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FRUIT QUALITY ASSESSMENT IN RASPBERRY BREEDING

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Abstract

The available raspberry cultivars are rapidly changing, highlighting the need for improvement in raspberry cultivars. Fruit quality assessment is crucial for red raspberry assortment breeding, with being essential for consumer acceptance. This study aimed to characterize raspberry fruits from different progenies morphologically. The data collected included average fruit weight, shape index, colour and soluble solids. The results showed significant variation in fruit weight and soluble solids content among the progenies. The fruit weight ranged from 2.50 g/fruit ('16-22-4') and 3.52 g/fruit ('16-22-5') and the soluble solids content: 11.20°Brix ('16-23-20') and 17.30°Brix ('16-1-23'). Based on the fruit quality, certain genotypes were identified as promising for future steps in the breeding program, including '16-1-10', '16-1-11', '16-1-22', '16-22-5', '16-22-11' and '16-23-20'.

***Key words**: Rubus idaeus, selection, fruit weight; soluble solids content; colour.*

INTRODUCTION

Rubus is one of the most diverse genera in the plant kingdom, with over 400 species (Bailey 1949) classified into 12 subgenera (Jennings, 1988). The cultivated subcategories include raspberries, blackberries, arctic fruits, and flowering raspberries, all of which have been used in breeding initiatives. The key varieties are the European red raspberry (*R. idaeus* L. subsp. *idaeus*), the North American red raspberry (*R. idaeus* subsp. *strigosus* Michx), and the black raspberry (*R. occidentalis* L.). Raspberry is believed to have originated from the Ide mountains in Turkey. *Rubus* species are low-growing to upright shrubs with thorns, producing new shoots from the ground (called canes). They are perennials because each bush comprises biennial canes that overlap in age. The leaves are compound with 3-5 leaflets, with the middle one being the largest, and the edges are serrated to irregularly toothed (Graham et al., 2007). The raspberry belonging to the *Rosaceae* family and widely cultivated in Asia (Veljkovi´c et al., 2019), are recognized for their exceptional cold and disease resistance, nutritional value, and flavor, making them widely available in the market (Xian et al., 2019). Ongoing research is focused on exploring their components and effectiveness. These small, soft fruits are rich in nutrients, including sugars, organic acids, vitamins, and phytochemical compounds (Vara et al., 2019). Approximately 50 active raspberry breeding programs are currently operating in 26 countries, with the majority located in Europe and North America (Kempler et al., 2012). Raspberry breeding programs for the fresh market aim to achieve fruit quality, productivity, and resistance to pathogens. The plant material forms the foundation for breeders' work, and new cultivars must be well-suited to the environmental conditions where they will be cultivated. Additionally, agronomy and the influence of different cultivation systems on plant behavior should be taken into account.

Therefore, breeders must consider genetics, environment, and agronomic technologies to develop new cultivars (F.R. Luz et al., 2022). Evaluating the quality of red raspberries is crucial, especially for product development and breeding programs, focusing on their physical and chemical characteristics. Genetic breeding of fruit yield is a primary goal in raspberry breeding programs globally (Way et al., 1983). While breeders have already made significant progress in increasing yield, there is still potential for further improvement in crops like raspberry, which have relatively short breeding histories (Jennings, 1988).

The consumer market has seen a growing interest in healthy eating and natural products in recent years, with raspberry aligning perfectly with these trends, leading to increased significance (Sawicka et al., 2023).

MATERIALS AND METHODS

Plant Material

The researches were carried out in 2021–2023 at the Research Institute for Fruit Growing (RIFG), Pitesti Romania (44°54'12" Northern latitude, and 24°52'18" Eastern longitude, 284 m altitude) in open an experimental field. There were twenty-three selections obtained in the year 2016 and one cultivar ('Heritage') was used as control in the evaluation (Table 1) in the randomized block design with three repetitions plots (10 plants/ genotype/ repetition).

Experiment Scheme

The selection evaluation plot was planted in April 2020 by using bare-root plants. Each genotype was planted twenty plants at distances 0.5 m from each other. The soil was soddy-podzolic clay loam showing medium and low humus content, the irrigation system used was the sprinkler irrigation type and plant protection treatments were applied. The field trials were in a conventional system, and before planting the following quantities were applied 40kg ha^{-1} N, 40 kg ha^{-1} P_2O_5 sand 60 kg ha^{-1} K_2O, as basic fertilization.

Table 1. The origin of the genotypes

Genotype	Parentage
16-1-2	Heritage × Polka
16-1-5	Heritage × Polka
16-1-10	Heritage × Polka
16-1-11	Heritage × Polka
16-1-12	Heritage × Polka
16-1-13	Heritage × Polka
16-1-14	Heritage × Polka
16-1-16	Heritage × Polka
16-1-17	Heritage × Polka
16-1-21	Heritage × Polka
16-1-22	Heritage × Polka
16-1-23	Heritage × Polka
16-22-2	92-7-40 × Yan Yan
16-22-4	92-7-40 × Yan Yan
16-22-5	92-7-40 × Yan Yan
16-22-7	92-7-40 × Yan Yan
16-22-8	92-7-40 × Yan Yan
16-22-11	92-7-40 × Yan Yan
16-22-15	92-7-40 × Yan Yan
16-23-7	BL 4 × Polana
16-23-12	BL 4 × Polana
16-23-18	BL 4 × Polana
16-23-20	BL 4 × Polana
Heritage	[(Milton × Cuthbert) × Durham]

Fruit quality parameters

The measured indicators were recorded during the optimal fruit harvesting period from a sample of 50 fruits. All measurements and analysis were conducted with 3 replications. The raspberry fruits were harvested manually directly in plastic pans. The length and diameter of the fruit were determined by measuring the fruit using a digital caliper. The shape index of the fruit was calculated as the ratio of these two dimensions (Titirica et al., 2023). The total soluble solids content (TSS) was measured using a digital refractometer Haana Instruments 96801 and values were recorded in °Brix. The external fruit color was determined with a colorimeter Konica Minolta CR 400, based on system Huntel L*, a*, b* on both sides of the fruit (L* corresponds to brightness, a* and b* chromaticity coordinates from green to red and from blue to yellow, respectively). Chroma index was determined by the formula $C = (a*2 + b*2)^{1/2}$ and hue angle of the formula h^0 = arctangent (b*/a*), where 0^0= red-purple, 90^0= yellow, 180^0= bluish-green and 270^0 =blue (McGuire, 1992).

Statistical analysis was performed using the IBM SPSS 14 program (SPSS Inc., Chicago, IL, USA). All results were statistically evaluated by analysis of variance (ANOVA), and Duncan's multiple test range. Differences were considered statistically significant for values of $p < 0.005$.

RESULTS AND DISCUSSIONS

Table 2 shows the values for average berry weight, shape index and total soluble solids, with the indication of the values of mean and standard deviation for the 24 raspberry genotypes.

Berry weight is a key quality parameter in the commercial raspberry market. While consumers typically prefer large berries, excessive berry weight (potentially > 15.0 g) is generally not suitable for either processed or fresh market use (Clark and Finn, 2011). The average weight of the fruit is a genetically determined characteristic, influenced by technical and cultural conditions, and has shown different values over the three years of study. For the three years of study, berry weight oscillated between 3.52 for the '16-22-5' hybrid to 2.5 g for the '16-22-4' hybrid (Table 2).

The physical fruit properties of floricane fruiting raspberry vary in *height*, ranging from 16.33 mm for the '16-22-4' hybrid to 21.29 mm for '16-23-20'. The fruit *diameter* varied from 12.77 mm for the '16-1-21' hybrid to 20.50 mm for the '16-1-10' hybrid. *The shape index*, the mean oscillated from 1.31 for the '16-1-21' hybrid (as well as long conical fruit shape with larger values than 1.00) to 0.87 for the '16-22-7' hybrid. Similar results are reported by Milivojević, (2011), the values of fruit shape index ranged from 0.93 to 1.10.

The analysis of variance revealed significant variation in *the soluble solids content* among the hybrids and the control. Cv. 'Heritage' exhibited significantly higher soluble solids (17.40 °Brix) in comparison with the hybrids ($P < 0.01$).

The value of soluble solids oscillated between 9.30 °Brix for '16-1-10' hybrid and 17.29 °Brix for '16-1-23' hybrid.

The color of the fruit is a major component in determining its quality, as it is closely linked to the levels and types of anthocyanins present in the fruit (García-Viguera et al., 1998). Robbins and Moore (1990) and Haffner et al. (2002) found that the relative color differences between cultivars are preserved during storage. Fruit color and adhesion to the receptacle are the main indicators for producers to determine the optimal ripeness for harvesting. Similarly, consumers primarily rely on color to assess the quality of the fruit. Anthocyanins play a significant role in imparting the red color to raspberry fruits (Stavang et al., 2015).

Table 2. Fruit weight, size and total soluble solid characteristics of raspberry genotypes (average 2021-2023)

Genotype	Berry weight (g/fruit)	Height (mm)	Diameter (mm)	Shape index	Total soluble solid (^{0}Brix)
16-1-2	2.80 ± 0.10^{fgh}	17.60 ± 0.10^{e}	18.82 ± 0.01^{f}	0.94 ± 0.01^{hi}	15.20 ± 0.10^{f}
16-1-5	2.51 ± 0.01^{i}	16.83 ± 0.01^{ghi}	18.74 ± 0.01^{g}	0.90 ± 0.01^{j}	11.60 ± 0.10^{p}
16-1-10	3.44 ± 0.01^{ab}	21.26 ± 0.01^{a}	20.50 ± 0.01^{a}	1.04 ± 0.01^{d}	9.30 ± 0.10^{r}
16-1-11	3.24 ± 0.01^{c}	20.51 ± 0.01^{b}	19.78 ± 0.01^{c}	1.04 ± 0.01^{d}	14.20 ± 0.10^{i}
16-1-12	2.97 ± 0.01^{de}	18.90 ± 0.07^{c}	19.83 ± 0.01^{c}	0.95 ± 0.01^{fg}	12.40 ± 0.01^{n}
16-1-13	2.74 ± 0.01^{gh}	17.17 ± 0.01^{efgh}	18.94 ± 0.01^{d}	0.91 ± 0.01^{ij}	13.10 ± 0.10^{k}
16-1-14	2.92 ± 0.01^{def}	18.34 ± 0.01^{d}	18.34 ± 0.01^{j}	1.00 ± 0.01^{e}	16.60 ± 0.10^{b}
16-1-16	2.84 ± 0.01^{efgh}	17.58 ± 0.01^{e}	19.45 ± 0.01^{d}	0.90 ± 0.01^{j}	14.50 ± 0.010^{h}
16-1-17	2.83 ± 0.01^{efgh}	17.57 ± 0.01^{e}	18.66 ± 0.01^{h}	0.94 ± 0.01^{h}	16.40 ± 0.10^{c}
16-1-21	2.76 ± 0.01^{gh}	16.72 ± 0.01^{hi}	12.77 ± 0.01^{q}	1.31 ± 0.01^{a}	16.01 ± 0.10^{d}
16-1-22	3.01 ± 0.01^{d}	20.01 ± 0.01^{b}	18.47 ± 0.01^{i}	1.08 ± 0.01^{c}	14.70 ± 0.01^{g}
16-1-23	2.85 ± 0.01^{efgh}	17.18 ± 0.01^{efgh}	18.50 ± 0.01^{i}	0.93 ± 0.01^{hi}	17.29 ± 0.01^{a}
16-22-2	2.75 ± 0.01^{gh}	17.21 ± 0.01^{efgh}	17.77 ± 0.01^{l}	0.97 ± 0.01^{fg}	12.50 ± 0.01^{mn}
16-22-4	2.50 ± 0.01^{i}	16.36 ± 0.01^{i}	17.25 ± 0.01	0.95 ± 0.01^{gh}	12.60 ± 0.01^{k}
16-22-5	3.52 ± 0.01^{a}	20.31 ± 0.01^{b}	18.86 ± 0.01^{f}	1.08 ± 0.01^{c}	14.10 ± 0.01^{m}
16-22-7	2.88 ± 0.01^{defg}	17.31 ± 0.01^{efg}	19.81 ± 0.01^{c}	0.87 ± 0.01^{k}	12.20 ± 0.01^{o}
16-22-8	2.94 ± 0.01^{def}	18.25 ± 0.01^{d}	17.47 ± 0.01^{m}	1.04 ± 0.01^{d}	13.30 ± 0.10^{j}
16-22-11	3.22 ± 0.01^{c}	20.06 ± 0.01^{b}	20.29 ± 0.01^{b}	0.99 ± 0.01^{ef}	11.50 ± 0.01^{p}
16-22-15	2.80 ± 0.10^{fgh}	19.01 ± 1.15^{c}	18.49 ± 0.01^{i}	1.03 ± 0.06^{d}	15.40 ± 0.01^{e}
16-23-7	2.71 ± 0.01^{g}	17.16 ± 0.01^{efgh}	17.40 ± 0.01^{n}	0.99 ± 0.01^{ef}	11.50 ± 0.01^{p}
16-23-12	2.88 ± 0.01^{defg}	17.34 ± 0.01^{efg}	16.45 ± 0.01^{p}	1.05 ± 0.01^{cd}	14.20 ± 0.01^{i}
16-23-18	2.70 ± 0.01^{g}	16.93 ± 0.01^{fgh}	17.75 ± 0.01^{l}	0.95 ± 0.01^{gh}	12.80 ± 0.01^{l}
16-23-20	3.31 ± 0.01^{bc}	21.29 ± 0.01^{a}	18.17 ± 0.01^{k}	1.17 ± 0.01^{b}	11.20 ± 0.01^{q}
Heritage	2.88 ± 0.36^{defg}	17.45 ± 0.78^{ef}	18.53 ± 0.19^{i}	0.94 ± 0.05^{gh}	17.40 ± 0.19^{a}

Table 3. Fruit quality colour characteristics of raspberry genotypes (average 2021-2023)

Genotype	Brightness (L*)	Chromaticity a*- axis (red-green)	Chromaticity b*- axis (yellow-blue)	Chroma Index (C*)	The angle (h °)
16-1-2	25.69±0.01[jk]	20.04±0.01[ghi]	6.29±0.01[hij]	20.70±0.61[jk]	17.42±0.01[ijk]
16-1-5	25.82±0.01[hijk]	20.42±0.01[gh]	6.60±0.01[ghi]	21.46±0.01[ghij]	17.9±0.01[hij]
16-1-10	24.53±0.01[l]	20.55±0.01[fg]	6.72±0.01[gh]	21.64±0.01[fgh]	18.11±0.01[hi]
16-1-11	27.90±0.01[d]	23.37±0.01[d]	8.28±0.01[c]	24.79±0.01[d]	19.50±0.01[ef]
16-1-12	23.41±0.01[m]	19.27±0.01[jkl]	5.93±0.01	20.16±0.01[kl]	17.10±0.01[jk]
16-1-13	26.60±0.01[fgh]	19.36±0.01[jkl]	4.56±0.01[l]	19.89±0.0[l]	13.24±0.01[m]
16-1-14	25.15±0.01[kl]	15.07±0.01[o]	4.36±0.01[l]	15.69±0.01[n]	16.12±0.01[l]
16-1-16	26.73±0.01[ef]	17.19±0.01[n]	5.15±0.01[k]	17.94±0.01[m]	16.67±0.01[kl]
16-1-17	26.52±0.01[fghi]	19.89±0.01[hij]	8.28±0.01[c]	21.54±0.01[ghi]	22.57±0.06[c]
16-1-21	27.80±0.01[d]	24.77±0.01[ab]	8.05±0.01[cd]	26.05±0.01[b]	18.03±0.06[hi]
16-1-22	25.71±0.01[jk]	23.81±0.01[cd]	7.72±0.01[de]	25.03±0.01[cd]	17.96±0.01[hij]
16-1-23	25.18±0.01[kl]	19.64±0.01[ijk]	6.92±0.01[fg]	20.83±0.01[ijk]	19.42±0.01[ef]
16-22-2	28.72±0.01[c]	19.65±0.01[ijk]	7.69±0.01[de]	21.10±0.01[hij]	21.38±0.01[d]
16-22-4	25.38±0.01[k]	16.64±0.01[n]	6.98±0.01[fg]	18.05±0.01[m]	22.76±0.01[c]
16-22-5	29.14±0.01[bc]	20.63±0.01[fg]	7.30±0.01[ef]	21.89±0.01[fg]	19.49±0.01[ef]
16-22-7	27.43±0.01[de]	18.51±0.01[m]	6.16±0.01[ij]	19.50±0.01[l]	18.42±0.01[gh]
16-22-8	31.72±0.01[a]	19.77±0.01[ijk]	9.30±0.01[b]	21.85±0.01[fgh]	25.20±0.01[b]
16-22-11	25.87±0.01[ghijk]	21.63±0.01[e]	7.62±0.01[de]	22.93±0.01[e]	19.41±0.01[ef]
16-22-15	29.81±0.01[b]	23.74±0.01[cd]	10.10±0.01[a]	25.80±0.01[b]	23.05±0.01[c]
16-23-7	25.77±0.01[ijk]	24.24±0.01[bc]	8.46±0.01[c]	25.67±0.01[bc]	19.24±0.01[efg]
16-23-12	26.32±0.01[fghij]	18.92±0.01[lm]	9.28±0.01[b]	21.07±0.01[hij]	26.13±0.01[a]
16-23-18	26.66±0.01[fg]	25.17±0.01[a]	9.09±0.01[b]	26.76±0.01[a]	19.86±0.01[e]
16-23-20	25.15±0.01[kl]	21.13±0.01[ef]	7.27±0.01[ef]	22.35±0.01[ef]	19.01±0.01[efg]
Heritage	26.65±2.10[fg]	19.13±1.74[kl]	6.53±1.28[ghi]	20.23±1.99[kl]	18.72±2.42[fgh]

The color of raspberries and berry pulps is a major factor linked to their quality, and preserving the natural color pigments in thermally processed foods poses a significant challenge in food production (Badin et al., 2020). This means that fruits with a lighter red color and less blue (higher Hue°) at harvest also maintain better (lighter) color after storage.

In our study the Brightness (L*) oscillated between 13.72 for '16-22-8' hybrid and 25.15 for '16-23-20' hybrid. The a*-axis (red-green) and b*-axis (yellow-blue) chromaticity have a higher value of 25.17 for '16-23-18' and 10.1 for '16-22-15'.

Chroma Index (C*) oscillated between 15.69 for '16-1-14' hybrid to 26.76 for '16-23-18' hybrid. The angle (h °) oscillated between 17.1 for '16-1-12' hybrid and 26.13 for '16-23-12' hybrid.

Table 3 displays the relationship between fruit quality traits from 2021 to 2023. A notably strong correlation is evident between the shape index and the berry, with a correlation coefficient of (r = 0.357**) (Table 4). This can be attributed to the fact that the weight of the berry is influenced by its size. Furthermore, the correlation matrix reveals a negative correlation between the color indexes (a, b, chroma) and total soluble solids (r = -0.122, and r = 0.524** respectively). The color indexes (a*, b* chroma) show a clear and significant correlation with the shape index (r = 0.466**, r = 0.389** si, r = 0.480). The color indexes, specifically b, also show a distinct and significant correlation with brightness (r = 0.499**) and a* (r = 0.655**).

Table 4. Pearson correlation coefficients for the quality indicators
for the studied raspberry genotypes (average 2021-2023)

Pearson Correlation	Berry weight (g/fruit)	Shape index	Total soluble solid (^{0}Brix)	Brightness (L*)	Chromaticity a*- axis (red-green)	Chromaticity b*- axis (yellow-blue)	Chroma Index (C*)	The angle (h °)
Berry weight (g/fruit)	1	0.357**	-0.202	-0.028	0.103	-0.005	0.088	-0.089
Shape index		1	0.043	0.200	0.466**	0.389**	0.480**	0.163
Total soluble solid (^{0}Brix)			1	0.174	-0.122	-0.021	-0.113	0.041
Brightness (L*)				1	0.199	0.499**	0.269*	0.469**
Chromaticity a*- axis (red-green)					1	0.655**	0.989**	0.076
Chromaticity b*- axis (yellow-blue)						1	0.755**	0.800**
Chroma Index (C*)							1	0.216
The angle (h °)								1

CONCLUSIONS

The weight of berries is significantly affected by the specific genotypes and agro-environmental and meteorological conditions. All the genotypes showed increased berry weight in the three years of the study.

The study's findings indicate that the climate in Pitesti-Mărăcineni is conducive to the commercial cultivation of the raspberry genotypes studied, provided that appropriate agricultural techniques are utilized. This is especially true for the hybrids '16-22-5', '16-23-20', '16-1-21', '16-22-8' which demonstrate superior fruit quality and berry weight.

While the 'Heritage' cv. produces attractive fruits, it is best suited for fresh consumption. Both the 'Heritage' cv. and the mentioned hybrids are of interest for breeding programs due to their potential as a source of genetic variability.

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