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DIVERSITY AND RELATIONSHIP OF YILED COMPONENTS AND FRUIT QUALITY IN PROMISING FLORICANE RASPBERRY HYBRIDS

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Abstract

RADOVICH, A., M. FOTIRICH AKSICH, V. RAKONJAC, J. MILIVOJEVICH, D. NIKOLICH and M. NIKOLICH, 2013. Diversity and relationship of yield components and fruit quality in promising floricane raspberry hybrids. *Bulg. J. Agric. Sci.,* 19: 750-755

Raspberry breeding objectives are primarily aimed at developing cultivars with higher productivity, large fruits with the excellent quality. Most of them were developed by the method of planned hybridization and much smaller number by inbreeding and clonal selection. Major yield components and fruit quality of 20 promising floricane raspberry seedlings with red and yellow fruits obtained by open pollination of cv. `Meeker` yellow clone were investigated in this study. Compared with the cv. `Meeker`, raspberry hybrids lagged behind the standard cultivar in yield components, but surpassed it in terms of fruit quality. Taking into account the yield components, number of fruiting laterals per cane showed a significant correlation with the largest number of morphological fruit traits tested. Results of multivariate analysis indicate that the first three components explained 73.12% of the total variability observed. The highest values of first principal component (PC1) are related to fruit weight, length and fruit width, number of fruiting laterals per cane and sucrose content. In PC2, the highest values were associated with length of fruiting laterals and the number of flowers. Some of the hybrids have many favourable characteristics that are commercially important for cultivation and can be used for further breeding. Principal component analysis showed that the most important traits to distinguish raspberry hybrids are those related to fruit size and number and length of fruiting laterals.

*Key words***:** chemical traits, correlation, fruit characteristics, generative potential, PCA

Abbreviations: fruiting laterals per cane (FLC), length of fruiting laterals (LFL), number of inflorescences per fruiting laterals (IFL), number of flowers per inflorescence (FPI), number of flowers per fruiting laterals (FFL), fruit weight (FW), fruit length (FL), fruit width (FWD), fruit shape index (FSI), number of drupelets per fruit (NDF), soluble solids content (SSC), total acidity (TA), total sugar content (TSC), invert sugar content (ISC) and sucrose content (SC), principal component analysis (PCA)

Introduction

Raspberry production in the world is increasing, primarily due to enhancing demand for fresh fruits in the world market. The fruits are very attractive and their good quality (sugar, acids, vitamins and minerals) makes them suitable for fresh consumption, freezing, and the various forms of processing. This is why in the world, and in our country, continuing work is done on its breeding and development of new cultivars of red and yellow fruit.

Raspberry breeding objectives are primarily aimed at developing cultivars with higher productivity, large fruits with the excellent quality. In addition, breeding programs around the world are creating new raspberry cultivars with high anthocyanins content in the fruit, with longer harvest season, increased resistance to adverse biotic and abiotic environmental conditions, together with breeding cultivars with yellow fruit (Knight and Fernandez, 2008; Badjakov et al., 2008; Weber et al., 2008). One of these programs, which create new raspberry cultivars with red and yellow fruit, is also

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realized at the Agricultural Faculty in Belgrade (Nikolić et al., 2009).

Up to date the largest number of new raspberry varieties was developed by the method of planned hybridization and much smaller number by inbreeding and clonal selection. However, in recent years, clonal selection of raspberries is increasingly used as a method for improving new cultivars. The occurrence of spontaneous mutation is quite common among the various raspberry traits (Daubeny, 1996), especially in cultivar `Meeker`. This primarily refers to the colour of the fruit, where its first clones with yellow fruit colour are created (Bañados et al., 2002; Malowicki, 2007; Nikolić and Milivojević, 2008).

Yield in raspberries is a complex trait that is quantitatively inherited and is the sum of many components (Pritts, 2002). Some of these components are determined by cultural methods and practical management factors, which vary according to the purpose of growing the crop, the planned market, and the desired hand and machine inputs (Hall et al., 2009). Although all yield components interact with environmental conditions prior to produce total yield, from a breeding point of view, there are certain components that are likely to be better correlated with yield (Stephens et al., 2009). Some studies declared that number of fruiting laterals per cane and cane diameter are closely correlated to yield (Dale and Daubeny, 1985). In addition, Mišić et al. (2004) and Mladin and Mladin (2008) added that the yield components that most strongly affect marketable yield are length of fruiting laterals, number of fruits per cane and fruit weight. Since there has been an increase in average fruit size of newly released cultivars, other yield components may be as important and may hold the key to major advances in fruit yield in the future (Stephens et al., 2009).

Although components key to increasing yield need to be identified and optimized, they cannot be the sole focus of a breeding program (Hall et al., 2009). Horticultural characters such as fruit quality are also important. Quality aspects considered in breeding include, among all, shape, sweetness, acidity, sugar/acid balance and nutritional attributes (Callahan, 2003). Berry shape is important for yield, fruit integrity, handling ability, shelf life and transportation. Perception of sweetness and sugar content is important for both fresh market and processing. Levels of acidity need to be moderate in raspberry to give a good flavour for fresh-market types, and levels need to be higher for processing cultivars (Hall et al., 2009).

Since internal and external fruit quality along with yield components represents complex traits, multivariate statistical methods can be a helpful and easy tool to separate useful from useless information. Principal Component Analysis (PCA) provides quick and automatic qualitative sample differentiation, in particular when quantization or characterization of specific components of the matrix is not necessary (Cagliero et al., 2012). PCA is a method of data reduction that transforms the original variables into a limited number of uncorrelated new variables. According to Martínez-Calvo et al. (2008), this technique is thus a useful device for representing a set of variables by a much smaller set of composite variables that account for much of the variance among the set of original variables. It allows visualization of the differences among the individuals, identification of possible groups and relationships among individuals and variables. Previously, PCA had been used to evaluate different genotypes of raspberry (Marshall et al., 2001; Patamsytė et al., 2004; Stafne et al., 2005; Badjakov et al., 2006).

The objective of this study was to determine a correlation relationship between the yield components and fruit quality parameters in 20 floricane raspberry hybrids with red and yellow fruit. Using multivariate analysis grouping of hybrids for further studies was performed as well.

Material and Methods

The experiment was carried out in the Experimental Station "Radmilovac" that belongs to the Faculty of Agriculture in Belgrade, University of Belgrade. The orchard was planted in 2005 with planting distance 3 x 0.5 m. As a material in this trial 20 promising floricane raspberry hybrids, obtained by open pollination of cv. Meeker`s yellow clone, were used. Hybrids I-3-2P, I-4-4, I-6-2, I-7-3, I-8-2, I-9-P, II-2-2P, II-3-4P, II-3-PP, II-5-4, II-6-3, II-8-2, II-8-2P, PP-II-2 had red fruit colour, while hybrids 2, 3, 6A, 6C, 9 and 10 showed yellow. In addition to the hybrids, standard cultivar `Meeker` was also examined.

During three consecutive years (2007-2009) major yield components such FLC, LFL, IFL, FPI and FFL, fruit morphology traits FW, FL, FWD, FSI and NDF, together with fruit quality parameters such as SSC, TA, TSC, ISC and SC were determined. FLC, IFL, FPI and FFL in selected hybrids were determined by counting, while LFL was measured and expressed in cm. FW, FL, FWD, FSI and NDF were determined at the stage of full maturity in a sample of 30 fruits. FW (g) was measured on a digital scale, while FL and FWD (mm) were obtained by measuring the digital calliper. From the ratio of FL and FWD, FSI was calculated. NDF was determined by counting. SSC was determined using a digital refractometer (Pocket PAL-1, Atago, Japan), TA was done by titration with 0.1 N NaOH converted to malic acid. TSC, ICS and SC were determined by the method of Luff – Schoorl.

As indicators of the traits variability in promising hybrids, minimum, maximum and mean values, standard deviation (S) and coefficient of variation (CV) were specified. Correla-

tion coefficients (r) among the traits were determined as the coefficient of Pearson.

PCA was used to group the variables into subsets that are relatively independent from each other as well as for reducing the dimensionality of the structure. Thus, it produced new accumulated variables (principal components, PCs) represent underlying processes responsible for inter-correlations of variables in the original dataset. To determine which of the PCs accounted for the greatest amount of variation for each trait, the eigenvalues of the 4 PCs were compared for each trait. The first two principal component scores were plotted in a two-dimensional plane to inspect the sample for interesting patterns of hybrids. 'Statistica' (StatSoft, Inc., Tulsa, Oklahoma, USA) obtained PCA and character correlations.

Results and Discussion

In Table 1 scores for the 15 variables in 20 promising raspberry hybrids and standard cultivar `Meeker` are shown. FLC of examined hybrids showed a variation between 8.6 and 19.8. For numbers of laterals, the quantitative inheritance has been shown to be additive in raspberry (Fejer, 1977), which indicates that it could be a character that is relatively easy to improve genetically. LFL showed a wide range, from 9.1 to 29.9 cm, where cv. `Meeker` had an average of 27.7 cm. According to Dale (1979) length of fruiting laterals is associated with its position on the cane, where longer laterals are formed going from the top to the cane basis. IFL and FPI presented small differences between the minimum and the maximum of the values, where first trait ranged from 2.4 to 5.7, and the second one from 2.0 to 3.3. According to Hall et al. (2009) FFL are usually less than 30 and frequently only 10 to 15, while in our study this property was ranged between 5.3 and 13.0, except for standard cultivar `Meeker` (15). By analyzing the yield components in promising hybrids and `Meeker`, it is obvious that the standard cultivar had higher values for almost all the yield components than the hybrid's average. The only exception to this is the FPI, which was the same (2.5) in both `Meeker` and promising hybrids.

Another fruit traits considered in breeding programs include fruit morphology. Fruit size has been discussed as one of the main components of yield. The highest FW showed standard cultivar `Meeker` (3.49 g). Maximum FW of some hybrids (II-8-2, PII-3-4P, I-3-2P, data not show) were on the same level like the standard cultivar (3.50 g). Since breeders often tend to select parents based on the fruit size, because it is the trait that is usually most readily identified (Daubeny, 1996), those four could be used in further breeding programs. In addition, fruit dimensions (FL and FWD), FSI and NKF were higher in cv. `Meeker` compared to average values of the promising hybrids. Yellow hybrids studied in our paper showed average FW 2.31 g (data not show). Obtained results from our study are similar with the results of Nikolić et al. (2009), who also showed average fruit weight in ten raspberry hybrids with yellow fruit (2.45 g). Weber et al. (2008) found lower fruit weight (2.1 g) in raspberry cultivars and se-

Table 1
Mean values of standard cultivar `Meeker` and variability parameters of yield components and fruit quality in promising hybrids

Trait	Meeker	Variability parameters of promising hybrids				
		Min	Max	Mean	S	CV, %
FLC	20.8	8.6	19.8	14.5±0.9	3.95	27.2
LFL, cm	27.7	9.1	29.9	21.2±1.1	5.08	24
IFL	6.1	2.4	5.7	3.8±0.2	0.77	20.1
FPI	2.5	2	3.3	2.5±0.1	0.29	11.8
FFL	15	5.3	13	8.9±0.4	2.03	22.7
FW, g	3.49	1.83	3.5	2.75±0.10	0.457	16.6
FL, mm	19.84	14.17	19.64	17.39±0.31	1.372	7.9
FWD, mm	18.11	15.02	18.58	17.14±0.24	1.083	6.3
IFS	1.1	0.94	1.14	1.02±0.01	0.05	4.9
NDF	88.87	67.57	118.94	85.71±2.51	11.205	13.1
SSC, %	10.43	10.2	13.67	11.72±0.22	0.994	8.5
TA, %	1.43	0.63	1.6	1.00±0.06	0.274	27.4
TSC, %	8.15	7.26	10.04	8.42±0.17	0.775	9.2
ISC, %	7.17	6.22	8.92	7.33±0.17	0.738	10.1
SC, %	0.93	0.59	1.16	0.94±0.03	0.124	13.1

lections with yellow fruit, compared to the cultivar `Meeker` (2.6 g). IFS, an important fruit quality parameter that affects handling ability, shelf life, and transportation (Hall et al., 2009) ranged from 0.94 – 1.14 in our study. It should be noted that the NDF in some hybrids reached a maximum of 118.94 compared to the cultivar `Meeker` (88.87).

Although many other characteristics such as agronomic performance remain important in the breeding programs, fruit quality must be considered as one of the premier factors. Considering SSC, TSC and ISC, mean values in studied hybrids was higher than in cv. `Meeker`, while SC was in the same level with the standard cultivar. Only TA values in cv. `Meeker` (1.43%) exceeded the average of hybrid's value (1.00%). However, the results of Weber et al. (2008) showed that the soluble solids content in both cultivars and hybrids of raspberries with yellow fruits are on the same level with cv. `Meeker`.

FLC, LFL, FFL and TA varied the most among yield components and fruit quality parameters, which was shown by coefficient of variation (over 20.1%). Traits such as IFL, FW, NDF and SC are in the group with medium coefficient of variation (between 11.8 and 20.1%). Compared with the cv. `Meeker`, raspberry hybrids lagged behind the standard cultivar in yield components, but surpassed it in terms of fruit quality.

Table 2 shows the correlation among variables. FLC showed a significant positive correlation with all fruit morphology traits studied (r = 0.51–0.82). Although correlation between these traits was highly significant, the correlation analysis as such does not prove a causal relationship between these variables. Significant positive correlation was found between LFL and FFL (r = 0.45). LFL was also significantly associated with FLC and IFL (r = 0.64; r = 0.67, respectively). Relationships between IFL and chemical traits (but SC) were found to be negative, but insignificant (except for IFL and SSC, that was significant) that can be explained with the fact that if organic matter is used for production of large number of flowers then less of organic matter remain for fruit forming.

FW, FL and FWD were correlated with one another (r = 0.82–0.95), and therefore, these parameters may be used to predict each other. In addition, FW was correlated with NDF (r = 0.51) which implies that advances in fruit size have occurred through increasing drupelets numbers. From the correlation matrices can be realized that no significant relationships were found between FW and the yield components (except between FW and FLC), which was also proved by Stephens et al. (2009).

SSC was significantly correlated with TSC and ISC (r = 0.67; r = 0.65, respectively). On the other hand, SSC was not significantly correlated with FW, which was the case in the study of Moore et al. (2008). By analyzing, the results can be noticed that most of the yield components were not significantly correlated with fruit quality parameters. Only IFL and FFL were significantly correlated with TA (r = 0.58; r = 0.68, respectively). In addition, SC was significantly correlated with FW, FL, FWD and FTC (r = 0.58 – 0.63). These kind of results where small number of relationships are found between group of traits means that characteristics tested are genetically independent, and can be improved separately.

More detailed relationships between perspective hybrids and standard cultivar Meeker were revealed by PCA. The first

Table 2
Correlation relationship between yiled components and fruit quility attributes in floricane raspberry hybrids y

	FTC	LFT	IFT	FPI	FFT	FW	FL	FWD	IFS	NDF	SSC	TA	TSC	ISC	SC
FLC	-	0.45	0.2	0.22	0.32	0.81	0.82	0.67	0.55	0.51	-0.31	0.16	0.14	0.07	0.58
LFL		-	0.67	-0.14	0.64	0.42	0.39	0.4	0.11	0.3	0.2	0.3	0.42	0.36	0.1
IFL			-	-0.27	0.89	0.05	0.04	-0.01	0.01	-0.05	0.21	0.68	0.18	0.21	-0.25
FPI				-	0.18	0.35	0.25	0.33	0.02	0.01	-0.43	-0.21	-0.21	-0.18	0.29
FFL					-	0.25	0.16	0.18	-0.02	-0.09	0.01	0.58	0.1	0.18	-0.13
FW						-	0.91	0.95	0.36	0.51	-0.37	0.1	0.19	0.14	0.63
FL							-	0.82	0.68	0.7	-0.38	0.15	0.18	0.11	0.62
FWD								-	0.13	0.48	-0.35	-0.03	0.17	0.13	0.6
IFS									-	0.57	-0.23	0.25	0.06	-0.01	0.3
NDF										-	-0.06	-0.03	0.22	0.11	0.35
SSC											-	-0.06	0.67	0.65	-0.25
TA												-	-0.05	-0.02	-0.26
TSC													-	0.93	0.3
ISC														-	0.16
SC															-

y Correlation coefficient significant at P = 0.05 with value ≥0.45

step in PCA was to calculate eigenvalues, which define the amount of total variation that is displayed on the PC axes. The PCs with eigenvalues greater than 1.0 were used as criteria to determine the number of PCs, four in our case. These components are enough to explain 84.20% of the total variability observed, with PC1, PC2, PC3 and PC4 accounting for 36.56%, 23.47%, 14.32% and 9.84% on the variance, respectively. The variance accumulated by the first four components was a relatively high, which according to Veasey et al. (2001), explains satisfactorily the variability manifested between hybrids.

Correlation between the original variables and the first four principal components is shown in Table 3. Variables with higher scores on PC1 (over 0.70, absolute value) are FW, FL, FWD, FTC and SC. The highest contribution of PC2 corresponded to variables LFB and IFT. High loading on PC3 had FFL and TSC. Finally, PC4 largest score were due to FSI. The rest of the components varied to a less extent with about 15% of total variance.

PC1 explain the largest proportion of variability as much as 5 traits showed a high loading. The summarization of these traits in one component reflected the strong correlation between them reciprocally. Similarly, in PC2, two traits that had the most considerable loading were significantly correlated. This result suggested a reduction of these traits to two main characters, fruit size and potential of fruitfulness.

Table 3
Eigenvalues, proportion of total variability and correlation between the original variables and the first four principal components

Trait	PC1	PC2	PC3	PC4
FW	0.95	-0.034	0.064	-0.13
FL	0.958	-0.034	0.037	0.214
FWD	0.879	0.006	0.008	-0.259
IFS	0.522	-0.008	0.034	0.711
NDF	0.645	-0.087	-0.181	0.501
FLC	0.865	-0.132	0.18	0.115
LFL	0.415	-0.74	0.231	-0.076
IFL	0.003	-0.792	0.562	-0.032
FPI	0.38	0.437	0.169	-0.507
FFL	0.191	-0.62	0.642	-0.322
SSC	-0.394	-0.657	-0.52	-0.009
TA	-0.578	-0.602	0.297	0.35
TSC	0.216	-0.675	-0.657	-0.133
ISC	0.137	-0.679	-0.598	-0.22
SC	0.737	0.174	-0.346	-0.143
Eigenvalue	5.484	3.521	2.148	1.477
% Variance	36.56	23.47	14.32	9.84
% Cumulative	36.56	60.29	74.34	84.2

The scatter plot (Figure 1) shows the distribution of on the PC1 and PC2 plot and geometrical distances among hybrids that reflect similarity among them in terms of variables measured. Proceeding from negative to positive values of PC1, hybirid showed a general increase in fruit dimensions and weight. From negative to positive values of PC2, hybrids were characterized by smallest LFB and IFL.

Based on the position of floricane raspberry hybrids, two groups of related hybrids were separated. Eight hybrids and cultivar `Meeker` belong to group A. While those hybrids are in the same group with the standard cultivar can be considered interesting for commercial growing or further breeding. Hybrids I/3/2P, I/6/2, II/2/2P, II/3/4P and II/8/2P with high positive PC1 scores could be good genitors for large fruit size. On the other hand, hybrids 2 and 6A with high negative PC2 score could be good genitors for yield potential. Group B includes nine hybrids that corresponded with low positive or negative value of PC1 and negative value of PC2. The rest two hybrids (II/3/PP and II/5/4) that have negative value of PC1 and high positive values of PC2 are not interesting for further work.

Conclusion

Breeding and biotechnological approaches are currently used to increase the content of specific bioactive components of raspberry plants, but the manipulation of yield components and fruit quality parameters, particularly colour of the fruit,

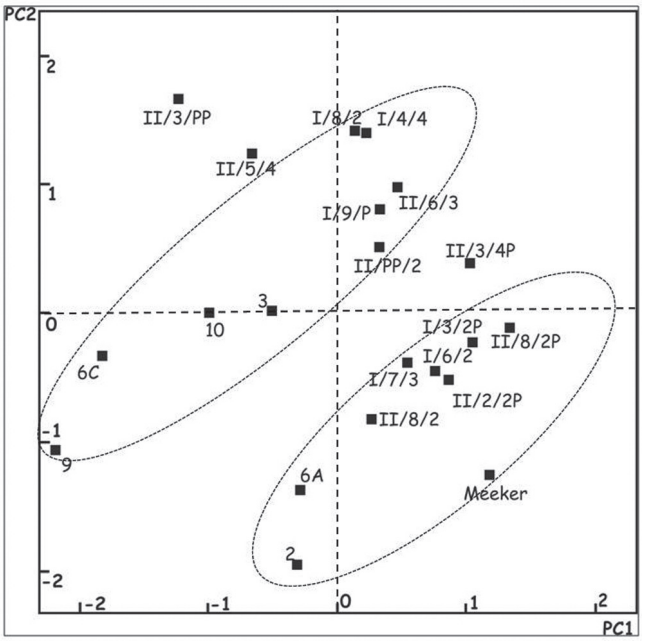

Fig. 1. Two-dimensional PCA scatter plot for 20 floricane raspberry hybrids

are still not easy to address. There is an increasing awareness that multiple genetic and environmental factors affect production and physical/chemical fruit traits, especially when breeding programs are aimed to produce new varieties with high yield efficiency combined with improved fruit quality.

The results of this study provide information about diversity of raspberry hybrids and show a wide spectrum of agronomic variability between the genotypes investigated. More specifically, raspberry hybrids in this study were superior in terms of fruit quality compared to the standard cultivar `Meeker`, whereas the values recorded for yield components were greater in the standard cultivar.

FLC showed a significant correlation with the largest number of traits tested. On the other hand, the most important parameters of fruit quality such as SSC, TSC and ISC did not correlated with the yield components, which means that those traits are genetically independent. It all points out the complexity of these characteristics, which makes the selection of raspberries and development of genotypes that will be characterized by both high yield and quality fruits very hard.

Some of the hybrids have many favourable characteristics that are commercially important for cultivation or hence they can be a good source for conventional breeding. This primarily applies to hybrids that are in the same group with the standard cultivar `Meeker`.

Using PCA a high correlation was found between some traits and principal components, which could reduce the number of traits to be studied in raspberry hybrids. In this regard as particularly important traits to distinguish raspberry hybrids are those related to fruit size and number and length of fruiting laterals.

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