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Yield and quality traits of two linseed (*Linum usitatissimum* L.) cultivars as affected by some agronomic factors

S. Andruszczak[1], U. Gawlik-Dziki[2], P. Kraska[1], E. Kwiecińska-Poppe[1], K. Różyło[1], E. Pałys[1]

[1]*Department of Agricultural Ecology, University of Life Sciences, Lublin, Poland*
[2]*Department of Biochemistry and Food Chemistry, University of Life Sciences, Lublin, Poland*

ABSTRACT

A field experiment was conducted on rendzina soil in the years 2010–2012. The seeds of two linseed cultivars (Szafir and Oliwin) were sown at row spacing of 15 cm and 25 cm. Three agrotechnical levels in different nitrogen doses and with or without application of herbicides were used. The objective of the study was to evaluate the effect of row spacing on yield, seed protein and oil content of two linseed cultivars grown under different conditions of mineral fertilization and chemical weed control. Results showed that cv. Szafir was characterized by significantly higher seed yield (on average by 20.2%) and protein content (by 2.6%) while cv. Oliwin had higher content of oil (by 4.9%). Intensive technology of cultivation (80 kg N/ha, Linurex 50 WP, Fusilade Forte 150 EC, Glean 75 WP), compared to the economical technology (40 kg N/ha, without herbicides), significantly increased the seed yield of both linseed cultivars (on average by 80–102%). This was due to higher plant density, higher number of branches, and higher number of capsules per plant. The intensive technology of cultivation had a beneficial effect on the content of α-linolenic acid in linseed seed.

Keywords: flax; flaxseed; seeding rate; yield components; fatty acids

Two forms of flax are distinguished (fibre flax and linseed) that are now-widely used. A noticeable tendency to reduce the crop area of fibre flax in favour of linseed has been observed in Poland in recent years. Because of a constantly increasing interest in flax as a plant used in the chemical, pharmaceutical, food and animal feed industries, it has a leading position among oilseed crops (Zając et al. 2012). Flaxseeds show dietetic, purgative and protective activity and therefore they have long been used in both the treatment of digestive tract diseases (constipation, gastritis, and enterocolitis) and respiratory system diseases (cough and dysphonia). Linseed oil is very rich in polyunsaturated fatty acids (PUFA), surpassing all major plant oils and even fish oil (Hunter 1990). It is a rich source of α-linolenic acid (ALA) belonging to the group of omega 3 (ω-3) acids (Bickert et al. 1994, Heller et al. 2010). Nevertheless, flaxseeds are a rich source of valuable protein, dietary fiber, lecithin, and lignans-chemical compounds of major importance for human health (Bhatty and Cherdkiatgumchai 1990, Ganorkar and Jain 2013).

There is not enough data available on linseed to develop an efficient agronomic guideline that can guarantee high and good quality seed yield. Improvements in linseed cultivation technology will be a significant element in meeting the growing domestic requirements for linseed oil production for food purposes (Zając et al. 2010). The paper presents evaluation of the effect of row spacing on yield, yield components, seed protein, oil content and fatty acid profile of two linseed cultivars grown under different conditions of mineral fertilization and chemical weed control.

MATERIAL AND METHODS

A field study was conducted in the years 2010–2012 in the Bezek Experimental Farm (51°19'N, 23°26'E).

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The experiment was established on the mixed rendzina soil derived from chalk rock with the granulometric composition of medium silty loam. According to the new classification of the Polish Society of Soil Science 2008 it was loam (PTG 2009). The soil was characterized by alkaline pH (pH in 1 mol/L KCl – 7.35); a high content of phosphorus (117.8 mg/kg of soil) and potassium (242.4 mg/kg of soil) and very low magnesium content (19.0 mg/kg of soil). The organic carbon content was 24.7 g/kg.

The three-factors of the experiment evaluated the yield potential of two linseed cultivars, a yellow-seeded cv. Oliwin and light brown-seeded cv. Szafir. Seeds of these cultivars were sown at a row spacing of 15 cm and 25 cm. Furthermore, the experimental design included three levels of agricultural technology. Under the conditions of extensive technology (treatment A), 40 kg N/ha was applied; in the medium-intensive technology (treatment B) the rate of nitrogen was 60 kg N/ha, while in the intensive technology (treatment C) it was 80 kg N/ha. At the same time, in all experimental treatments, phosphorus and potassium fertilizers were applied at a rate of 20 and 50 kg of nutrient per hectare, respectively. In treatments B and C, immediately after linseed was sown soil-applied herbicide (Linurex 50 WP) was used at a rate of 1.5 kg/ha (linuron – a compound from the group of urea derivatives – 50%), whereas at the 1–2 true leaf stage (12–13 BBCH), when the plants reached a height of about 6–12 cm, they were sprayed with another herbicide (Fusilade Forte 150 EC) against monocotyledonous weeds at a rate of 1 L/ha (fluazifop-p-butyl – it is a compound from the group of arylphenoxy acids – 150 g per 1 L of the herbicide). Under the conditions of intensive production technology (treatment C), the herbicide Glean 75 WG for controlling dicotyledonous weeds was additionally used at a rate of 15 g/ha (chlorosulfuron 75% – a compound from the group of sulphonylurea derivatives).

The experiment was set up as a split-split plot design. Two linseed cultivars were allocated in main plots and the treatments put in supplots in triplicate and the harvested plot area was 20 m^2. Linseed was sown in the third 10-day period of April using sowing rate of 650 seeds per 1 m^2 when row distance was 15 cm and 400 seeds per 1 m^2 for row spacing of 25 cm. Sowing rate was calculated by taking into account measured germination capacity and seed weight. During the growth of linseed plants at stem elongation (32–36 BBCH) and full flowering stages (65 BBCH), LAI (leaf area index) was evaluated in the canopy of the linseed crop by performing non-destructive measurements using a LAI-2000 plant canopy analyzer (LI-COR, Nebraska, USA). The plants of linseed were harvested when seed capsules had started to turn brown (89 BBCH). The cv. Oliwin, due to long period from sowing to emergence and slow growth rate at the initial stage of growth, was harvested later than cv. Szafir, on average from 7 to 10 days, depending on the year of experiment. Before harvest, plants were pulled out from 1 m^2 sampling areas to calculate plant density in each plot. Subsequently, the yield-determining components – number of first-level branches, number of capsules per plant, and number of seeds per capsule – were determined in 30 randomly selected plants per each replicate. After threshing, done with a Wintersteiger LD 180 laboratory thresher, the weight of 1000 seeds was evaluated based on seed samples collected from each plot. Furthermore, seed protein content was determined by using the Kjeldahl method (PN-75/A-04018), while Soxhlet method was applied for determining the oil content (PN-64/A-74039). In seed samples collected in the second and third year of the study, the fatty acid content was established by gas chromatography (PN-EN ISO 5509, 2001). The obtained results were statistically analyzed by the analysis of variance (ANOVA), and least significant differences (*LSD*) were calculated using the Tukey's confidence half-intervals with an error rate of 5%. ARStat software of the Computing Centre of the University of Life Sciences in Lublin was used for calculations.

RESULTS AND DISCUSSION

Previous reports on the yield potential of linseed show that the productivity of this crop largely depends on its morphological characters associated with foliage (Zając 2005). The total leaf area per 1 m^2 of ground area has a determining effect on photosynthesis and indirectly it can be an indicator of plant productivity. This study demonstrated that at the stem elongation stage, cv. Szafir showed a significantly higher value of LAI than cv. Oliwin (Figure 1). Zając (2005) reported that LAI of the linseed crop reached the highest values at flowering. This was confirmed in the present study, but at flowering stage, LAI was differentiated most significantly by the level of agricultural technology.

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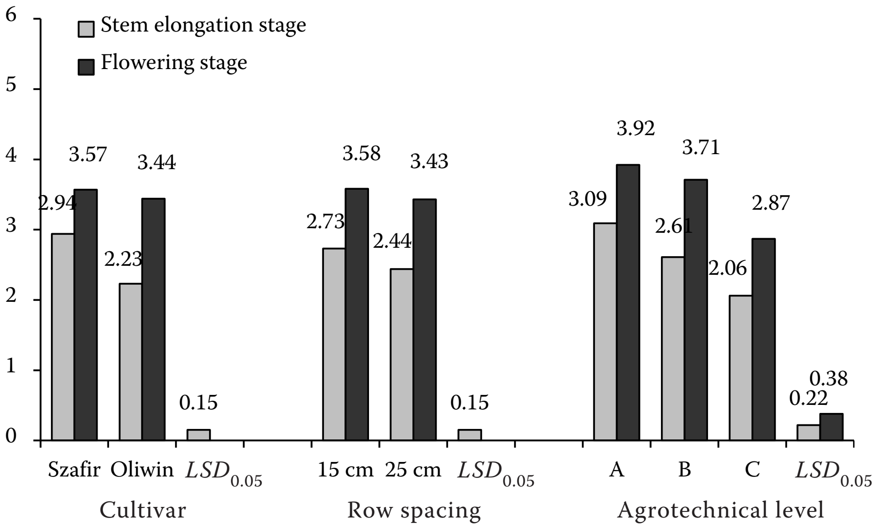

Figure 1. Leaf area index (m^2/m^2) in the linseed canopy depending on experimental factors. A – extensive technology (40 kg N/ha; without herbicides); B – medium-intensive technology (60 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC); C – intensive technology (80 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC; Glean 75 WP); *LSD* – least significant difference

Diepenbrock et al. (1995) as well as D'Antuono and Rossini (1995) reported that the variation in linseed productivity largely depends on the cultivar. In turn, the Polish brown-seeded linseed cv. Opal and the Hungarian yellow-seeded cv. Hungarian Gold produced yields at a similar level (Zając 2005, Klimek-Kopyra et al. 2013). Under the conditions of the present study, cv. Szafir produced significantly higher seed yield, which resulted mostly from its higher plant density, higher 1000 seed weight and the higher number of branches per plant compared to cv. Oliwin (Table 1).

This study demonstrated that the narrower row spacing (15 cm) resulted in higher seed yield, but the differences in relation to the row spacing of 25 cm were statistically insignificant. It should be indicated that the obtained increase in yield mainly resulted from a higher number of plants per unit area. However, interaction between cultivars and row spacing showed that row distance of 15 cm as compared to 25 cm significantly increased plant density of cv. Szafir but had no significant effect on cv. Oliwin. According to Casa et al. (1999) and Zając (2004), very low density negatively affects the seed yield, despite the fact that flax plants growing at a low density seek to compensate it by more intensive branching and an increase in the number of seed capsules per plant. These findings are also confirmed by the results of the present study which shows that plants grown at wider row spacing were more branched and produced significantly more seed capsules (regardless of cultivar and agrotechnical level). In the opinion of Diepenbrock and Pörksen (1992), the most optimal number of linseed plants per 1 m^2 is about 400. According to Turner (1991), at such density plants produce more branches, which stimulate the formation of a larger number of capsules and seeds on the stems. However, lodging propensity of flax is lower at this plant density.

The effectiveness of mineral fertilization of linseed is still little known and, there is still no explanation for the effect of this factor on the biological determinants of yield potential (Zając 2005). The experiments of Hocking et al. (1997) did not show a significant effect of increasing nitrogen rates on seed yield of linseed, while Dordas (2010) is of opinion that the nitrogen nutrition status of plants is one of more important nutritional factors that determine the level of yield components. In the study by Strašil and Vorlíček (2004), the application of 60 kg N/ha increased seed yield of linseed by 5.8% compared to the treatment without nitrogen fertilization. However, Grant et al. (1999) claim that too high rates of mineral fertilizers, in particular nitrogen fertilizers, can cause excessive branching of plants, which promotes their lodging and reduction in yield. In the present study, independently of cultivar and row spacing, linseed fertilized with nitrogen at rates of 60 and 80 kg N/ha, compared to a rate of 40 kg N/ha, was characterized by significantly higher plant density per unit area as well as better productivity per plant and per crop. However, a significant increase in seed yield under the conditions of medium-intensive and intensive cultivation technology, compared to the extensive technology, resulted not only from a better nitrogen supply to the plants but also from

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Table 1. The effect of cultivar, row spacing and agrotechnical level on seed yield and some morphological features of linseed

	Treatment	Seed yield (t/ha)	Number of plants per 1 m^2	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	Weight of 1000 seeds (g)	Single plant yield (g)
Cultivar	Szafir	2.38	344	8.90	17.2	6.12	6.88	0.73
	Oliwin	1.98	291	7.52	17.4	6.71	5.88	0.69
	$LSD_{0.05}$	0.38	41	0.95	ns	0.35	0.20	ns
Row spacing	15 cm	2.34	355	7.77	16.3	6.51	6.42	0.67
	25 cm	2.02	281	8.65	18.3	6.32	6.34	0.74
	$LSD_{0.05}$	ns	41	ns	1.8	ns	ns	ns
Agrotechnical level	A	1.43	255	5.48	13.6	6.43	6.49	0.57
	B	2.34	337	9.27	18.7	6.16	6.44	0.74
	C	2.76	362	9.87	19.7	6.65	6.21	0.81
	$LSD_{0.05}$	0.56	60	1.40	2.7	ns	ns	0.12
Cultivar × row spacing	Szafir × 15 cm	2.52	390	8.51	15.8	6.09	6.94	0.66
	Szafir × 25 cm	2.23	299	9.29	18.6	6.16	6.81	0.80
	Oliwin × 15 cm	2.16	319	7.02	16.8	6.93	5.89	0.69
	Oliwin × 25 cm	1.18	263	8.01	18.1	6.48	5.87	0.68
	$LSD_{0.05}$	ns	77	ns	ns	ns	ns	ns
Cultivar × agrotechnical level	Szafir × A	1.56	282	5.76	13.1	6.21	7.00	0.57
	Szafir × B	2.41	360	10.13	17.9	5.62	6.92	0.71
	Szafir × C	3.16	391	10.81	20.6	6.54	6.71	0.91
	Oliwin × A	1.31	227	5.21	14.0	6.65	5.98	0.56
	Oliwin × B	2.27	314	8.42	19.5	6.71	5.95	0.78
	Oliwin × C	2.36	332	8.92	18.8	6.76	5.71	0.72
	$LSD_{0.05}$	0.97	104	2.41	4.6	ns	ns	0.21
Row spacing × agrotechnical level	15 cm × A	1.66	288	5.43	13.4	6.74	6.62	0.59
	15 cm × B	2.51	379	8.75	16.9	6.32	6.47	0.70
	15 cm × C	2.84	397	9.12	18.7	6.47	6.16	0.73
	25 cm × A	1.20	221	5.54	13.8	6.12	6.36	0.54
	25 cm × B	2.17	295	9.79	20.5	6.00	6.40	0.79
	25 cm × C	2.68	326	10.61	20.7	6.84	6.26	0.89
	$LSD_{0.05}$	0.97	ns	ns	4.6	ns	ns	ns

A – extensive technology (40 kg N/ha; without herbicides); B – medium-intensive technology (60 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC); C – intensive technology (80 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC; Glean 75 WP); ns – non-significant; *LSD* – least significant difference

lower weed infestation of the crop. Flax shows a low competitive ability against weeds, which is determined by traits such as weak root system, small area of leaves, and slow growth rate at the initial stage of growth. In the study of Heller and Wielgusz (2011), herbicide Afalon 50 WP, applied before emergence, and herbicide Chwastox 750 SL or Glean 75 WP, post emergence, increased seed yield of linseed on average from 44–59%, whereas in the present study an increase in seed yield in the herbicide-sprayed plots was on average from 63.6–93.0%. Interaction between cultivars and agrotechnical levels showed that medium-intensive technology (60 kg N/ha and two herbicides) as compared to the extensive technology (40 kg/ha and without herbicides) had no significant effect on seed yield and plant density of both linseed cultivars, however, the increase of these traits was significant only in the intensive cultivation technology (80 kg N/ha and three herbicides). From the analysis of variance over three years of the experiment, it was found that only seed yield and capsules per plant were significantly influenced by interaction between row spacing and agrotechnical level, while interactions between

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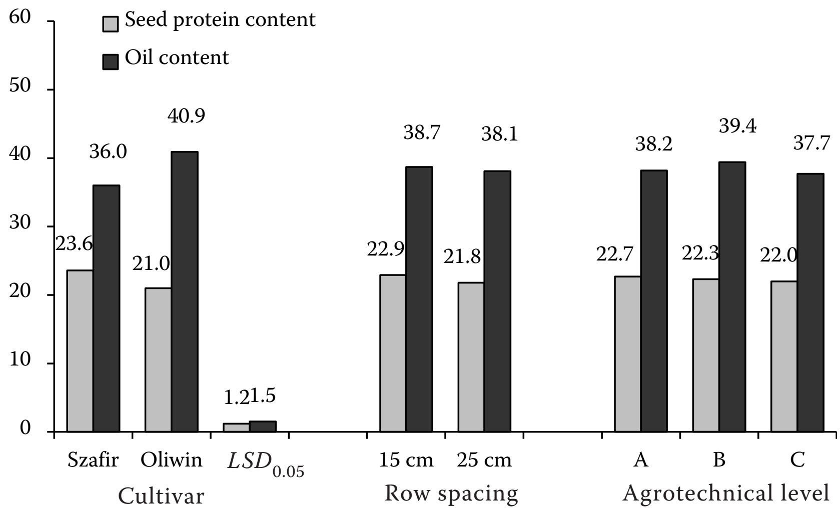

Figure 2. Seed protein and oil content of linseed (%) depending on experimental factors. A – extensive technology (40 kg N/ha; without herbicides); B – medium-intensive technology (60 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC); C – intensive technology (80 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC; Glean 75 WP); *LSD* – least significant difference

cultivar, row spacing and agrotechnical levels were never significant (data not shown).

The analysis of the chemical composition of seeds of linseed showed that seed protein and oil content was dependent on the cultivar and was not significantly differentiated under the influence of the agronomic factors compared (Figure 2). Bhatty and Cherdkiatgumchai (1990) and Saastamoinen et al. (2013) established that the protein content in seeds depends on their oil content; the higher its amount, the lower the protein content. The present study confirms this thesis.

Linseed seed is characterized by a very stable proportion of polyunsaturated fatty acids. Compared to other oilseed crops, it is the richest source of *n*-3 α-linolenic acid, which has a beneficial effect on the prevention of diseases of affluence (Oomah 2001, Gambuś et al. 2003, Zając et al. 2010). In the present study, the content of this acid ranged from 47.7–55.5% (Table 2) and was slightly lower than the values given by Heller and Wielgusz (2011) (61.1–62.91%). Jelińska (2005) found the content of α-linolenic acid to be at a level of 54.5%, while in the study of Klimek-Kopyra et al. (2013) this value was in the range of 53.1–55.1%. The results of the present study show that increased mineral fertilization up to 80 kg N/ha, simultaneously combined with intensive crop protection against weeds, significantly increased the content of α-linolenic acid in seeds of cvs. Szafir and Oliwin but the level

Table 2. The effect of agrotechnical level on the fatty acid profile of linseed cultivars (%)

Fatty acid	Cv. Szafir					Cv. Oliwin				
	A	B	C	mean	$LSD_{0.05}$	A	B	C	mean	$LSD_{0.05}$
$C_{16:0}$	6.1	6.0	6.0	6.0	ns	6.0	6.0	6.1	6.0	ns
$C_{18:0}$	5.6	5.4	5.1	5.4	ns	5.3	5.3	4.9	5.2	ns
$C_{18:1}$	26.1	24.2	18.5	22.9	0.8	22.9	23.1	18.4	21.5	0.9
$C_{18:2}$	12.0	12.4	12.4	12.3	ns	11.9	12.1	12.4	12.1	ns
$C_{18:3}$	47.7	49.5	55.5	50.9	0.8	51.3	51.0	55.5	52.6	0.8
$C_{20:1}$	1.0	1.0	1.0	1.0	ns	1.0	1.0	1.2	1.1	ns
Others	1.5	1.5	1.5	1.5	ns	1.6	1.5	1.5	1.5	ns
SFA	12.8	12.6	12.3	12.6	ns	12.4	12.3	12.0	12.2	ns
MUFA	27.1	25.2	19.5	23.9	0.8	24.0	24.1	19.7	22.6	0.8
PUFA	60.1	62.2	68.2	63.5	0.8	63.6	63.6	68.3	65.2	1.1

A – extensive technology (40 kg N/ha; without herbicides); B – medium-intensive technology (60 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC); C – intensive technology (80 kg N/ha; Linurex 50 WP; Fusilade Forte 150 EC; Glean 75 WP); ns – non-significant; SFA – saturated fatty acid; MUFA – mono unsaturated fatty acid; PUFA – poly unsaturated fatty acid; *LSD* – least significant difference

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of oleic acid significantly decreased, as compared to extensive and medium-intensive technology. Increasing the level of mineral fertilization, Klimek-Kopyra et al. (2013) obtained an increase in the content of palmitic and oleic acids, whereas the proportion of α-linolenic acid decreased.

In conclusion, cv. Szafir was characterized by significantly higher seed yield and protein content while cv. Oliwin had higher content of oil. The yield potential of linseed was most strongly dependent on the level of agricultural technology. Compared to the extensive cultivation technology (40 kg N/ha, without herbicides), an increase in the rate of nitrogen up to 80 kg N/ha and the application of herbicides to control weed infestation significantly increased seed yield of both linseed cultivars as well as α-linolenic acid content in seeds. Sowing at a spacing of 15 cm resulted in seed yield slightly higher in relation to a spacing of 25 cm.

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Corresponding author:
Dr. Sylwia Andruszczak, University of Life Sciences, Department of Agricultural Ecology, Akademicka 13, 20 950 Lublin, Poland; e-mail: sylwia.andruszczak@up.lublin.pl