease in fruit weight with increasing 1 unit in number of canes, holding X2, X3, and X4 constants. The regression of fruit weight on cane height for the cultivar was found as 0.0123 ($P < 0.001$), which means that we expect 0.0123 g increase in fruit weight for each 1 cm increase in cane height, holding X1, X3, and X4 constants. The regression of fruit weight on cane yield for Rubin cultivar was found as: 0.0091 ($P < 0.001$), which means that we expect 0.0091 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants. Multiple regression modeling

was found sufficient to explain total variation of fruit weight of the cultivar.

Tulameen cultivar

Coefficient of determination for Tulameen cultivar was estimated as 65.22%. Nearly two-third of total variation of its fruit weight was explained by all cane traits (Table 5). The regression of fruit weight on cane diameter for the cultivar was 1.15233 ($P < 0.05$), which means that it is expected 1.15233 g increase in fruit weight for each 1 mm increase in cane diameter, holding X1, X2, and X4 constants.

Willamette cultivar

Determination coefficient for Willamette cultivar was estimated as 92.68% which means that 92.68% of total variation of its fruit weight was explained by all cane traits studied (Table 5). Multiple regression modeling was more sufficient to explain total variation of fruit weight of the cultivar. The regressions of fruit weight on number of canes, cane height and cane diameter were non-significant, but the regression of fruit weight on cane yield ($P < 0.01$) was significant. The regression of fruit weight on cane yield for the cultivar was found as: 0.0503 ($P < 0.01$), which means that we expect 0.0503 g increase in fruit weight for each 1 g increase in cane yield, holding X1, X2, and X3 constants.

Conclusion

According to determination coefficients for each cultivar, it is clear that cultivars having the best fit (giving the best R^2 values and the lowest RMSE) in MRA were determined as Holland Dwarf (99.64%), followed by Heritage I (99.06%), Summit (98.6%), Aksu Red (92.82%), Willamette (92.68%), Heritage II (90.46%), Rubin (90.28%) and Canby (85.45%) cultivars. Multiple Regression Modeling gave good results for these cultivars. R^2 values of these cultivars were found higher (better fit) than those of Nuburg and Tulameen cultivars. In general, we observed that:

1. Number of canes had significant negative effect on fruit weights of Heritage I ($P < 0.05$) and Summit ($P < 0.001$) cultivars, but significant positive effect on only fruit weight of Rubin cultivar ($P < 0.05$).
2. Cane height had significant positive effect on fruit weights of Aksu Red ($P < 0.001$), and Summit ($P < 0.001$) cultivars, whereas it had significant negative effect on fruit weights of Canby ($P < 0.05$) and Heritage I ($P < 0.05$).
3. Cane diameter had significant positive effect on fruit weights of Aksu Red ($P < 0.001$), Heritage I ($P < 0.001$) and Tulameen ($P < 0.05$) cultivars. However, no cane trait had significant negative effect influencing fruit weight.
4. Cane yield had significant positive effect on fruit weights of Canby ($P < 0.05$), Heritage I ($P < 0.001$), Heritage II ($P < 0.05$), Holland Dwarf ($P < 0.001$), Summit ($P<0.001$) and Willamette ($P < 0.01$) cultivars, but significant negative effect on fruit weight of Aksu Red cultivar ($P < 0.01$).

It was concluded that cane traits with the positive and negative effects on fruit weight for each cultivar might provide valuable clues for breeding proposes in order to improve fruit weight.

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