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Fruit weight and primary metabolites content of plum fruits as affected by planting density

Svetlana M. Paunović[1]✉, Radivoj V. Prodanović[2], Mira Milinković[3], Žaklina Karaklajić-Stajić[1], Jelena Tomić[1], Boris Rilak[1]

[1]*Fruit Research Institute, Čačak, Serbia*
[2]*University Business Academy in Novi Sad, Faculty of Economics and Engineering Management, Novi Sad, Serbia*
[3]*Institute of Soil Science, Belgrade, Serbia*

✉ svetlana23869@gmail.com

Abstract

An experiment was conducted to evaluate the effect of different dense planting (4×1 m; 4×2 m and 5×3 m) on the fruit weight and contents of primary metabolites (soluble solids, total sugars, invert sugars, total acids, and pH) in the fruits of eight plum cultivars ('Čačanska Rana', 'Čačanska Lepotica', 'Timočanka', 'Krina', 'Mildora', 'Čačanska Najbolja', 'Čačanska Rodna' and 'Stanley'). During the three-year experimental period, results showed variability in fruit weight and chemical composition between different cultivars and planting densities. The highest fruit weight was recorded at the planting distance of 4×2 m in cultivars 'Čačanska Rana', 'Čačanska Lepotica', 'Krina', 'Mildora' and 'Čačanska Najbolja', while the cultivars 'Timočanka', 'Čačanska Rodna' and Stanley' had the highest value at the standard distance of 5×3 m. Regarding primary metabolites, in all tested cultivars, the accumulation and synthesis of soluble solids and sugars in the fruit increased with increasing planting density, while pH and total acids showed the opposite trend. The present results indicated that different planting densities have an important effect on fruit weight and plant metabolism, promoting the synthesis and accumulation of primary metabolites in the fruits, thus positively affecting the quality and commercial value of the fruit.

Key words: plum, high-density planting, fruit weight, primary metabolites

INTRODUCTION

In the Republic of Serbia, the plum (*Prunus domestica* L.) is a traditional fruit crop and a leading fruit species. Tradition, favourable natural conditions, brandy processing, etc., influence producers' decisions to grow plums. However, plum production is characterized by extensive growing technology, low, unstable yields, and low-quality fruit. In recent years, plum production has been increasing, which indicates that extensive production has been increasingly replaced with semi-intensive and intensive ways of growing. In the Republic of Serbia, cultivars developed at the Fruit Research Institute in Čačak, such as 'Čačanska Lepotica' and 'Čačanska Rodna' are being grown more and more, and they are slowly taking a leading position in plum growing, and to a lesser extent, there are also 'Čačanska Rana', 'Timočanka' and 'Čačanska Najbolja'. Plum is primarily grown grafted on rootstock Prunus cerasifera L. stock, requiring large planting spaces and classical crown forms (Mišić, 2006). In recent years, there has been a need to raise new plum plantations according to the principles of modern cultivation technology using different dense planting (Mićić et al., 2006; Peppelman et al., 2007). Planting distance is an important agricultural activity to capture environmentally efficient natural resources and plays a major function in regulating competition between neighboring plant canopies (Li et al., 2020). According to Haque and Sakimin (2022), high-density orcharding is one of the recent novel concepts of fruit cultivation, involving the planting of

fruit trees at a density for better light interception and distribution and increased yield. Policarpo et al. (2006) reported that high planting density besides the changes in the quantity and quality of intercepted light, the partitioning of assimilates between vegetative and reproductive shoots may be responsible for the effects on fruit quality. In plums, planting density, in combination with adequate cultivation forms and the application of specific pomo-technical measures, contributes to establishing a balance between vegetative and generative potential, which directly affects the yield and quality of fruits (Miletić et al., 2011a, 2011b).

With this in mind, the objective of the experiment was to examine the effect of planting density on the fruit weight and the content of primary metabolites in plum fruits.

MATERIALS AND METHODS

Plant material

The research was conducted at the Zdravljak facility of the Fruit Research Institute, Čačak, Western Serbia. The plantation was set up in 2006 at 550 m above sea level on a lot with a south-east exposition. Plum cultivars are grafted on rootstock *Prunus cerasifera* L. The analysis involved 8 plum cultivars (‘Čačanska Rana’, ‘Čačanska Lepotica’, ‘Timočanka’, ‘Krina’, ‘Mildora’, ‘Čačanska Najbolja’, ‘Čačanska Rodna’, and ‘Stanley’) and three treatments with a different planting density (4×1 m; 4×2 m and 5×3 m). In treatments I and II, using corresponding pomo-technical measures, trees were given the shape of the modified planning form – the spindle bush, with changes in the layout, position, and number of skeletal branches from the base to the top of the crown. In this manner, it was possible to regulate the development of the vegetative mass in the higher sections of the crown by developing shorter fruiting twigs and thorn shoots. In treatment III, the adopted shape was the classical improved pyramid crown. Orchard management was consistent with standard cultural practice (pruning, fertilization, pest and disease control, drip irrigation).

Analysis of fruit samples

The fruits were sampled in the phase of physiologic maturity. A total of 100 g fruits were sampled from 5 trees per replication. The analysis of the plums included the following parameters: 1. Fruit weight was determined on a Mettler precision scale with an accuracy of 0.01 g; 2. Soluble solids content was determined by a digital refractometer (Kruss); 3. Total and invert sugars (%) were analyzed by the Loof-Schoorl method (Egan et al., 1981); 4. Total acids were measured using a burette containing 0.1 N NaOH; 5. Actual acidity (pH value) was measured by a pH Meter Iskra MA 5707, Slovenia.

Statistical Analysis

The experimental data obtained during the three-year research period were subjected to statistical analysis using Fisher's two-factor analysis of variance – ANOVA, using the MSTAT-C statistical computer package (Michigan State University, East Lansing, MI, USA). Significant differences between the mean values of the tested factors and the interaction means were determined by LSD test at $P \leq 0.05$ significance levels. The paper presents the average values of the tested parameters during the study period.

RESULTS AND DISCUSSION

The results on the fruit weight in the tested plum cultivars depending on the planting density are presented in Figure 1. The cultivars grown at different planting densities showed significant differences in the fruit weight. The highest fruit weight was recorded at a planting density of 4×2 m in cultivars ‘Čačanska Rana, ‘Čačanska Lepotica’, ‘Krina’, ‘Mildora’ and ‘Čačanska’ Najbolja, whereas the cultivars ‘Timočanka’, ‘Čačanska Rodna’ and ‘Stanley’ had the highest value fruit weight at a planting density of 5×3 m, which is consistent with the results of Mitrović et al. (2005) and Miletić et al. (2011c). However, the present results differ from the findings of Haque and Sakimin (2022), Kumar et al. (2015) and Kumawat et al. (2014), who reported that fruit size increases with decreasing planting density in plants, while Mika et al. (1998), Meland (2005) and Molnár and Holb (2023) found that tree spacing has not strongly influenced plum fruit weight.

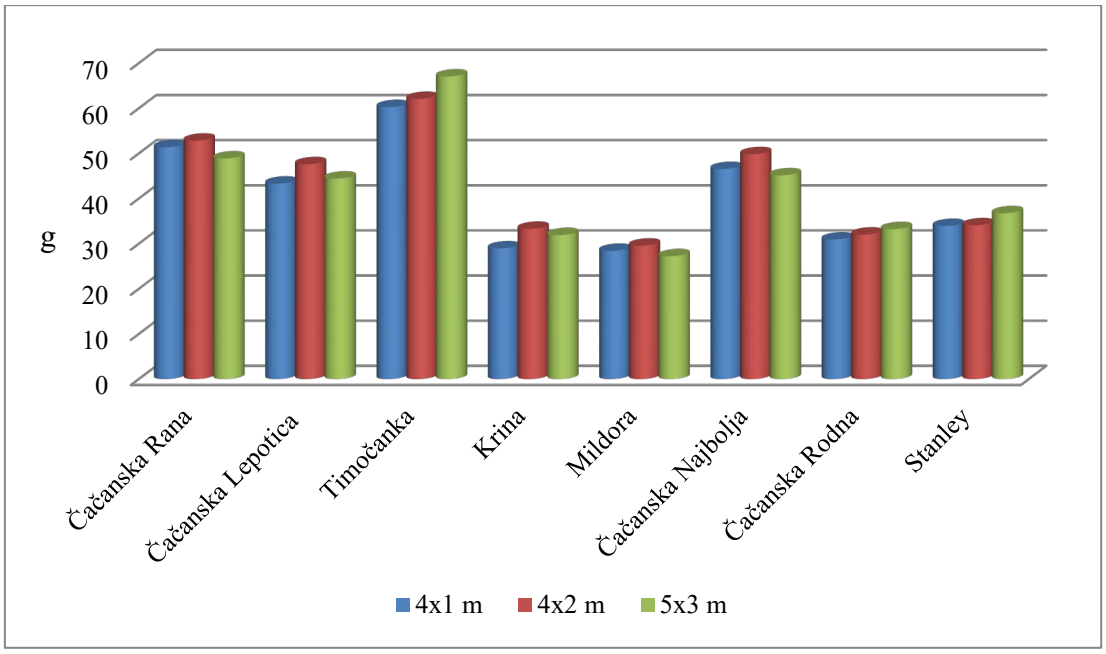

Figure 1. Effect of planting density on fruit weight in different plum cultivars

The content of primary metabolites in plum fruits was significantly affected by planting density (Figure 2 and Table 1). The experimental results showed that the soluble solids content varied from 13.2% to 24.8%. The highest soluble solids, total and invert sugar contents in fruit extracts were obtained in cultivars 'Čačanska Rana', 'Mildora', 'Timočanka' and 'Čačanska Najbolja' grown in the treatment of dense planting of 4×2 m. In contrast, the cultivars 'Čačanska Lepotica', 'Krina', 'Čačanska Rodna' and 'Stanley' gave the highest values at a standard planting distance of 5×3 m. It is probably due to less competition among plants for light, considering that fruits require photoassimilates from leaves to accumulate sugars during ripening; thus, wider spacing probably provides larger canopies that provide more photoassimilates. Also, lower sugar contents in the high-density plot may be due to a lower sugar conversion from starch.

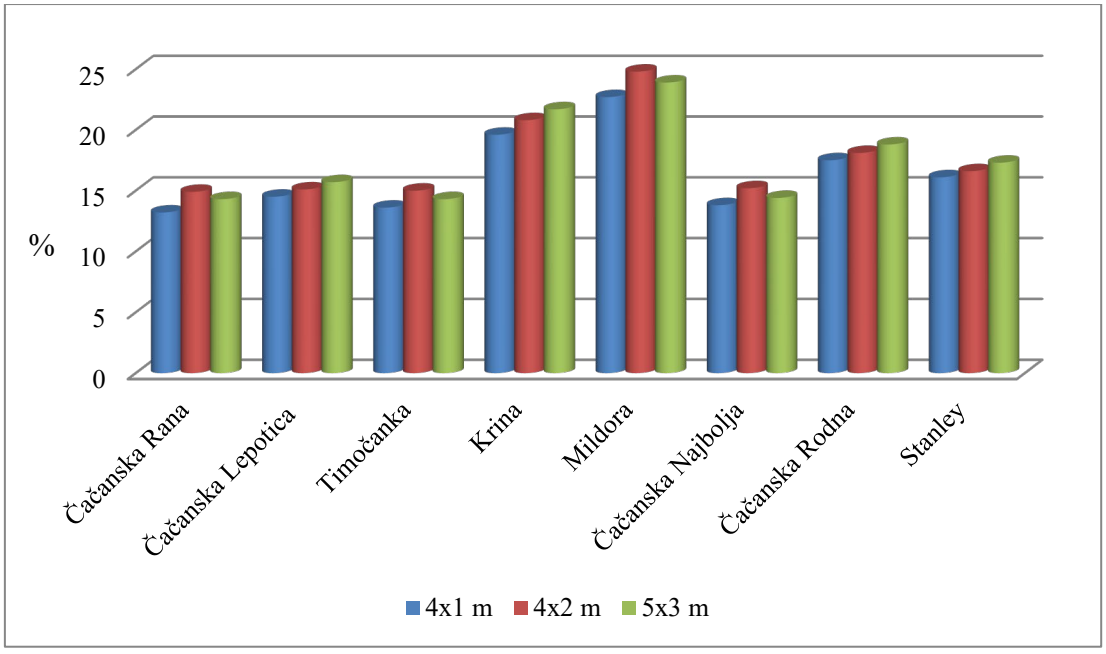

Figure 2. Effect of planting density on soluble solids content in different plum cultivars

As for acids, the total acids were the highest at a planting distance of 4×1 m in cultivars 'Čačanska Rana', 'Čačanska Lepotica', 'Timočanka' and 'Čačanska Najbolja', whereas in cultivars 'Krina', 'Mildora', 'Čačanska Rodna' and 'Stanley' the highest values were recorded at a planting distance of 4×2 m. Conversely, the higher pH value was obtained in almost all tested cultivars at a planting density of 4×2 m, except for cultivars 'Čačanska Rodna' and 'Stanley' which had a higher level at a distance of 4×1 m. The higher acidity in the high-density plot may be due to the shade effect, which results in increased competition among plum trees, resulting in a lower production of photoassimilates directed to the fruit and lower sugar conversion from organic acid, which is hampered due to a lack of sufficient light (Haque and Sakimin, 2022).

Table 1. Contents of primary metabolites in plum fruit depending planting density

Cultivar	Planting density	Total sugars (%)	Invert sugars (%)	Total acids (%)	pH
Čačanska Rana	4×1 m	7.23±0.33 k	4.46±0.24 j	1.18±0.08 a	3.21±0.01 kl
	4×2 m	8.67±0.75 jk	6.27±0.55 hij	1.03±0.06 b	3.34±0.02 jk
	5×3 m	8.25±0.64 k	5.69±0.39 ij	0.95±0.03 cd	3.15±0.02 l
Čačanska Lepotica	4×1 m	9.72±0.62 fgh	7.33±0.51 fgh	1.16±0.09 a	3.28±0.01 kl
	4×2 m	9.93±0.84 efg	7.78±0.65 ef	0.99±0.07 bc	3.43±0.04 j
	5×3 m	10.55±1.03 de	8.42±0.84 de	0.93±0.04 cd	3.17±0.02 l
Timočanka	4×1 m	10.53±0.81 de	7.70±0.64 ef	0.84±0.03 ef	3.60±0.04 gh
	4×2 m	11.97±0.89 cd	8.90±0.88 c	0.76±0.02 gh	3.71±0.05 efg
	5×3 m	10.71±0.86 d	8.23±0.75 de	0.68±0.01 ijk	3.33±0.02 jk
Krina	4×1 m	10.43±1.21def	8.85±0.94 c	0.61±0.03 lmn	3.65±0.02 fgh
	4×2 m	12.08±1.58 bc	9.37±1.10 b	0.66±0.04 klm	3.96±0.06 bc
	5×3 m	12.65±2.02 b	10.05±1.17 a	0.55±0.02 no	3.84±0.04 cde
Mildora	4×1 m	13.77±1.85 a	8.73±0.82 cd	0.50±0.03 o	4.00±0.02 b
	4×2 m	14.38±2.40 a	9.32±1.03 b	0.58±0.05 n	4.29±0.04 a
	5×3 m	12.82±1.48 b	8.40±0.77 de	0.41±0.02 p	3.88±0.01 bcd
Čačanska Najbolja	4×1 m	8.50±0.54 jk	5.45±0.29 ij	0.79±0.08 fg	3.52±0.03 hi
	4×2 m	9.36±0.77 hij	6.85±0.68 ghi	0.74±0.06 ghij	3.78±0.07 def
	5×3 m	8.87±0.68 ijk	6.42±0.55 hij	0.67±0.04 jkl	3.61±0.04 gh
Čačanska Rodna	4×1 m	11.85±1.23 cd	6.95±0.54 ghi	0.85±0.04 ef	3.73±0.04 efg
	4×2 m	12.23±1.44 bc	7.56±0.63 fg	0.88±0.06 de	3.64±0.02 fgh
	5×3 m	12.85±1.60 b	7.82±0.71 ef	0.80±0.03 fg	3.40±0.01 ij
Stanley	4×1 m	8.91±0.43 ijk	6.10±0.42 hij	0.60±0.02 mn	3.59±0.06 gh
	4×2 m	9.55±0.71 ghi	7.07±0.97 fgh	0.75±0.05 ghi	3.54±0.03 hi
	5×3 m	9.73±0.82 fgh	6.73±0.56 ghi	0.70±0.03 hijk	3.55±0.02 hi
ANOVA					
Cultivar (A)		**	**	**	**
Treatment (B)		**	**	**	**
A × B		**	**	**	**

Means followed by different letters within columns are significantly different at $P \leq 0.05$ according to LSD test and ANOVA (F-test) results

The present results are comparable to those obtained by Mehta et al. (2006) and Kumar et al. (2013), who reported that soluble solids in apricots increase at wider spacing, while acidity was maximum in closer spacing, as a result of higher photosynthesis, which can improve fruit quality. Also, Gaikwad et al. (2017) noted that in mango, a decrease in soluble solids and an increase in acid content with increased planting density probably occurred due to poor interception of light, air circulation, and competition for nutrients in dense planting orchards. Likewise, Sarrwy et al. (2012) and Chaudhury and Baruah (2010) showed that bananas raised at lower density exhibited lower fruit quality in terms

of soluble solids and sugar contents, while titratable acidity and non-reducing sugar showed the opposite trend. Singh et al. (2020) found that the fruit of *Litchi chinensis* had higher soluble solids at higher planting density, while the acidity of fruits decreased with increasing spacing. In contrast, Kumawat et al. (2014) obtained a higher content of soluble solids and sugars in the fruit grown at lower planting density and high acidity in higher-density planting systems. According to Mika et al. (1998) and Meland (2005), important quality components in plum fruits, such as soluble solids content, are not strongly influenced by planting densities. Also, Kumar et al. (2015) and Mano et al. (2011) recorded that in figs, soluble solids and acidity were not influenced by planting distance.

The presented results demonstrated significant differences among cultivars regardless of planting density. During the three-year experimental period, the average fruit weight ranged from 28.4 g to 63.1 g. The highest value for fruit weight was obtained in cultivar 'Timočanka' (63.1 g), and the lowest in the cultivar 'Mildora' (28.4 g). Also, the high fruit was detected in 'Čačanska Rana' (51.3 g). In terms of primary metabolites, the soluble solids content in the fruit ranged from 13.2% to 24.8%. 'Mildora' fruits had the highest content of soluble solids and total sugars (23.8% and 13.6%, respectively), whereas the lowest values were found in 'Čačanska Rana' (14.1% and 8.05%, respectively). 'Krina' had the highest content of invert sugars (9.42%), as opposed to 'Čačanska Rana' (5.47%), which exhibited the lowest values. In contrast, as regards acids, the highest values for total acids were obtained in 'Čačanska Lepotica' (1.03%) and 'Čačanska Rana' (1.05%), whereas the lowest levels were recorded in 'Mildora' (0.50%). On the other hand, the fruit of 'Mildora' (4.06) outperformed the other cultivars in terms of fruit pH, which was the lowest in 'Čačanska Lepotica' (3.29) and 'Čačanska Rana' (3.23) fruit. The contents of primary metabolites were in agreement with cultivar-specific traits and are comparable to the results of Mitrović et al. (2006), Glišić et al. (2016) and Tomić et al. (2019). Milatović et al. (2016) recommend plum cultivars 'Čačanska Lepotica' and 'Čačanska Najbolja' for fresh fruit consumption, and 'Čačanska Rodna' and 'Mildora' for fresh consumption and processing Popović et al. (2013) reported that fruits of 'Čačanska Rodna' had a high content of total sugars, which is typical of this cultivar. Also, Miletić et al. (2014) observed that cultivar 'Mildora' had very high soluble solids and low acid content, which confirms its suitability for drying. In Bosnia and Herzegovina Zavišić and Rosić (2016) found that the cultivars 'Čačanska Lepotica' and 'Čačanska Rodna' can be recommended for different purposes due to the size and quality of the fruit, suitable for various kinds of processing and drying.In Montenegro, Božović et al. (2017) recorded higher soluble solids content and sugar but lower acid levels in the fruits of plum, which can be attributed to the effect of climatic factors on the studied plum cultivars.

CONCLUSIONS

The results indicated that different planting densities in commercial plum orchards directly led to fruit weight and plant metabolism, promoting the synthesis and accumulation of different primary metabolites in the fruits, which should be considered when establishing commercial plum orchards and choosing planting density.

The tested plum cultivars exhibited significant differences in the content of primary metabolites. Fruit chemical accumulation (soluble solids, sugars, and acids) was non-uniform, being cultivar-dependent and planting density. Given their good chemical characteristics, the tested cultivars deserve to find a place in intensive plum orchards, as they are suitable for growing at different planting densities.

Generally, the data obtained in this study confirm that plums represent a valuable source of primary metabolites and can be used as a new source of natural foods in human nutrition and preventive medicine.

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