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MORPHOMETRIC CHARACTERISTICS AND VALORIZATION OF *PRUNUS DOMESTICA* L. STONES

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Abstract

European plum (Prunus domestica L.) is one of the most important fruit species in the Balkan Peninsula, where it is predominantly used for fruit brandy production. Destoning during processing generates large quantities of stones and seeds that are mostly discarded as waste. This study aimed to evaluate the morphometric characteristics of plum stones and seeds of four cultivars ('Čačanska Lepotica', 'Stanley', 'Empress', and 'Požegača') to assess varietal differences relevant for further processing. For valorisation studies, seeds were subjected to cold-press oil extraction to determine the fatty acid composition and oxidative stability of the obtained oils. Oleic acid was the dominant fatty acid in plum seed oil, reaching 72.49% in Stanley and 58.55% in Empress, followed by linoleic acid. Oxidative stability ranged from 35.17 (Empress) to 73.51 h (Stanley), indicating high oil stability. Oil cakes were further evaluated for techno-functional properties and for their potential as a source of bioactive compounds using eutectic solvent-based extraction. These results highlight plum stones as a valuable raw material for sustainable processing.

Key words*: plum stones, seed, seed oil, oil cake.*

INTRODUCTION

European plum (*Prunus domestica* L.) is one of the most economically important fruit species in many European countries, particularly in the Balkan region, where it represents a traditional and widely cultivated crop. Its fruits are used for fresh consumption as well as for various processed products, including dried fruits, jams, juices, and distilled beverages, which significantly increases its economic importance in the food industry (Dimkova et al., 2018). Plum is the most widely cultivated fruit species in Bosnia-Herzegovina. Although it is predominantly grown under traditional production systems, increasing demand on the domestic market (distilled spirit production) and on international markets for fresh consumption highlights the need for more intensive cultivation and improved production efficiency (Cvetković and Mićić, 2018). Successful plum production requires rootstocks and cultivars well adapted to specific environmental conditions (Milošević et al., 2022). Given the interaction between genotype and environment, it is necessary to evaluate the morphological and agronomic performance of cultivars under local growing conditions to determine their suitability for production and processing (Vitanova et al., 2004; Nesheva et al., 2021). Beyond modernizing cultivation technologies, maximizing the use of all components of the production process offers additional opportunities to enhance the sustainability of plum cultivation. In recent years, our research has been devoted to the valorization of agro-industrial by-products as sustainable sources of bioactive compounds and functional ingredients (Ćirić et al., 2024; Dabić Zagorac et al., 2024). After industrial processing of plums into various food products, a large number of by-products remains, such as plum pits, skins, and similar materials. Plum pits are the source of plum seeds, which have great potential as an

unconventional oil source, with oil content up to 50% (Vladić et al., 2020). The dominant fatty acid in this oil is the monounsaturated oleic acid, at over 60%, which significantly contributes to the oil's good oxidative stability (Rabrenović et al., 2021). In addition to food, this oil can be used for biodiesel production and in the cosmetics and pharmaceutical industries. After cold pressing, in addition to plum seed oil, a significant amount of oil cake with a high protein content remains. Plum seed oil cake can be considered an inexpensive and readily available source of protein (up to 40%) (Čakarević et al., 2019). The aim of this study was to evaluate the morphological characteristics of plum stones and seeds of four European plum cultivars, as well as to assess the techno-functional properties of the obtained oilcakes and their valorisation potential as a source of bioactive compounds. Particular attention was given to the morphometric traits of stones and seeds, since these parameters may influence the yield and technological potential of plum seed oil and its by-products. Considering the intended industrial use of functional ingredients in bakery products, the research plan was designed in accordance with green chemistry principles, using eutectic solvent systems for extraction. Additionally, determining the total polyphenol content and antioxidant activity of the extracts provides valuable information on the potential utilization of the studied cultivars and their processing by-products.

MATERIALS AND METHODS

Stone and seed analysis. Uniform plum fruits were harvested during the 2024 growing season at optimal technological maturity. Fruits of the cultivars 'Čačanska Lepotica', 'Stanley', and 'Empress' were collected from the Experimental and Educational Center of the Faculty of Agriculture, University of Banja Luka, while fruits of 'Požegača' were obtained from a nearby commercial orchard (44.948174, 17.209729). Stones were separated by mechanical crushing and air-dried in the shade for 40 days, then labeled and stored under ambient conditions. At the end of 2025, stones and seeds were subjected to morphometric analyses. Measurements were performed on 15 stones and 15 seeds per cultivar, in two replications. Stone and seed mass were determined using a precision balance, while linear dimensions (height, width, and width across the suture) were measured with a digital caliper. The seed-to-stone ratio was subsequently calculated. Morphometric analyses were conducted at the Laboratory of Pomology and Biotechnology, Faculty of Agriculture, University of Banja Luka. For further valorization studies, 500 ± 20 g of seeds per cultivar were prepared, labeled, and delivered to the Faculty of Chemistry at the University of Belgrade.

Cold-pressing. Plum seeds were dried at room temperature for 24 hours immediately before pressing, after which the cold-pressing procedure was performed using a laboratory screw press (Gorenje OP650V, Slovenia). During pressing, the temperature of the extracted oil was monitored by an infrared thermometer (TFI 260, Ebro-Xylem, Germany) and did not exceed 45°C. After 24 hours of sedimentation, the oils were filtered through filter paper and stored in 10 mL plastic cuvettes at -20°C until analysis. Oil cakes were ground, sieved, and further evaluated for techno-functional properties.

Fatty acid composition. Fatty acid methyl esters were prepared according to the standard method (SRPS EN ISO 12966-2:2017). Separation and detection of methyl esters were performed by gas chromatography, following the standard (SRPS EN ISO 12966-1:2015), using a gas chromatograph (Agilent Technologies 6890, USA) equipped with a split-splitless injector, a flame ionisation detector (FID), and a Supelco SP-2560 capillary column (100 m length × 0.25 mm inner diameter × 0.20 μm film thickness, Supelco, Bellefonte, USA). Helium at a flow rate of 5 mL/min was used as the mobile phase. Injector and detector temperatures were 250°C and 260°C, respectively. The injected volume was 1 μL, and the injector split ratio was set to 20:1. The column temperature was programmed from an initial 50°C (held for 5 minutes) to 240°C (held for 20 minutes) at a rate of 4°C/min. Chromatographic peaks in the sample were identified by comparing the relative retention times of the fatty acid methyl esters in the samples with those of the Supelco 37 Component FAME Mix standard. The fatty acid content was calculated in mg/g of lipids and

expressed, as a relative quantity, as a mass percentage of total fatty acids.

Oxidative stability. The oxidative stability of the oil samples was tested using an OXITEST device (Velp® Scientifica, Usmate, Italy). Ten grams of each oil sample were weighed into two titanium thermostatic chambers of the device. The chambers were hermetically sealed. The temperature was set to 90°C, and the initial O2 pressure to 0.6 MPa. Using dedicated software (OXISoft, Velp, Italy), the change in pressure in the chambers was monitored, thereby indirectly measuring the oxygen consumed by individual components. For each chamber, the software calculated the induction period (IP) at the end of the test, in minutes or hours. A longer IP indicates better oxidative stability of the sample.

Techno-functional characteristics of oil cakes.

Moisture content. The moisture content of the POC was determined in accordance with the SRPS EN ISO 665:2020 standard method. The moisture content of a portion of the test sample was determined by drying at 103°C ± 2°C in an oven at atmospheric pressure until a constant mass was reached.

Swelling Capacity (SC). The swelling capacity was determined as follows: 1.0 g of each oil cake was placed in a measuring vessel, and 30 mL of distilled water was added. The mixture was left to stand for 18 hours without mixing, and the volume of the plum oil cake (POC) layer was recorded at the end of this period. Results are expressed as the volume bound by the POC relative to the original weight of the POC (mL/g) (Zlatanovic et al., 2019).

Water Holding Capacity (WHC). POC samples (1.0 g) were dispersed in 30 mL of distilled water and left to stand at room temperature for 24 hours. After centrifugation at 3600 rpm for 20 minutes, the aqueous supernatant was removed, and the residue was measured. Results are expressed as the weight of bound water per gram of POC (g/g) (Rana et al., 2015).

Oil Holding Capacity (OHC). A POC sample (1.0 g) was dispersed in 10 mL of sunflower oil in a pre-weighed plastic centrifuge cuvette and left undisturbed at room temperature for 24 hours. The contents were then centrifuged at 3600 rpm for 25 minutes. The supernatant was decanted and dried, and the precipitate was measured as the residue after centrifugation. The result is expressed as the weight of bound oil per gram of POC (g/g) (Zlatanovic et al., 2019).

Solvent Retention Capacity (SRC). The SRC is defined as the weight of solvent (g) retained by the POC after centrifugation, expressed as a percentage. Four solvents were used: water, a 50% sucrose solution, a 5% sodium carbonate solution, and a 5% lactic acid solution. A POC sample with known moisture content (5.0 ± 0.05 g) was weighed into a pre-measured cuvette (with lid) of 50 mL volume and conical bottom. 25 ± 0.05 g of the selected solvent was added, the cuvette was sealed, and the mixture was shaken vigorously to disperse the flour in the solvent without lumps. The sample was hydrated for 20 minutes, with vigorous shaking five times during this period. After hydration, the POC suspension in the solvent was immediately centrifuged at 3000 rpm for 15 minutes. The supernatant was decanted, the pellet was drained for 15 minutes, and then weighed. SRC values were calculated as described by Haynes, Bettge, and Slade (2009):

$$\text{SRC\%}=\left(\frac{wet\ pellet\ (g)}{oil\ cake\ (g)}-1\right)\cdot\left(\frac{86}{100-oil\ cake\ moisture\ \left(\frac{g}{100g}\right)}\right)\cdot 100$$

Determination of total phenolic content (TPC) and radical-scavenging activity (RSA).

Three different mixtures (malic acid and sucrose in a molar ratio of 1:1, glycerol and urea in a molar ratio of 1:1, and glycerol and citric acid in a molar ratio of 4:1) were used to prepare NADES. Detailed conditions for preparing NADES were presented in our previous research (Ćirić et al., 2024). Freshly prepared NADES were used to extract polyphenols from plum seed oil cakes. The solid-to-liquid ratio used was 2 g to 30 mL of solvent. Extraction was performed in an ultrasonic bath for 30 minutes. After centrifugation at 8000 rpm for 7 min, the supernatant was separated and used for the determination of TPC and RSA. TPC and RSA were determined following the procedures described in our previous paper (Fotirić Akšić et al., 2022). TPC amounts were expressed as gram gallic acid equivalents (GAE) per kg of plum oil cake. Results of RSA were presented as mmol trolox equivalents (TE) per kg of plum oil cake. Data were analyzed by one-way ANOVA using Statgraphics Centurion software, and Tukey's

HSD test was used to separate means at $p \leq 0.05$. Results are presented as mean ± SD.

RESULTS AND DISCUSSIONS

Stone morphology. The results of this study revealed significant differences among the examined plum cultivars in stone and seed morphometric characteristics. These results confirm that stone morphology is strongly influenced by cultivar genotype. Highly significant differences were observed among the four plum cultivars for all analyzed stone morphometric traits (Table 1), confirming a strong cultivar-dependent effect on stone size and shape.

Table 1. Morphometric characteristics of plum stones of four plum cultivars

	Stone mass (g)	Stone height (mm)	Stone width (mm)	Stone width across the suture (mm)
'Č.lepotica'	1.37 ± 0.10^{a}	24.99 ± 1.52^{a}	8.45 ± 0.46^{b}	13.17 ± 0.72^{b}
'Stanley'	1.24 ± 0.10^{b}	22.11 ± 1.46^{b}	9.19 ± 0.66^{a}	13.71 ± 0.73^{a}
'Požegača'	0.59 ± 0.06^{c}	19.75 ± 0.98^{c}	6.52 ± 0.35^{c}	11.21 ± 0.55^{c}
'Empress'	1.26 ± 0.18^{b}	24.04 ± 2.52^{a}	8.75 ± 0.53^{b}	13.28 ± 0.80^{ab}
F	260.36^{***}	54.55^{***}	160.51^{***}	74.45^{***}
p	< 0.001	< 0.001	< 0.001	< 0.001

Values are presented as mean ± standard deviation (SD).
Different superscript letters within the same column indicate significant differences according to Tukey's HSD test ($p \leq 0.05$).

Stone mass ranged from 0.59 g in 'Požegača' to 1.37 g in 'Čačanska Lepotica', with 'Stanley' and 'Empress' showing intermediate and statistically similar values. A nearly identical stone mass for the cultivar 'Čačanska Lepotica' (1.35 g) was reported by Milošević et al. (2022). In contrast, higher stone mass values for the cultivar 'Stanley' were reported by Dimkova et al. (2018), ranging from 1.34 to 1.86 g, as well as by Nesheva et al. (2021), who recorded a value of 1.89 g, and Vitanova et al. (2004), who reported a stone mass of approximately 1.6 g, indicating considerable variability of this trait among different studies and agro-ecological conditions. Stone height followed a comparable pattern, with the highest values recorded in 'Čačanska Lepotica' and 'Empress', intermediate values in 'Stanley', and the lowest in 'Požegača'. Cultivar-dependent differences were also evident for stone width and stone width across the suture. 'Stanley' exhibited the widest stones, while 'Požegača' consistently showed the smallest values for both parameters. 'Čačanska Lepotica'and 'Empress' formed a homogeneous group with intermediate measurements. Overall, the high F-values emphasize the dominant influence of cultivar on stone morphology. These results demonstrate that stone size and shape in European plum are strongly cultivar-specific traits, with potential relevance for processing systems.



Figure 1. Morphological appearance of plum seeds of the studied cultivars: (a) 'Empress', (b) 'Čačanska Lepotica', (c) 'Stanley', and (d) 'Požegača'

Seed morphology. All analyzed seed morphometric traits differed significantly among the four plum cultivars (Table 2), confirming a strong cultivar effect on seed size and shape. Seed mass ranged from 0.13 g in 'Požegača' to 0.27 g in 'Čačanska Lepotica', with 'Empress'showing comparable values and forming a homogeneous group with 'Čačanska Lepotica', while 'Stanley' and 'Požegača' exhibited significantly lower values. A similar cultivar-dependent pattern was observed for seed height, with the highest values recorded in 'Čačanska Lepotica' and 'Empress', and significantly lower values in 'Stanley' and 'Požegača'. Clear differences were also evident for seed width and seed width across the suture. 'Empress' and 'Čačanska Lepotica' exhibited wider seeds, whereas 'Stanley' and 'Požegača' consistently showed lower values for both parameters. Overall, the high F-values highlight the dominant influence of cultivar on seed morphology.

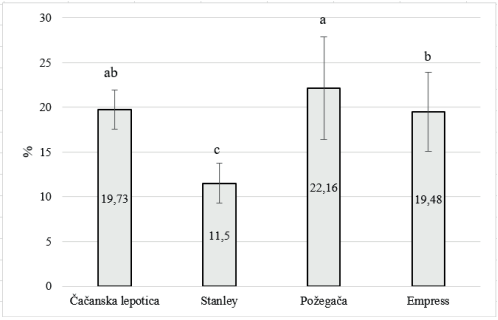
These results demonstrate that seed size and shape in European plum are strongly cultivar-specific traits and should be considered when comparing cultivars intended for different production and processing systems.

Table 2. Morphometric characteristics of plum seeds of four plum cultivars

	Seed mass (g)	Seed height (mm)	Seed width (mm)	Seed width across the suture (mm)
'Č.lepotica'	0.27±0.03^{a}	15.76±0.87^{a}	3.95±0.34^{a}	7.33±0.43^{a}
'Stanley'	0.14±0.02^{b}	11.69±1.05^{b}	3.45±0.63^{b}	6.50±0.70^{b}
'Požegača'	0.13±0.03^{b}	12.23±0.73^{b}	3.53±0.42^{b}	6.13±0.45^{b}
'Empress'	0.25±0.06^{a}	15.15±1.14^{a}	4.06±0.61^{a}	7.39±0.56^{a}
F	93.49***	135.21***	10.44***	36.96***
p	< 0.001	< 0.001	< 0.001	< 0.001

Values are presented as mean ± standard deviation (SD).
Different superscript letters within the same column indicate significant differences according to Tukey's HSD test ($p \leq 0.05$).

The seed-to-stone ratio differed significantly (Graph 1), indicating a cultivar-dependent allocation of biomass between seed and stone. The highest ratio was recorded in 'Požegača' (22.16%), followed by 'Čačanska Lepotica' (19.73%) and 'Empress' (19.48%), which were statistically comparable, while 'Stanley' exhibited the lowest ratio (11.50%).



Bars represent mean values ± SD.
Different letters above the bars indicate significant differences according to Tukey's HSD test ($p \leq 0.05$).

Graph 1. Seed-to-stone ratio (%) of four European plum cultivars

The higher seed proportion in 'Požegača' corresponds to its smaller stone size, whereas the lower ratio observed in 'Stanley' reflects its wider, more robust stone structure. Intermediate values in 'Čačanska Lepotica' and 'Empress' indicate a more balanced relationship between stone and seed size. Overall, these results confirm that the seed-to-stone ratio is a strongly cultivar-specific trait closely linked to differences in stone and seed morphology.

Fatty acid composition. As shown in Table 3, the dominant fatty acid in the examined oil samples was monounsaturated oleic acid, with a content ranging from 58.55% ('Empress') to 72.49% ('Stanley'). The second most abundant fatty acid was linoleic acid, a polyunsaturated fatty acid, with a content ranging from 19.68% ('Stanley') to 32.11% ('Empress'). Among the saturated fatty acids, palmitic acid was present in significant amounts, ranging from 5.19% to 6.40%. The results obtained are consistent with the findings of Rabrenović et al. (2021) regarding the content of oleic fatty acid (56.5-61.8%), linoleic acid (21.9-29.9%), and palmitic fatty acid (5.3-5.6%) in plum seed oil, which are a by-product of plum brandy production.

Oxidative stability - The OXITEST method. Given the high proportion of monounsaturated fatty acids, the tested samples exhibited excellent oxidative stability, as indicated by the induction period (h), which ranged from 35.17 h ('Empress') to 73.51 h ('Stanley') (Table 3). Tsao et al. (2021) examined the oxidative stability of 10 cold-pressed oil samples using the OXITEST method under identical experimental conditions. The induction period ranged from 4.60 h (linseed oil) to 81.52 h (peanut oil).

Table 3. Fatty acid composition and induction period of the examined samples

Fatty acid (%)*	'Č. Lepotica'	'Stanley'	'Požegača'	'Empress'
C14:0	0.03±0.005^{c}	0.06±0.006^{b}	0.02±0.001^{c}	0.09±0.001^{a}
C16:0	5.19±0.33^{b}	5.47±0.38^{ab}	5.62±0.33^{ab}	6.40±0.40^{a}
C16:1	1.07±0.02^{bc}	0.95±0.05^{c}	1.10±0.06^{b}	1.58±0.06^{a}
C18:0	0.62±0.04^{b}	1.02±0.05^{a}	0.61±0.06^{b}	1.02±0.08^{a}
C18:1	72.16±2.03^{a}	72.49±1.61^{a}	71.53±2.08^{a}	58.55±2.35^{b}
C18:2	20.74±2.18^{b}	19.68±1.95^{b}	20.95±1.28^{b}	32.11±1.19^{a}
C18:3	0.03±0.002^{c}	0.08±0.01^{a}	0.03±0.003^{c}	0.05±0.004^{b}
C20:0	0.10±0.01^{c}	0.16±0.01^{a}	0.09±0.01^{c}	0.13±0.01^{b}
C20:1	0.04±0.004^{bc}	0.07±0.01^{a}	0.03±0.003^{c}	0.05±0.003^{b}
IP** (h)	56.23±1.29^{b}	73.51±1.51^{a}	51.54±1.51^{c}	35.17±0.90^{d}

*C14:0 - Myristic acid; C16:0 - Palmitic acid; C16:1 - Palmitoleic acid; C18:0 - Stearic acid; C18:1 - Oleic acid; C18:2 - Linoleic acid; C18:3 - Linolenic acid; C20:0 - Arachidic acid; C20:1 - Gondoic acid; **IP - induction period*

Techno-functional characteristics of oil cakes. The techno-functional characteristics of the tested oil cakes are presented in Table 4. The SRC of water is the reference SRC value because this parameter is influenced by all functional components of the analyzed food matrix (Kweon et al., 2011). SRC values for water varied among the analyzed POCs, with the highest in the 'Empress' variety and the lowest in the 'Požegača' variety.

Table 4. Techno-functional characteristics of plum oil cakes

Parameter	'Č. Lepotica'	'Stanley'	'Požegača'	'Empress'
Moisture (%)	6.45±0.56^{a}	6.90±0.41^{a}	6.71±0.50^{a}	6.61±0.44^{a}
Water holding capacity (g/g)	2.93±0.27^{b}	4.02±0.38^{a}	2.85±0.18^{b}	2.84±0.16^{b}
Oil holding capacity (g/g)	1.00±0.06^{b}	1.33±0.10^{a}	1.22±0.12^{ab}	1.24±0.13^{ab}
Swelling capacity (mL/g)	5.58±0.48^{c}	9.83±0.78^{a}	7.37±0.73^{b}	6.33±0.53^{bc}
Solvent retention capacity (%)				
Distilled water	223.85±3.52^{b}	217.72±2.61^{b}	182.41±3.30^{c}	234.04±3.89^{a}
5% Lactic acid	285.68±5.58^{b}	380.44±4.92^{a}	287.27±6.15^{b}	268.00±3.24^{c}
5% Sodium carbonate	245.81±3.90^{c}	374.87±3.65^{a}	276.76±3.81^{b}	254.77±4.36^{c}
50% Sucrose solution	303.38±2.37^{d}	477.81±3.71^{a}	405.15±4.04^{b}	371.15±2.88^{c}

Differences in this parameter among POCs could be explained by variations in the contents of fibers, proteins, and hydrophilic polysaccharides (Rosell et al., 2010), as well as by genotypic differences among the analyzed varieties (Ram and Singh, 2004). The POC of the 'Stanley' variety was superior to other varieties in terms of SRC for lactic acid, sodium carbonate, and sucrose. This suggests that this POC has the highest content of functional proteins, or proteins with greater hydration capacity, as confirmed by the highest swelling capacity of this variety (Kweon et al., 2011; Xue et al., 2018). It is also the POC with the highest proportion of pectin, a soluble fiber, and the greatest ability to form viscous dispersions, indicating potential for use in the production of functional food products (Rosell et al., 2010). In addition to these parameters, the POC of the Stanley variety exhibited the highest water-holding capacity (WHC), oil-holding capacity (OHC), and swelling capacity among the samples. The WHC depends on the content of hydrophilic compounds, particularly fibers and proteins, as it is a seed. Higher WHC values indicate greater water-holding capacity (Elleuch et al., 2011). Xue et al. (2018) reported similar values for this parameter in plum seed proteins. Meanwhile, OHC, according to Deng et al. (2019), reflects the ability of components to interact with lipids, with protein type being the most influential factor. This is consistent with the SRC sucrose results, which indicate the highest content of hemicellulose and other polysaccharides, thereby enhancing lipid-holding efficiency. Variations in the functional and technological properties of the tested POC across different plum varieties can be attributed to differences in genotype, chemical composition, seed structure, grinding conditions, particle size after grinding, degree of cellular damage, moisture content, ecological growing conditions, and other factors.

Results of TPC and RSA of the investigated plum oil cakes. TPC values of the investigated plum oil cakes ranged from 2.74 to 4.09 g GAE kg^{-1} (Table 5), depending on both the plum cultivar and the NADES extraction system used. Three different eutectic mixtures (malic acid/sucrose, glycerol/urea, and glycerol/citric acid) were used to extract bioactive compounds from plum oil cakes.

Table 5. TPC (g GAE kg^{-1}) and RSA (mmol TE kg^{-1}) were determined in the investigated plum oil cakes

Samples	NADES	TPC	RSA
'Č.Lepotica'	malic acid: sucrose (1:1)	3.65 ± 0.01^{f}	1.01 ± 0.04^{g}
'Stanley'		3.93 ± 0.01^{d}	1.26 ± 0.04^{c}
'Požegača'		3.87 ± 0.00^{e}	1.13 ± 0.02^{f}
'Empress'		2.89 ± 0.01^{j}	0.74 ± 0.00^{i}
'Č.Lepotica'	glycerol:urea (1:1)	3.43 ± 0.02^{h}	0.86 ± 0.02^{h}
'Stanley'		3.65 ± 0.00^{f}	1.12 ± 0.00^{f}
'Požegača'		3.57 ± 0.00^{g}	0.88 ± 0.04^{h}
'Empress'		2.74 ± 0.00^{k}	0.62 ± 0.06^{j}
'Č.Lepotica'	glycerol: citric acid (4:1)	3.99 ± 0.01^{c}	2.02 ± 0.04^{c}
'Stanley'		4.09 ± 0.01^{a}	3.26 ± 0.06^{a}
'Požegača'		4.03 ± 0.00^{b}	2.46 ± 0.00^{b}
'Empress'		3.03 ± 0.00^{i}	1.91 ± 0.04^{d}

Values are presented as mean ± standard deviation (SD).
Different superscript letters within the same column indicate significant differences according to Tukey's HSD test ($p \leq 0.05$).

Among the tested NADES, the glycerol/citric acid (4:1) system provided the highest extraction efficiency for all cultivars, with the maximum TPC observed in 'Stanley' (4.09 g GAE kg^{-1}) and 'Požegača' (4.03 g GAE kg^{-1}) samples. In contrast, slightly lower TPC values were obtained with the malic acid/sucrose (1:1) and glycerol/urea (1:1) systems. Differences among the investigated cultivars were also observed. Generally, lower TPC values were observed in Empress plum oil cakes than in the 'Stanley', 'Požegača', and 'Čačanska Lepotica' samples. The obtained TPC values are in agreement with the literature data. For instance, Savić and Savić-Gajić (2022) reported TPC values for defatted plum seed cakes ranging from 1.8 to 2.7

g GAE kg^{-1}, depending on the extraction conditions. The slightly higher values obtained in our study may be attributed to differences in the extraction solvents, as NADES systems are known to enhance the extraction efficiency of phenolic compounds compared with some conventional extraction methods.

RSA values of the extracts ranged from 0.62 to 3.26 mmol TE kg^{-1}. The highest antioxidant capacity was also observed in extracts obtained using the glycerol/citric acid (4:1) mixture, particularly for the Stanley cultivar (3.26 mmol TE kg^{-1}). Other cultivars extracted with this solvent also showed relatively high RSA values (Table 5), indicating a strong antioxidant potential of these extracts. On the other hand, the lowest RSA values were observed for the glycerol/urea system, with the minimum value recorded for Empress (0.62 mmol TE kg^{-1}).

CONCLUSIONS

The results of this study confirmed that the morphometric characteristics of plum stones and seeds are cultivar-dependent. Significant differences were observed among the examined cultivars for all analyzed parameters, indicating that stone and seed size and shape are largely determined by genotype. Larger stones and seeds were characterized by 'Čačanska Lepotica' and 'Empress', whereas 'Požegača' showed the smallest stone dimensions but the highest seed-to-stone ratio. In contrast, 'Stanley' exhibited relatively large and robust stones with the lowest proportion of seed mass. The observed differences in the seed-to-stone ratio indicate variations in biomass allocation between seed and stone among cultivars. Such differences may be relevant when considering cultivars for processing and the utilization of plum pits as a potential source of valuable raw materials. The morphometric characteristics of stones and seeds, therefore, represent useful indicators for assessing the technological and processing potential of different plum cultivars.

Finally, the results presented indicate that plum seed oil represents a vegetable oil, with a favourable fatty acid profile and high oxidative stability. The high oleic acid content and exceptional oxidative stability of plum seed oil, particularly from the seeds of the Stanley cultivar, provide a promising basis for further research into its application as a functional edible oil. In addition, considering the techno-functional and nutritional properties of plum seed oil cakes, their potential remains largely unexplored, opening opportunities for further studies and possible industrial-scale applications.

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