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GENOTYPE AND SOIL TYPE INFLUENCE ON MORPHOLOGICAL CHARACTERISTICS, YIELD AND OIL CONTENT OF OIL-FLAX

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Abstract

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The three-year trial investigated the individual and the mutual interaction among three genotypes of oil-flax (Olin, Zlatko, Ljupko) and subtype of soil (chernozem with signs of gleyzation and chernozem on sandy loess) and their influence on morpho-physiological traits, yield and oil-flax oil content. The tallest stems (70.3 cm) had the Olin variety in agro-ecological conditions of Southern Banat region. Number of capsules per plant and number of grains per capsule was dependent on agro-ecological conditions in the investigated year. The largest number of capsules (68) per plant had the Zlatko variety, while the highest average grains number in the capsules (8.2) was at the Olin variety. The obtained values of the studied varieties for these two variables were not statistically significant.

On average, the highest oil-flax seed yield gave the Ruben variety (1416.3 kg ha^{-1}), which was higher for about 9.45% compared to the Ljupko variety, and 9.65% compared to the Olin variety. The highest oil content was at the Ljupko variety (41.1%). This value was higher by 1.21 rel.% compared to the Zlatko variety (40.6%), and 0.07 rel.% compared to the Olin variety (40.8%). Three-year average grains yield (Starcevo locality) was 1430.6 kg ha^{-1}.

The yield increasing at chernozem with signs of gleyzation compared to plants grown on chernozem on sandy loess (Devojacki Bunar locality) was 17%. On the other hand, the oil content in general was higher in this type of soil than on chernozem with signs of gleyzation (41.0% vs. 40.7%).

Key words: oil-flax, morphological characteristics, seed yield, oil content

Introduction

Flax (*Linum usitatisimun* L.) is annual herbaceous plant from the family Linoaceae. In the past, the demands for oil-flax seeds were continuously increased due to the growing usage in the humans diet and domestic animals breeding. High quality grain nutritive characteristics aligned flax in the category of the most respected oil-seed plants as sunflower and rapes. According to the oil energy value it is similar to sunflower, and by amino acid composition it is similar to soybean. Mikhailouskaya (2006) asserts that oil-flax grains have a high content of vitamins and mineral salts, as well as sunflower and soya beans, the common oil crops in temperate climate area.

Related to agronomic and morphological characteristics, flax represents suitable plant for the production in accordance with methods prescribed by the organic production (Bavec and Bavec, 2007). It is rarely used for human consumption, and its greater usage is in the industrial raw materials production (Vaisey-Genser and Morris, 2003).

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Seeds cold pressing produces high quality oil, which is present on the market in small dark bottles. Due to the high concentration of alpha-linolenic acid (40% of total fatty acids), it easily oxidized. Therefore, it should be stored in a cold dry place, the best in the refrigerator, and after packaging opening should be spent within three weeks because the fatty acids by oxidizing give strange fragrance (rancidity).

With the aim to have oil suitable for use in human nutrition, the proportion of alpha-linolenic acid should be reduced (Filipović et al., 2010). Resolving the issue of a large alpha-linolenic acid proportion can be achieved by new varieties creating with altered fatty acid composition.The first varieties with reduced content of these fatty acids were obtained by oil-flax plant breeding in Canada (Simetic, 2008). The world best known flax varieties are Dutch and Russian.

In the late twentieth century, investigations on oil-flax genotypes suitable for oil and direct usage in nutrition have been started in Serbia, in The Center for Agricultural and Technology Researches in Zajecar (Stanković et al., 2003). Three varieties of oil-flax brown grains were created during that period. Recently, we obtained varieties of yellow grain, also (Dijanović et al., 2002).

Flax can be successfully grown on different soil types, but the best results it achieves on a well-drained, medium to heavy textured soils as pointed by Casa et al. (1999). A soil type has a major impact on the oil-flax production. As asserted by Berti et al. (2009) high grain yields of oil-flax could be achieved without usage of mineral nutrients on the fertile soils.

This investigation was performed on soils, which were different on agrochemical properties, so soil influence on three flax oil varieties productive characteristics could be assessed.

Materials and Methods

Materials for investigation were three varieties of oil-flax (*Linum usitatisimun var. brevimulticaulia* L.) created in the Center for Agricultural and Technological Research, Zajecar (Serbia).

The Olin variety was product of selection carried during 1997th. It is grown for fiber and grain and has brown grains. The second variety Zlatko has brown grains also, and branch stems with an average height of 55 cm. The third variety was Ljupko, a typical oilseed variety with low-branched stem and yellow grain-coat grains (Stanković et al., 2003).

Field trials had been conducted during 2008, 2009. and 2010., in the South Banat region on two soil types: carbonate chernozem in gleyzation (Starcevo, N 44° 48′, E 20° 41′) and the sandy loess chernozem (Devojacki Bunar, N 44° 59′, E 20° 57′). The experiment was based on a randomized complete block system with four replications with randomized layout variants. Size of the basic plot was 12 m^2 (2 m x 6 m). Oil-flax was sown after potatoes during the three years. Hand sowing was done in the first half of April at 25 cm row spacing, densely, in order to achieve the optimum number of 800 plants per m^{-2} (Pospisil et al., 2004). Such drilling with hoeing, as pointed out by Alessi and Power (1970), can reduce weeds number in the early stages of growth. The hoeing was measure that had been carried out during the growing season with the aim to suppress weeds and breaking the crust.

Ten sample plants from each experimental plot were taken for plant height determination (cm), capsule number per plant and number of grains in the capsule before harvest. Hand harvesting was carried out for three years in the third week of August, and grains yield was determined after grains separation from capsules and grains drying on humidity level of 9%. Oil content was determined by DICKEY-John, NIR analyzer. Agrochemical analyzes were done in the PDS Tamis Institute laboratory, Pancevo.

Significance of differences testing among investigated factors mean values was performed by variance analysis model, with following mathematical form:

$$y_{ijk} = \mu + \alpha_i + \beta_i + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (i=1,2,3; j=1,2; \quad k=1,2,3,4)$$

All reviews were carried out on the significance of the F-test and LSD test for the significance level of 5% and 1%. Two-way analysis of variance (Two-way ANOVA in Randomized Blocks) were performed by statistical software Statistica v. 10th

Agro-ecological conditions

Meteorological data for Starcevo region were obtained from the meteorological station of the Tamis Institute Pancevo, and for Devojacki Bunar from the meteorological station in Banatski Karlovac (Tables 1 and 2).

According to meteorological data, listed in the tables, the greatest amount of precipitation for both regions had been during 2010. Total precipitation and schedule by month was equal to the long-term averages of investigated regions. During 2009. the water regime in the Starcevo region was at the level of long-term averages, while in the Devojacki Bunar region it was about 13% less rainfall. The first year (2008), had a minimum of rainfall during the oil-flax vegetation period with strong expressed dry periods at both regions during July and August.

The weather conditions are unpredictable and variable in Serbian climate area (Popovic et al., 2012, 2013). Mean monthly air temperatures were higher than long-term averages during all three years of investigation. The year 2009. was the warmest period according to the monthly temperature schedule during the growing period. Variation in morphological and productive characteristics were expressed independently during all three years as well as in the results of previous researches (Diepenbrock et al., 1995; Casa et al., 1999; Adugna and Labuschagne, 2003; Milic et al., 2004; Berti et al., 2010).

Adapting Agriculture to Climate Change is a fundamental resource for primary industry professionals, land managers, policy makers, researchers and students involved in preparing the world for the challenges and opportunities of climate change (Abumhadi et al., 2012).

According agrochemical analyzes, the carbonate chernozem in gleyzation (Starcevo) is characterized as highly productive land. The pH value in KCl humus horizon was about 7.36, $CaCO_3$ was at the level of about 4.0%, humus content on average had a value of about 3.7%, while readily available K_2O and P_2O_5 on averages were present with 42.0, respectively 56.4 mg in the 100 g of the soil. These values often vary, primarily due to the abundant plants' nutrition.

On the sandy loess chernozem (Devojacki Bunar), all indicators of agrochemical analysis of the observed values were less, what characterized this subtype of the soil, compared to the first subtype, as less productive soil. The biggest difference was for easily accessible K_2O and P_2O_5 as well as the pH reaction of the soil solution (Table 3).

Despite differences in the phosphorus and potassium content in the soil solution, in oil-flax nutrition on chernozem soil type, these two nutrients may be omitted. At oil-flax on

Table 1
Monthly participations sums, mm

Month \ Year	2008		2009		2010		1994-2007	
	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar
IV	34.0	70.9	12.6	12.5	36.5	38.7	58.5	54.5
V	48.0	40.0	48.9	112.9	92.2	86.7	51.9	49.0
VI	81.5	67.2	141.5	69.9	126.7	89.5	81.8	88.2
VII	37.2	24.1	130.1	89.1	54.7	112.1	64.4	84.8
VIII	24.6	18.3	24.2	13.2	70.4	97.1	60.1	60.8
Sum	225.3	220.5	357.3	297.6	380.5	424.1	316.5	337.4

Table 2
Average monthly temperatures, ^0C

Month \ Year	2008		2009		2010		1994-2007	
	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar	Starčevo	Devojački Bunar
IV	13.7	12.4	15.6	14.9	13.4	12.6	12.8	11.9
V	19.4	17.6	20.0	18.7	18.1	17.3	18.4	17.8
VI	23.3	21.2	20.9	20.3	21.8	20.7	21.8	20.8
VII	23.5	21.7	24.2	22.6	24.8	23.0	23.6	22.4
VIII	23.9	22.6	24.3	22.5	23.7	22.1	23.2	21.8
T sr. Aver. T	20.8	19.1	21.0	19.8	20.4	19.1	20.0	18.9

Table 3
Agrochemical soil properties of experimental fields

Soil type	Year	pH in KCl	$CaCO_3$ %	Humus %	Total N %	Available mg/100 g soil	
						P_2O_5	K_2O
Chernozem with signs of gley in loess	2008	7.32	3.62	3.52	0.246	38.7	59.8
	2009	7.39	4.37	3.88	0.272	43.9	53.7
	2010	7.41	4.12	3.65	0.258	42.2	54.5
Chernozem on sandy loess	2008	7.02	3.51	3.03	0.212	10.9	14.7
	2009	7.14	4.16	3.22	0.225	12.4	13.9
	2010	7.18	4.32	3.17	0.220	13.7	13.8

fertile soils, phosphorus and potassium have no significant affect on yield and oil content in a grain Berti et al. (2009).

Results and Discussion

Morphological characteristics

Basic morphological indicators as stem height, number of capsules per plant and grains number per capsule, showed significant variations in study years (Table 4).

Variety and soil conditions were significantly affected by variations of these morphological parameters. The tallest stems in the overall average was at the Olin variety (70.3 cm). The largest number of capsules per stem was at the Zlatko variety (68), and the highest grains number in a capsule had the Olin variety (8.2). Variation of individual treatments were not significant but the interaction of the first and second level was statisticaly significance. Adugna and Labuschagne (2003); Copur et al. (2006) and Gauraha and Rao (2011); Rahimi et

Table 4
Morphophological characteristics of oil-flax plants

Year (A)	Soil type (B)	Plant height (cm) – PH			Number of capsules per plant - NCP			Number of seeds in capsule - NSC			Average		
		Cultivar (C)											
		Zlatko	Ljupko	Olin	Zlatko	Ljupko	*Olin*	*Zlatko*	*Ljupko*	*Olin*	PH	NCP	NSC
2008	CH1	63.0	56.6	69.7	64.5	66.3	63.8	7.1	6.6	7.1	63.1	64.8	6.9
	CH2	53.7	58.8	67.3	61.3	55.3	61.8	6.9	7.0	7.4	59.9	59.4	7.1
	Average	58.4	57.7	68.5	62.9	60.8	62.8	7.0	6.8	7.2	61.5	62.1	7.0
2009	CH1	67.6	59.1	72.2	62.3	65.3	64.0	8.1	8.6	8.7	66.3	63.8	8.5
	CH2	64.5	67.0	72.0	62.0	68.0	53.5	8.5	8.0	8.8	67.8	61.2	8.4
	Average	66.1	63.1	72.1	62.1	66.6	58.8	8.3	8.3	8.8	67.1	62.5	8.4
2010	CH1	72.7	72.6	73.3	84.5	82.0	85.5	9.2	8.5	8.9	72.9	84.0	8.9
	CH2	67.1	66.9	67.4	73.8	70.3	73.3	9.0	9.0	8.5	67.1	72.4	8.8
	Average	69.9	69.8	70.3	79.1	76.1	79.4	9.1	8.7	8.7	70.0	78.2	8.8
2008 – 2010	CH1	67.8	62.8	71.7	70.4	71.2	71.1	8.1	7.9	8.2	67.4	70.9	8.1
	CH2	61.8	64.2	68.9	65.7	64.5	62.8	8.1	8.0	8.2	65.0	64.3	8.1
	Average	64.8	63.5	70.3	68.0	67.8	67.0	8.1	7.9	8.2	66.2	67.6	8.1

CH1 - Chernozem with signs of gley in loess, CH2 - Chernozem on sandy loess

Table 5
F - Test and LSD – Oil-flax plants morphogical characteristics test values

	Plant height (cm) – PH		Number of capsules per plant – NCP		Number of seeds in capsule - NSC	
Source of variation	d.f.	F pr.	d.f.	F pr.	d.f.	F pr.
Cultivar	2	0.389	2	0.120	2	0.542
Soil Type	1	20.917	1	1.592	1	1.431
Year	2	29.746	2	20.641	2	133.945
Soil Type x Cultivar	2	19.386	2	3.300	2	1.842
Year x Cultivar	4	0.431	4	0.525	4	4.927
Year x Soil Type	2	10.228	2	0.119	2	1.287
Year x Soil Type x Cultivar	4	3.838	4	1.489	4	0.457
Error	51		51		51	
Total	71		71		71	
LSD	5%	1%	5%	1%	5%	1%
	A: 2.42	A: 2.99	A: 5.736	A: 7.645	A: 0.239	A: 0.319
	B: 1.83	B: 2.44	B: 4.683	B: 6.242	B: 0.195	B: 0.261
	C: 2.42	C: 2.99	C: 5.736	C: 7.645	C: 0.239	C: 0.319

al. (2011) assert very high positive correlation between the number of capsules per plant and grain yield.

Grain yield. Three-year grain yield of oil-flax at both regions was 1.326 kg ha^{-1} (Table 6). Under similar climatic conditions Pospisil et al. (2011.), in North-Western Croatia, by examining of eight oil-flax varieties, achieved yield of 1244 kg ha^{-1} up to 1644 kg ha^{-1}. During the three-year average on carbonate chernozem in gleyzation (Starcevo) the highest grains yield had the Zlatko variety (1.549 kg ha^{-1}). This value was higher by about 14.1% compared to the yield at the Olin variety (1330 kg ha^{-1}) and 8.82% compared to the Ljupko variety (1412.5 kg ha^{-1}). Similar relations have been established among study years. On the sandy loess chernozem (Devojacki Bunar) the three-year average has no significantly differences in grains yield among varieties.

Based on three-factorial analysis of variance it was determined that there was a very significant (p <0.01) influence of soil type on the oil-flax grains yield (Table 7).

The yield of flax grain is largely dependent on the genotype as closed by Maletic and Jevdjovic (2006), who explored productive characteristics of registered varieties and new genotypes of flax in the South Banat region. Based on the two-year average, the highest yield was at genotype ″Z″ (1.182 kg ha^{-1}), while one of the older generation varieties - Mira gave the lowest grains yield of 843 kg $ha^{1.}$ Burton (2007) obtained similar results by examining fertility potential of three oil-flax and one

Table 6
Grain yield, kg ha^{-1}

Year (A)	Soil type (B)	Cultivar (C)			Average
		Zlatko	*Ljupko*	*Olin*	
2008	Chernozem with signs of gley in loess	1443	1425	1363	1410
	Chernozem on sandy loess	1073	943	1165	1060
	Average	1258	1184	1264	1235
2009	Chernozem with signs of gley in loess	1758	1495	1323	1525
	Chernozem on sandy loess	1413	1360	1278	1350
	Average	1585	1428	1300	1438
2010	Chernozem with signs of gley in loess	1448	1318	1305	1357
	Chernozem on sandy loess	1365	1155	1245	1255
	Average	1406	1236	1275	1306
2008/ 2010	Chernozem with signs of gley in loess	1549	1413	1330	1431(B)
	Chernozem on sandy loess	1283	1153	1229	1222(B)
	Average	1416(C)	1283(C)	1280(C)	1326

Table 7
F – test and LSD – test values of the grain yield

Source of variation	d.f.	s.s.	m.s.	F pr.	P
Cultivar	2	24411.1	12205.5	1.39	2.572ns
Soil Type	1	568888.9	568888.8	65.00	0.000**
Year	2	506877.8	253438.8	28.95	0.000**
Soil Type x Cultivar	2	589911.1	294955.5	33.70	0.000**
Year x Cultivar	4	210922.2	52730.5	6.02	0.005**
Year x Soil Type	2	30144.4	15072.2	1.72	0.189ns
Year x Soil Type x Cultivar	4	230105.5	57526.3	6.57	0.002**
Error	51	446327.7	8751.5		
Total	71	2673111.1			
LSD		5%		1%	
		A: 54.2		A: 72.3	
		B: 44.3		B: 59.0	
		C: 54.2		C: 72.3	

textile-flax variety in Canada. Textile flax had significantly lower grains yield in all variants. Under the agro-ecological and soil conditions of Croatia Butorac et al. (2009) concluded that the genotype has a major affect on grains yield. Previous studies which were performed by Filipović et al. (2010) confirmed the high statistical dependence of variety and soil type on yield and flax grains quality.

Significantly higher oil-flax grains yield among these three varieties was achieved in the second year, as a result of higher quantity and better distribution of rainfall compared with the dry first year season and the third very wet year.

Analysis of the average grains yield according to the soil type showed that the yields had less values on the chernozem in gleyzation soil type than on the sandy loess. Three-year yield average on this soil type was 1.222 kg ha^{-1}, what was less than the yield (1.431 kg ha^{-1}) on carbonate chernozem in gleyzation for 7.54% in Starcevo region. Quoted difference in the oil-flax grains yield was a statistically significant variation ($p<0.01$).

The variety influence on oil-flax grains yield was not statistically significant ($F=2.572^{NZ}$, p=1.39).

Only the interaction among years of the investigation and the soil type was not significant different, while there was significant statistical variation among all other interactions of the first and second level.

Oil content

Three-year average oil content in grains of investigated flax varieties for the entire experiment was 40,8% (Table 8).

Table 8
Oil content in oil-flax grain (%)

Year (A)	Soil type (B)	Cultivar (C)			Average
		Zlatko	*Ljupko*	*Olin*	
2008	Chernozem with signs of gley in loess	40.3	41.1	41.1	40.8
	Chernozem on sandy loess	40.6	41.4	41.4	41.1
	Average	40.4	41.2	41.2	41.0(A)
2009	Chernozem with signs of gley in loess	41.2	42.0	41.1	41.4
	Chernozem on sandy loess	41.5	42.5	41.4	41.8
	Average	41.3	42.2	41.2	41.6(A)
2010	Chernozem with signs of gley in loess	39.8	39.7	39.8	39.8
	Chernozem on sandy loess	40.4	39.8	39.8	40.0
	Average	40.1	39.8	39.8	39.9(A)
2008/ 2010	Chernozem with signs of gley in loess	40.4	40.9	40.7	40.7(B)
	Chernozem on sandy loess	40.8	41.2	40.9	41.0(B)
	Average	40.6(C)	41.1(C)	40.8(C)	40.8

Table 9
Oil content in oil- flax grain (%), F – test and LSD – test values

Source of variation	d.f.	s.s.	m.s.	F pr.	P
Cultivar	2	0.3008	0.1504	1.45	0.244ns
Soil Type	1	0.7401	0.7401	7.13	0.010*
Year	2	35.5308	17.7654	171.17	0.000**
Soil Type x Cultivar	2	3.5252	1.7626	16.98	0.000**
Year x Cultivar	4	2.5583	0.6395	6.16	0.004**
Year x Soil Type	2	1.9519	0.9759	9.40	0.003**
Year x Soil Type x Cultivar	4	2.1688	0.5422	5.22	0.013**
Error	51	5.2931	0.1037		
Total	71	52.4587			
LSD	5%	A: 0.186	1%	A: 0.248	
		B: 0.152		B: 0.203	
		C: 0.186		C: 0.248	

Varieties had the highest oil content in general at 2009, and it was 41,6%. This value was higher than in the first (2008) year for 1.44 rel.%, and compared to the third year for 4.08 rel.%. Variations by year of investigation were statistically significant ($p<0.01$). During the first (2008) year, long drought period at flowering and fertilization stage affected the yield and yield components. Mirshekari et al. (2012) ended that unfavorable agro-ecological conditions significantly affect the quality of the grains.

Soil conditions had huge impact on the grain oil content at varieties included in the experiment. On the sandy loess soil the three-year average oil content (41%) was significantly higher than on chernozem in gleyzation soil. Among varieties, in total average, there was no significant variations while the interaction among year x soil type, year x variety, soil type x variety, year x soil type x variety have showed highly statistical significance (Table 9).

Many authors, for example Fontana et al. (1996), Kurt (1996); Pospisil et al. (2004), Khan et al. (2005), Pospisil et al. (2011) and Rahimi et al. (2011) ended that there are significant correlations among grain oil content, soil type, year of investigation and meteorological conditions during the flax growing season.

Conclusion

Based on investigated influences of different soil types and agro-ecological conditions of southern Banat region on morphological characteristics, yield and oil-flax varieties grain oil content, it can be ended:

- The Zlatko variety gave, in the three-year average, the highest grains yield (1416 kg ha^{-1}) and had the least variation over studied years (from 1258 kg ha^{-1} up to 1585 kg ha^{-1}).
- In the three-year average varieties were not significantly different according to the oil content in the grains, from 40,6% (*Zlatko*), up to 41,1% (*Ljupko*).
- The influence of soil characteristics on grains yield was significant so on the chernozem with signs of gleyzation it was in general higher for 17.1% compared to the sandy loess chernozem.
- On the other hand, chernozem on sandy loess was more suitable for the grain oil synthesis, and in the three-year average, at the plants grown on this soil type, was 41.0% and on the chernozem with signs of gleyzation it was 40.3%.
- Variable weather conditions during three years period significantly influenced on the grains yield and oil content at all three varieties.
- Investigated factors (soil type, variety and weather conditions) showed a significant affect on the main indicators of morphological and productive characteristics, the stem height, number of capsules per plant and number of grains per capsule.

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