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THE QUALITY AND USE VALUE OF THE FALSE FLAX (*CAMELINA SATIVA* [L.] CRANTZ)

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SUMMARY

Alternative plant cultures with favorable agronomic characteristics are a great source of refined edible oil and renewable industrial oil products. False flax stands out as a species with modest growing requirements, short vegetation and diverse use. Accordingly, the breeding program of the Institute of Field and Vegetable Crops in Novi Sad created two cultivars of false flax, NS Zlatka and NS Slatka, which were the research material of this study. The use and production value of these false flax cultivars were determined by examining important seed quality characteristics: oil content, oil yield, protein content and protein yield. The highest oil content was obtained in NS Slatka (45.90%) in 2016, while the highest protein content was 30.30%. The highest oil yield (801 kg/ha in 2017) and the highest protein yield (424 kg/ha in 2017) were detected in NS Zlatka. The data obtained from the field and laboratory were analyzed by analysis of variance, Duncan test and Spearman's correlation coefficient. Statistically significant differences were identified between the cultivars, and strong environmental influence was affirmed. By examining the correlations of the analyzed features, statistically significant correlations were found. The most common fatty acids included linolenic acid (33.80%), linoleic acid (18.81%), oleic acid (15.99%), eicosenoic acid (14.22%) and erucic acid (2.90%). The results obtained are applicable in further breeding program of false flax. They are of special importance in increasing the use value of false flax owing to the oil and meal high quality and potential for even more diverse use.

Key words:
false flax, oil content, protein content, oil yield, protein yield

INTRODUCTION

Oil crops are among the most important industrial plants on which the agricultural production of many countries is based. False flax (*Camelina sativa* (L.) Crantz) is an annual, self-fertile flowering plant and agricultural oil crop of great economic importance. It belongs to the cabbage family (Brassicaceae), which includes other important oil plant species (Berti et al., 2016). The main product obtained from seeds and a source of fatty acids is oil. The by-product after oil production is oil cake or oil meal rich in amino acids (Zubr, 2003). False flax products have been used since ancient times in the food and cosmetics industry, alternative and veterinary medicine. Additionally, they have been used for production of biofuels and biolubricants (Zubr, 1997). In the Republic of Serbia, places with high concentration of charred *Camelina* seed were found in the Autonomous Province of Vojvodina (Filipović, 2015).

The importance of false flax as a crop has declined several times during the last century (Berti et al., 2016). False flax has been replaced by other oil plant species, primarily sunflower and oilseed rape, due to their uncomplicated use in the modern food industry (Ehrensing & Guy, 2008). The consumption of natural resources is steadily increasing as the world's population is expanding. Therefore, the demand for refined edible oil products and renewable industrial oil sources is growing. Currently, the world market for oilseeds is dominated by soybeans, oilseed rape and sunflower (FAO, 2020). In the areas where the production of these oilseeds is growing, there is also an increasing need for crop rotation, greater diversity of cultivated plant species and sustainable production. In meeting these needs, alternative plant cultures with favourable agronomic characteristics are of great importance (Gehringer et al., 2006; Marjanović Jeromela et al., 2021; Kuzmanović et al., 2021). False flax stands out as one of such species with modest growing requirements, short vegetation and diverse use. These features are the reason why agronomic teams today re-research false flax (Eidhin et al., 2003; Lily et al., 2021). Owing to its mechanical composition, false flax crops are often grown on less used lands in intensive agriculture. It quickly absorbs water and nutrients from the soil and has little need for mineral and organic fertilizers. Due to its tolerance to pests and diseases, false flax does not require significant investments in protection measures. Moreover, false flax is characterized by adaptability to different environmental conditions (Cvejić et al., 2016).

According to Vollmann et al. (2007), the seed oil is considered a significant source of omega-3 fatty acids. The oil is of golden yellow colour, with a characteristic cabbage scent and a mild taste. The oil content in the seeds varies from 320 to 460 g/kg and includes a high percentage of unsaturated fatty acids, natural antioxidants, low levels of harmful erucic acids and cholesterol – high-density lipoproteins (HDL). About 90% of the total amount of oil consists of unsaturated fatty acids: of which 25-42% is alpha-linolenic acid, 13-21% linoleic acid, 14-20% oleic acid, 12-18% eicosenic acid and 2-4% erucic acid (Kurasiak-Popowska et al., 2021). After obtaining oil from false flax seeds, there is a by-product called oil cake obtained mechanically by the pressing technique. A more efficient extraction technique reduces fat and increases the amount of protein in the meal. The protein content is a qualitative indicator of the nutritional value of seeds and meals. The oil cake and oil meal are rich in crude protein which is mainly constituted of arginine, cysteine, lysine, methionine and threonine amino acids (Zubr, 1997). The mass of crude protein in the seed is 390-470 g/kg and the content of glucosinolate ranges between 13.2 and 36.2 mol/g of dry seed (Zubr, 2003).

The possibility of increasing production areas under false flax should be taken seriously due to its similarity with flax (*Linum usitatissimum* L.) and oilseed rape (*Brassica napus* L.) in terms of use, seed chemical composition and production technology. Lower production costs compared to any other oilseed crops is also a benefit.

This study was conducted to determine the yield and oil and protein content of the two cultivars of false flax grown under different environmental conditions. Moreover, the gained results were used for analyzing the potential high quality and use value of the two false flax cultivars.

MATERIAL AND METHODS

The research material consisted of two cultivars of false flax: NS Zlatka and NS Slatka, which are the result of the breeding program of the Institute of Field and Vegetable Crops, Novi Sad (Marjanović Jeromela et al., 2018). The methods for testing cultivars in the experimental field and the laboratory are prescribed by the Rulebook on testing the variety *Camelina sativa* L., which was published in the "Official Gazette of RS", No. 30/10. The experiment was conducted as a randomized complete block design, in four replications, across two locations, Sombor and Pančevo. Alfalfa in 2016 and pepper in 2017 were the pre-crops on the experimental field on the Sombor site. Barley in 2016 and wheat in 2017 were the pre-crops on the experimental field on the Pančevo site. The cultivars were sown on soil tested for soil pests before sowing and, if necessary, treated with insecticides before sowing. The mineral fertilizers and other agro-technical measures were fully applied to manifest the highest genetic potential of the cultivars. The sowing of the cultivars in one experiment was performed on the same day and within the period considered optimal for that locality. The laboratory analyses were performed in the SP Laboratory Joint Stock Company Bečej. The process of obtaining cold-pressed oil in laboratory conditions was applied after taking the seed samples. The oil was then extracted from the seeds using a solvent to determine the fatty acid profile from the obtained sample. The method of testing physical and chemical characteristics of oils in laboratory conditions was gas chromatography with a flame ionization detector, according to the standard SRPS EN ISO 12966-1: 2015 developed by ISO (International Organization for Standardization). The analysis of the obtained experimental data was performed with the statistical package SPSS for Windows and Microsoft Excel 2007. Significance assessments were performed based on Duncan's test for a significance level of 0.5%.

RESULTS AND DISCUSSION

Meteorological conditions and sowing date affect the physiological processes determining the critical phases of plants in terms of seed yield formation and quality (Popović et al., 2016; Righini et al., 2019; Lily et al., 2021). The vegetative period of the spring form of false flax is short (85-100 days) and it is characterized by several critical phases. The water needs vary during the vegetative period depending on the phenophase of plants and meteorological conditions. The seedlings of the spring form are characterized by tolerance to short-term frosts of the surface layer of the soil and the absence of dormancy (Ehrensing & Guy, 2008). During the vegetative period in 2016, the average annual temperatures were recorded for Sombor (11.9 °C) and Pančevo (11.8 °C), while the total amount of precipitation on these sites was higher in Pančevo (956.3 mm) compared to Sombor (761.6 mm), Fig. 1. During 2016, the total monthly rainfall of over 60 mm was recorded at both localities, starting from the emergence of plants and then every following month, and the average daily temperature was above 15°C. The optimal sowing period for mainspring field crops in the north of Serbia is the beginning of April. However, on the Sombor site, sowing was done in May, despite the optimal growth temperatures (above 13 °C) in April, due to the drought limiting factor. Concerning the Pančevo site, the sowing layer of the soil had good humidity, which, along with the appropriate temperature, enabled uniform and quality germination of the sown spring cultivars. Owing to the large amounts of precipitation during the winter period, especially in March, the moisture supply in the deeper layers of arable land was very good, and sowing was done in April. The vegetative period lasted longer (91 days) compared to the Sombor site (73 days). In the following year (2017), the total amount of precipitation was 542.7 mm on the Sombor site, while it was 397.5 mm on the Pančevo site, which is significantly less than in 2016 on both sites. Year 2017 on the Pančevo site was characterized by low level of precipitation during the winter period, vegetative period and immediately before the harvest. There was no significant difference between the average annual temperatures. On the Sombor site, the average annual temperature was 12 °C, while on the Pančevo site it was 12.1 °C, which is approximately the average annual temperature of the previous year on the same sites (Fig. 1). At the Sombor locality, sowing was done in April, and the vegetative period of the sown plants was 77 days, unlike the Pančevo locality, where sowing was done earlier, in March, and the vegetative period lasted longer (99 days). Despite the slight precipitation, the plants developed well and had high yields. During this experiment the average monthly temperatures at both locations were approximately in the same months and optimal for this period of the year. However, in 2016, sowing was performed earlier at both localities, so the same phenophases of plants were not in the same months. Therefore, it was not even at approximate temperatures, as in 2017, in the second year of the experiment. On the Pančevo site in 2016, the plants of the selected cultivars passed through the flowering phase under the influence of lower temperatures compared to 2017 and achieved higher oil content. On the Sombor site in 2016, the plants underwent a flowering phase under the influence of lower temperatures compared to 2017 and achieved higher oil content. By comparing these two localities in 2016, the plants of both cultivars were under the influence of lower temperatures on the Pančevo locality and achieved higher oil content. Therefore, the lowest temperature during the flowering phase of false flax plants contributed to the highest oil content (Fig. 1, 2). There is ample evidence that oil content increases with decreasing temperature in oilseeds, but there are also reports showing that lower temperature does not affect oil content (Harris & James 1969; Kirkhus et al., 2013; Schulte et al., 2013). Jiang et al. (2014) indicated that lower temperature in the phases after flowering leads to an increase in oil content but does not affect its composition, which is in line with the results obtained in this study. Therefore, the plants of *Camelina* cultivars under the influence of lower temperatures during flowering were also under the influence of lower temperatures during the grain pouring and ripening phases.

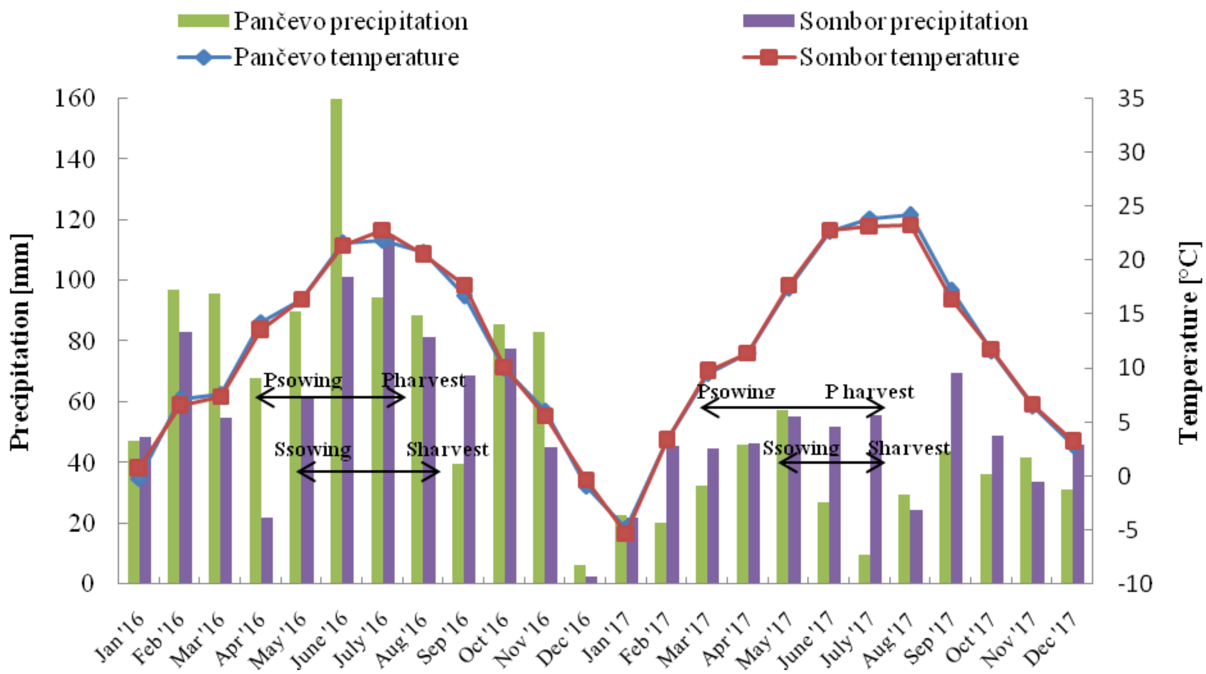
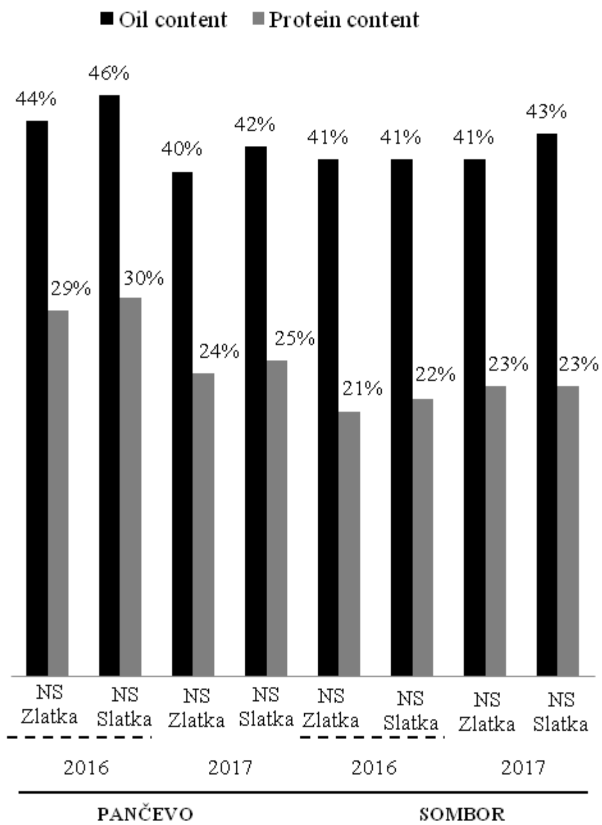


Figure 1. Meteorological conditions on the sites Pančevo (P) and Sombor (S) during two years (2016/17)

The use and production value of the false flax cultivars are determined based on the results of examining important seed quality characteristics: oil content, oil yield, protein content and protein yield (Fig. 2, 3). All values of the monitored traits proved to be optimal and in line with the values of previous research (Jiang et al., 2014; Popa et al., 2017). The optimal values of the mentioned properties include oil content in the range 30-50%, oil yield over 300 kg/ha, protein content over 20% and protein yield over 200 kg/ha. The cultivar NS Slatka had higher average oil content (42.76%) and average protein content (24.74%) in the seed compared to the cultivar NS Zlatka (41.28% and 23.90%, respectively). NS Zlatka cultivar achieved higher oil yield (392 kg/ha) and protein yield (317 kg/ha) compared to NS Slatka cultivar (379 kg/ha and 210 kg/ha) (Tab. 1). Additionally, the use value of *Camelina* cultivars is determined by obtaining the fatty acid profile (Fig. 2). A large percentage of polyunsaturated fatty acids was determined by discovering the fatty acid composition of the oil. The obtained percentages of fatty acids were in accordance with previous research on false flax oil (Kurasiak-Popowska et al., 2021). The values of the most abundant unsaturated fatty acids were linolenic (Pančevo 35.18%; Sombor 48.04%), linoleic (Pančevo 23.9%; Sombor 19.20%) and oleic (Pančevo 22.42%; Sombor 16.20%). Also, a large percentage of eicosenoic unsaturated fatty acids were present (Pančevo 14.12%; Sombor 13.82%). Eicosenoic fatty acids are less common in vegetable oil content, but their high % in false flax oil has already been noted in previous research by Cvejić et al. (2016) and Mladenov et al. (2017). The most common saturated fatty acids were palmitic (Pančevo 6.57%; Sombor 5.80%) and stearic (Pančevo 2.85%; Sombor 2.34%). The optimal value of erucic acid in plant oil is 5%, which the cultivars of false flax also meet with the recorded 3.08% and 2.87% on the Pančevo and Sombor sites, respectively (Popa et al., 2017). The exception was linolenic fatty acid, present in a higher percentage on the Sombor site. Zubr et al. (2003) found out that the percentage of fatty acids is affected by uncontrolled conditions such as soil quality and climatic conditions. As already mentioned, lower temperature conditions prevailed on the Pančevo site compared to the Sombor site, but Jiang et al. (2014) and Schulte et al. (2013) indicated that the lower temperature in the phases after flowering does not affect the composition of the oil, which is not in accordance with the results of this study. However, it has been documented that fatty acid content increases with lowering temperature for rapeseed, flaxseed and sunflower (Canvin, 1965; Harris & James, 1969).

Table 1. Use value of the two false flax cultivars (average values obtained in a two-year experiment on two sites)

***Camelina* cultivars**	**Oil yield (kg/ha)**	**Protein yield (kg/ha)**	**Oil content (%)**	**Protein content (%)**
NS Slatka	379	210	42.7	24.7
NS Zlatka	392	217	41.3	23.9



fatty acid		content % Pančevo	content % Sombor
Caproic	C6:0	<0.02	<0.02
Caprylic	C8:0	<0.02	<0.02
Capric	C10:0	<0.02	<0.02
Undecylic	C11:0	<0.02	<0.02
Lauric	C12:0	<0.02	<0.02
Tridecylic	C13:0	<0.02	<0.02
Myristic	C14:0	0.08	0.06
Myristoleic	C14:1	<0.02	<0.02
Pentadecylic	C15:0	0.02	0.02
Pentadecenoic	C15:1	<0.02	<0.02
Palmitic	C16:0	6.57	5.80
Palmitoleic	C16:1	0.12	0.12
Margaric	C17:0	0.05	0.04
Heptadecenoic	C17:1	0.04	<0.02
Stearic	C18:0	2.85	2.34
Oleic	C18:1	22.42	16.20
Linoleic	C18:2	23.98	19.20
Linolenic	C18:3	35.18	48.04
Arachidic	C20:0	1.75	1.44
Eicosenoic	C20:1	14.12	13.82
Eicosadienoic	C20:2	1.66	1.67
Mead	C20:3	1.02	1.19
Arachidonic	C20:4	0.03	0.02
Eicosapentaenoic	C20:5	<0.02	<0.02
Heneicosanoic	C21:0	<0.02	<0.02
Behenic	C22:0	0.40	0.32
Erucic	C22:1	3.22	2.87
Docosaidenoic	C22:2	0.20	0.21
Docosahexaenoic	C22:6	<0.02	<0.02
Tricosylic	C23:0	<0.02	<0.02
Lignoceric	C24:0	0.23	0.17
Nervonic	C24:1	0.76	0.73

Figure 2. Oil and protein content of two false flax cultivars with Fatty Acid Profile

The highest yields of oil and protein were achieved by false flax cultivars on the Pančevo site in 2017 (Tab. 2). The lowest amount of precipitation was recorded this year, and the vegetative period of plants lasted the longest. The lack of precipitation prolongs the maturation – the vegetative period of plants (Zhang et al., 2020). In combination with earlier sowing, optimal temperature and optimal amount of precipitation during sowing, germination and growth of plants resulted in the increase in yield. Berti et al. (2011) states that higher yields depend on the earlier sowing time, but they also indicated that earlier sowing does not result in higher oil content. Also, Zubr (1997) and Blackshaw et al. (2011) confirmed that false flax tolerates the lack of precipitation well, which is in line with these results. All the results above indicate that the quality of seeds is influenced by environmental factors (temperature and precipitation) and that selected cultivars are highly adaptable, which is in accordance with Jiang et al. (2014) and Cvejić et al. (2016).

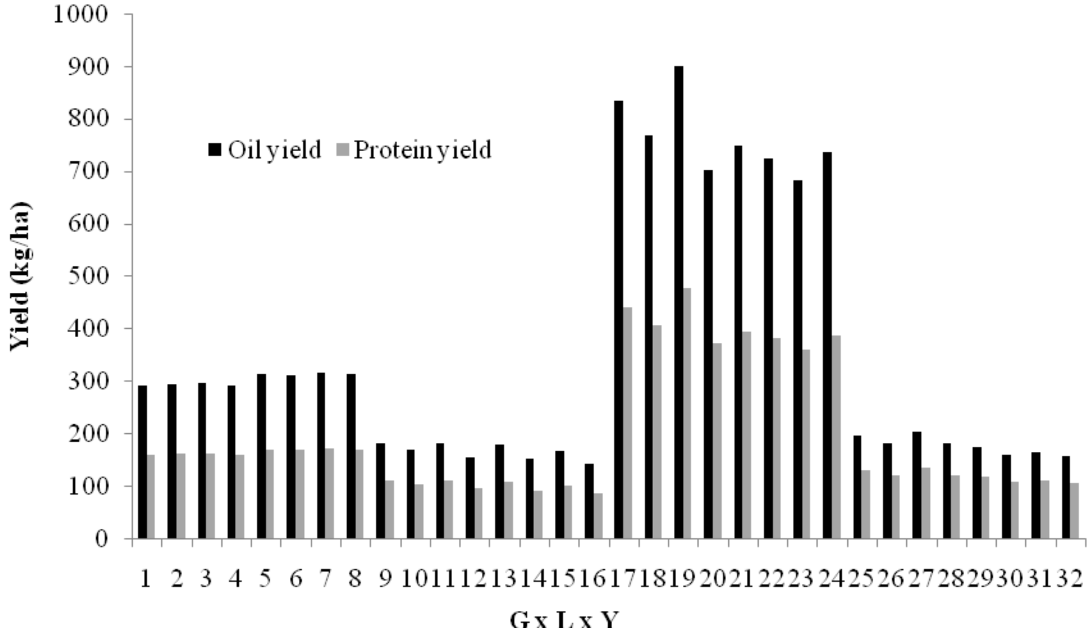


Figure 3. Oil and protein yield of two false flax cultivars during two years (2016/17) on the sites Pančevo and Sombor (G – genotype; L – location; Y – year; 1-4 Sombor 2017 Zlatka; 5-8 Sombor 2017 Slatka; 9-12 Sombor 2016 Slatka; 13-16 Sombor 2016 Zlatka; 17-20 Pančevo 2017 Zlatka; 21-24 Pančevo 2017 Slatka; 25-28 Pančevo 2016 Slatka 29-32 Pančevo 2016 Zlatka)

The F-test of variance analysis showed statistically significant differences between the examined cultivars in the interaction with the locality (Tab. 2). Interaction between genotype, locality and year (G x L x Y) significantly affected the yield and content of oil and protein, indicating that genotypes reacted differently to different agrometeorological conditions at different localities for two years. These results are in accordance with Jiang et al. (2014), where the yield and oil and protein content of oils varied depending on the effects of the external environment at different localities and during different years. Analysis of variance was followed by a post-hock test which confirmed the significance indicated by the F test. Duncan's test divided the values into groups (Tab. 3).

Table 2. Significance of the effect of false flax cultivars, locality and year's conditions on the yield (kg/ha) and content of oil and protein (%)

Source of variance	df	Oil content MS	Oil yield MS	Protein content MS	Protein yield MS
Repetitions	**3**	0.030	1689.78	0.041	541.31
G x L x Y	**7**	14.759	271413.6	43.834	67686.82
Error	**21**	0.011	1002	0.007	278.91
Total	**31**				
F value		1347.587**	270.871**	6694.582**	242.68**

Legend: G – genotype; L – location; Y – year; *P<0.05; **P<0.01 probability levels

Table 3. Duncan's test for the yield and content of oil and protein of two false flax cultivars at the localities of Sombor and Pančevo

Location	Year	NS Zlatka				NS Slatka			
		OY	**PY**	**OC**	**PC**	**OY**	**PY**	**OC**	**PC**
Sombor	2016	159.954^{A}	95.736^{A}	40.60^{A}	24.30^{A}	171.481^{A}	104.911^{A,B}	40.70^{A}	24.90^{B}
Pančevo	2016	163.557^{A}	109.414^{A,B}	43.50^{B}	29.10^{C}	190.046^{A}	125.455^{C}	45.90^{C}	30.30^{D}
Sombor	2017	293.408^{A}	160.878^{C}	41.40^{D}	22.70^{E}	313.085^{B}	169.314^{C}	41.80^{E}	30.30^{F}
Pančevo	2017	801.104^{A}	432.526^{D}	42.90^{G}	23.20^{H}	722.302^{C}	380.159^{E}	40.10^{F}	21.20^{G}

Legend: OY – oil yield; PY – protein yield; OC – oil content; PC – protein content; In a column, means with different letter denote statistically significant difference between treatment groups according to Duncan's test (P<0.05).

Table 4 shows the correlation coefficients between oil and protein content and yield. The results of the correlation analysis indicate that there is a statistically significant negative correlation between oil content and oil yield, as well as between protein content and protein yield. In addition, a statistically significant positive correlation was observed between oil content and protein content and between oil yield and protein yield. The positive correlation between oil content and protein content was unexpected due to numerous reports of their strong negative correlation (Lošák et al., 2011; McVay & Khan, 2011; Jiang et al., 2014). However, Engqvist & Becker (1993) explain that a positive correlation between oil content and protein content is result of different oil and protein content determinations. When oil content is determined on the total mass of dry seeds and when protein content is determined on the whole meal obtained after oil extraction with solvents, and not on the mass of dry seeds, which is the case in this paper, there is a positive correlation between these two traits. In addition, the ratio of oil content and protein content depends on the method of seed oil production, i.e., correlation relationship. Oil extraction by organic solvents versus mechanical pressing gave higher oil content and lower protein content, i.e., a negative correlation. However, even the extraction of oil through organic solvents can affect the increase in oil content depending on the size of the seed, the type of organic solvent and the temperature (Popa et al., 2017). Qatar et al. (2012), in their study on false flax, indicate a positive correlation between oil yield and oil content, which is not in accordance with the results of this research. As the mentioned properties depend on external factors, the interaction G x L x Y must be considered during the breeding work. Confirmation of this is the research by Guy et al. (2014), in which they state that the influence of external factors on the oil content is more significant than the selection of cultivars. However, the research of Lošák et al. (2011) showed that the application of nitrogen fertilizer contributes towards higher oil yield but reduces the oil content, which is in line with the results of this study. This leads to the conclusion that the yield and oil content are influenced by other environmental factors such as the mineral composition of the soil and that the soil on which the experiment was set up had the optimal composition to increase oil yield. In the research by Jiang et al. (2014), it is stated that the increase in oil yield increases the protein yield, which is in line with the results of this study. In addition to being positively correlated with each other, it is stated that they are positively correlated with seed yield. It is possible to simultaneously increase oil and protein yields by breeding work to increase seed yield (Engqvist & Becker, 1993).

Table 4. Spearman correlation between yield and content of oil and protein

	Oil content	**Oil yield**	**Protein content**	**Protein yield**
Oil content	-	-0.158	0.613**	-0.078
Oil yield	-0.158	-	-0.761**	0.989**
Protein content	0.613**	-0.761**	-	-0.734**
Protein yield	-0.078	0.989**	-0.734**	-

Legend: ** correlation is significant at 0.05 level

CONCLUSION

The selected cultivars of false flax in this research are the result of the breeding program of the Institute of Field and Vegetable Crops. Owing to their characteristic and improved properties, which are important for production, processing and use of false flax, they belong to the group of highly valuable cultivars. High oil and protein content and high seed and oil yield of the selected cultivars are the basis for further improvement of this species. Increasing the oil content or yield is the primary breeding goal and enabling its high production contributes to the increased use and share in the world market of seeds and oils. The results of this and other breeding groups are of special importance in increasing the use value of false flax since oil and false flax meal are of high quality and have potential for even more diverse use. New multidisciplinary research results will enable the expansion of the area on which false flax is grown and the diversity of this oil plant species.

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