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REGULAR ARTICLE

The effects of varied plant density and nitrogen fertilization on quantity and quality yield of *Camelina sativa* L.

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ABSTRACT

False flax (*Camelina sativa* L.), is an oil plant, of the *Brassicaceae (Cruciferae)* family. It is a rediscovered crop with multiple uses, it is a frost proof, low-soil and climatic conditions plant. In Poland the variety is not very widespread, despite of its health benefits. The particular value of *camelina* oil is given by its content in polyunsaturated fatty acid (50-60%), by its content in omega 3 (35-40%) and by its content in omega 6 (15-20%). The seeds are used for the extraction of oil (used in medicine or as bio fuel) or directly as animal feed. The research was carried out in the years 2012-2014 at the Experimental Station of Cultivar Assessment in Przecław, Poland. The summer *Camelina sativa* cv. 'Omega'was used for the experiment. The studied factors were: A-plant density (200, 300, 400 pcs. m^{-2}) and B-nitrogen fertilization (50, 100 $kg \cdot ha^{-1}$). With the increase of the sowing density significantly increased plant density after emergence and before harvest, but reduced the number of silicles per plant. Increase in the rates of sowing from 200 to 400 pcs. m^{-2} decreased the 1000 seeds weight. Sowing 200 seeds m^{-2} compared to higher norms had significant effect on reduction the number of seeds in silicle, seed yield and the content of the seeds Fe, but resulted in an increase in the content of the seeds Mn and Zn. On the other hand, sowing 400 seeds m^{-2} caused a reduction the protein in the seeds, K, and Mg, and an increase fat yield and crude fat content in seeds. The higher nitrogen dose significantly increased the number of silicles per plant, total protein content, Fe, Zn in the seeds, seed yield, yield total protein and the percentage of linoleic and linolenic acids, while reduced the number of seeds per silicle, the crude fat content in seeds and the percentage of oleic acid.

Keywords: Chemical composition; False flax; Fatty acids; Seed yield; Yield components

INTRODUCTION

Camelina sativa (L.) Crantz was cultivated in Poland for centuries, but now occupies a small area in Poland, due to the higher prevalence of yielding rape. There are two cultivated forms such as winter and summer, but the winter forms yielding higher than summer (Toncea, 2014; Mosio-Mosiewski et al., 2015). Martinelli and Galasso (2011) and Zanetti et al. (2017) claim that there are multiple environmental and agrotechnical benefits of *camelina* for eg.: small climatic and soil requirements. The seeds of *camelina* can be used universally, eg.: as feed (Steppa et al., 2017; Wang et al. 2017) and derived oil from them as food (Vollmann et al., 2007; Mińkowski et al., 2010) as well as technical oil, including biofuel (Karcauskiene et al., 2014; Mohammed et al., 2017). The nutritional value of oil is mainly due to a high content of unsaturated fatty acids, particularly n-3 (omega-3) fatty acids and multiple use values (Zubr and Matthäus 2002; Zubr, 2003a). It is appropriate to conduct further researches on the improvement of genetic traits of *camelina* (Vollmann et al., 2007) as well as the optimization agricultural technology. Gesch et al. (2017) as well as Koncius and Karcauskiene (2010) pay attention to the need of usage optimum sowing rate, which affects on plant habit and seed yield. An important agricultural treatment is also a mineral fertilization. Like other cultivated plants in the family *Brassicaceae (Brassicaceae* Burnett) false flax strongly respond to nitrogen fertilization (Solis et al., 2013; Jiang and Caldwell, 2016; Waraich et al., 2017).

The aim of this study was to estimate a reaction of the summer form of *camelina* to varied plant density and nitrogen fertilization. In the research hypothesis it was assumed that the varied plant density and nitrogen

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fertilization modifies evaluation parameters as well as quantity and quality yield of *Camelina sativa* [L.] Crantz.

MATERIALS AND METHODS

Crop management

The research was carried out in the years 2012-2014 in Przecław (The Experimental Station of Cultivar Assessment), south-eastern Poland (50°11'N, 21°29'E). It was a two-factorial experiment (split-plot) conducted in three replications. The experimental factors were: (A) plant density (200, 300, 400 pcs. m^{-2}) and (B) nitrogen fertilization (50, 100 kg·ha^{-1}). The breeder of summer *Camelina sativa* cv. 'Omega' was Poznań University of Life Sciences, Poland. The experiment was set up on alluvial soils created from silt loam. The soil was classified in valuation class IIIb of the good wheat complex with pH slightly acid or inert in the range from 6.38 to 7.11. Soil samples were collected by a sampling stick to a depth of 0–60 cm. The content of available forms of phosphorus was high or very high, potassium – average or high, and magnesium – very high (Table 1). Soil analysis was carried out at the Chemical and Agricultural Station in Rzeszów, with generally accepted methods in Polish Stanards.

The data concerning weather conditions came from the Experimental Station of Cultivar Assessment in Przecław. From March to July in 2012 was the period in which the lowest total precipitation appeared. In May and June 2013 as well as in May and July 2014 high level of rainfalls was recorded and it exceeded considerably the long-term average (Table 2). During the plant growth higher air temperatures were noticed in 2012, and the lowest in 2014 (Table 3). Irrigation was not used in field trials.

The seeds of false flax were received from the Department of Genetics and Plant Breeding in Poznań University of Life Sciences. Oat was the forecrop of false flax in every year of research. The area of a plot was 7.5 m^2, for harvesting 5 m^2. The row spacing amounted to 15 cm, and sowing depth 1.5 cm. Seed dressed material was sown in three periods: 4.04.2012, 22.04.2013 and 24.03.2014. The sowing date was optimal for the area of the research. Under the autumn ploughing granular triple superphosphate (40 P_2O_5 kg·ha^{-1}) and potash salt (60 K_2O kg·ha^{-1}) were used. Nitrogen fertilization (34% ammonium saltpeter) was applied in varied doses and terms (Table 4).

The herbicide Butisan SC 400 (2.5 $dm^3 \cdot ha^{-1}$) were applied after sowing. The secondary weed infestation was removed manually. The diseases and pests were not combated. Plant density per 1 m^2 was calculated after emergence and before harvest. At the technical maturity stage, 20 representative plants were collected from each plot for determine yield components: a number of silicles per plant, a number of seeds per silicle and the 1000 seeds weight. Data regarding thousand seeds weight were recorded by counting randomly selected 1000 seeds from each plot and weighed with sensitive electronic balance. BBCH scale for false flax was given by Martinelli and Galasso (2011).

The harvest was conducted on the following dates: 18.07.2012, 29.07.2013 and 21.07.2014. The seed yield obtained from the plots was converted into yield per 1 ha, assuming a humidity of 15%. The seed yield was adjusted for missing plants collected for biometric measurements. Total protein yield and crude fat were calculated from seed yield and percentage content of these components in seeds.

Experimental design and treatments

The content of total protein and crude fat in the seeds was determined with the NIRS method in near infrared on the apparatus Spectrometer FT NIR MPA Bruker (Billerica, USA). Macro- and microelements were developed at the University of Rzeszow (The Laboratory of the Faculty of

Table 1: Chemical characteristics of experimental soil

Measurement	2012	2013	2014
Soil acidity (1 mol L KCl)	6.38	7.11	7.00
Humus (%)	1.92	1.84	1.72
N_{min} 0–60 cm (kg·ha^{-1})	66.4	60.8	56.8
(mg kg)*			
P	71.1	96.6	79.8
K	153.6	175.9	160.2
Mg	72.4	66.9	60.9

* - available forms

Table 2: Rainfall during the test crop cultivation (mm)

Years	Months					Total
	III	IV	V	VI	VII	
2012	27.8	21.7	66.7	66.9	65.6	248.7
2013	73.6	39.4	111.7	192.4	58.3	475.4
2014	49.6	34.8	108.9	69.0	146.8	409.1
multi-annual average	35.9	48.1	39.2	79.3	101.6	304.1

Table 3: Air temperatures during the test crop cultivation (°C)

Years	Months					Mean
	III	IV	V	VI	VII	
2012	3.9	9.9	14.7	18.2	20.9	13.5
2013	-1.3	8.8	15.0	18.5	19.4	12.1
2014	5.4	8.8	13.3	15.1	19.4	12.4
multi-annual average	2.6	8.8	14.2	17.5	19.4	12.5

Table 4: Fertilization diagram

Dose N (kg·ha^{-1})	Application time, dose N (kg·ha^{-1})	
	Before sowing	BBCH (21)
50	50	-
100	60	40

Biology and Agriculture). To determine macroelements and microelements, plant samples were mineralized in a mixture of concentrated acids HNO_3:$HClO_4$:HS_2O_4 in the ratio 20:5:1, in an open system, in the heating block Tecator. In obtained mineralisates the contents of Ca, K, Mg, Zn, Mn, Cu, Fe were determined with atomic absorption spectroscopy (AAS), using the apparatus Hitachi Z-2000 (Tokyo, Japan), whereas P was determined with colorimetry, using the spectrophotometer UV-VIS Shimadzu (Kyoto, Japan), with the vanadium-molybdenum method. Analysis of fatty acids was performed using gas chromatograph Shimadzu's GC-17A (Kyoto, Japan) according to standards: PN-EN ISO 12966-4:2015-07.

Statistical analysis

The results were subjected to statistical analysis of variance. Calculations were made in the Statistica 8.0 programme (StatSoft, Tulsa, USA). Significance of differences between the means was indicated with the use of Tukey test, with a significance level of α =0.05.

RESULTS AND DISCUSSION

Yield and yield components

Increasing the density of sowing resulted in a significant increase in plant density after emergence and before harvest (Table 5). In 2012, the plant density was the lowest impacted by low rainfall during the germination and plant emergence. Gesch et al. (2017) recommend that sowing should be not less than 3 kg·ha^{-1}.

Nitrogen fertilization did not modify plant density. While Koncius and Karcauskiene (2010) obtained the diversity of the *camelina* plant density per 1m^2 with variable doses of NPK.

In own study, an increase the density of sowing significantly reduced the number of silicles per plant. The increase in nitrogen fertilization significantly increased the number of silicles per plant, an average of 9.1 psc. It confirmed the diversity of characteristics in years of the research.

Sowing 200 seeds m^{-2} compared to the sowing of 300 and 400 seeds m^{-2} contributed to the significant reduction in the number of seeds in silicle. The use of higher doses of nitrogen resulted in a significant decrease in the number of seeds in silicle. Increasing the amount of sowing seeds from 200 to 400 pcs. m^{-2} reduced the 1000 seeds weight (Table 5). The resulting difference was significant and amounted to an average of 0.18 g.

The application of sowing seeds of 300 and 400 pcs. m^{-2} resulted in a significant increase in yield compared to 200 pcs. m^{-2}. Seed yield was significantly higher with higher doses of nitrogen and the resulting difference as compared to the lower dose was 0.11 t·ha^{-1}. Between 2013 and 2014 the seed yield was significantly higher in relation to 2012.

Dobre et al. (2014) considered that plant density in spring should be over 350 pcs. m^{-2}, which guarantees a high yield of seeds. The effect of higher doses of nitrogen on the growth of the yield was confirmed in previous studies by other authors (Jiang et al., 2013; Jiang et al., 2014; Sintim et al., 2015). For the optimal dose of nitrogen for false flax Jiang et al. (2013) reported 120 to 160 kg·ha^{-1}. Afshar et. al. (2016) considered that higher doses than 45 kg·ha $^{-1}$ are not effective in growing *camelina*. Wysocki et al. (2013) said that

Table 5: Plant density, yield components and seed yield (average of years)

Experience factor		Number of plants		Number of silicles per plant	Number of seeds per silicle	1000 seeds weight (g)	Seed yield (t·ha^{-1})
sowing density (psc.m^{-2})	nitrogen fertilization (N kg·ha^{-1})	after emergence (pcs.m^{-2})	before harvest (pcs.m^{-2})				
200	50	185	180	103.2	9.0	1.02	1.67
	100	182	178	116.8	7.7	1.13	1.78
300	50	278	272	72.5	9.5	0.98	1.78
	100	281	274	83.1	8.5	1.00	1.87
400	50	365	355	61.8	9.5	0.87	1.75
	100	361	354	65.1	9.0	0.93	1.87
200		183.5^{c}	179.0^{c}	110.0^{a}	8.4^{b}	1.08^{a}	1.73^{b}
300		279.5^{b}	273.0^{b}	77.8^{b}	9.0^{a}	0.99a^{b}	1.83^{a}
400		363.0^{a}	354.5^{a}	63.5^{c}	9.3^{a}	0.90^{b}	1.81^{a}
50		276.0	269.0	79.2^{b}	9.3^{a}	0.96	1.73^{b}
100		274.7	268.7	88.3^{a}	8.4^{b}	1.02	1.84^{a}
2012		269.5^{b}	262.7^{b}	83.3a^{b}	8.82	0.96	1.69^{b}
2013		276.8^{a}	270.1^{a}	86.4^{a}	8.73	0.99	1.82^{a}
2014		279.8^{a}	273.7^{a}	81.5^{b}	9.01	1.02	1.85^{a}

Note. The mean marked by the same letter do not differ significantly the *camelina* requires about 12 kg of kg·ha $^{-1}$ per 100 kg of expected seed yield. Toncea (2014) reported that yield of *camelina* also depends on weather conditions and varieties.

Chemical composition of seeds

The increase in seeding rate to 400 pcs. m^{-2} resulted in reduction of the content in seed protein, and increased fat content and fat yield (Table 6). The higher dose of nitrogen in comparison to the lower contributed to an increase in seed content of protein and protein yield, and reduced crude fat content in seeds. In 2012 it was reported the highest total protein content in the seeds, and the lowest crude fat and fat yield.

Many authors (Jiang et al., 2013; Jiang et al., 2014; Sintim et al., 2015) confirmed that higher doses of nitrogen increase the protein content and lower fat content in the seeds of false flax. It has been shown that nitrogen fertilization increases protein yield (Jiang et al., 2013) and fat yield (Jiang et al., 2014). Zubr (2003b) as well as Zubr and Matthäus (2002) conclude that the differences in the quality of false flax seeds are mainly due to the varietal characteristics and conditions of climate and soil in which the plants were grown.

Applied the highest seed rate (400 psc. m^{-2}) resulted in an increase in the content of the seeds K and Mg. In turn, the plating 200 psc. m^{-2} increased the content in the seeds of Mn and Zn a decrease and of Fe. Increasing the nitrogen fertilization with 50 kg·ha^{-1} to 100 kg·ha^{-1} increased the Fe and Zn content in seeds. In the study period content of Fe and Zn in seeds was varied (Table 7). The average macro- and micronutrient content in the seeds of false flax was different from given by Zubr (2010).

Varied sowing rates had no significant effect on the percentage of fatty acids. The higher dose of nitrogen in comparison to the lower increased the proportion of linoleic acid and linolenic acid and reduced oleic. Otherwise, it was proved that the contribution of certain fatty acids in the period was variable (Table 8). Jiang et al. (2013, 2014) showed that higher doses of nitrogen increase the percentage of polyunsaturated fatty acids, and reduce the percentage of monounsaturated fatty acids. Wang et al. (2017) reported that the *camelina* was rich in $C_{18:4,n-3}$ and in C_{20} FA.

CONCLUSIONS

The agricultural practices, ie.: the sowing rates and nitrogen fertilization diversified yield components, yield and chemical composition in seeds of summer *Camelina sativa* L.

The increase in the sowing density significantly developed plant density, but reduced the number of silicles per plant. Sowing 400 seeds · m^{-2} resulted in a decrease of 1000 seeds compared to 200 seeds ·m^{-2}. In turn, 200 seeds · m^{-2} significantly decreased the number of seeds in the silicle, seed yield and content of Fe in the seeds. However, it increased the content of seeds in Mn and Zn. It was found that the sowing of 400 seeds · m^{-2} reduced the protein content in the seeds, K and Mg, and increased the fat yield and crude fat content in the seeds. The higher nitrogen dose (100 kg · ha^{-1}) significantly increased the number of silicles per plant, total protein content, Fe, Zn in seeds, seed yield, protein yield and percentage of linoleic and linolenic acids. The lower nitrogen dose (50 kg · ha^{-1}) increased the number of seeds in the silicle, the fat content in the seeds and the percentage of oleic acid.

The studies proved that spring summer *Camelina sativa* L. reacts preferentially at the higher dose of nitrogen (100 kg · ha^{-1}) and a higher sowing rates (300 - 400 pcs.m^{-2}).

Table 6: Seed content and yield total protein and crude fat (average of years)

Experience factor		Total protein (% DM)	Crude fat (% DM)	Yield (t·ha^{-1})	
sowing density (psc. m^{-2})	nitrogen fertilization (N kg·ha^{-1})			total protein	crude fat
200	50	27.3	29.4	0.46	0.49
	100	28.4	28.2	0.51	0.50
300	50	27.0	29.8	0.48	0.53
	100	27.7	28.5	0.52	0.53
400	50	26.1	31.2	0.46	0.55
	100	26.9	30.6	0.50	0.57
200		27.9^{a}	28.8^{b}	0.48	0.50^{b}
300		27.4^{a}	29.2^{b}	0.50	0.53^{b}
400		26.5^{b}	30.9^{a}	0.48	0.56^{a}
50		26.8^{b}	30.1^{a}	0.46^{b}	0.52
100		27.7^{a}	29.1^{b}	0.51^{a}	0.54
2012		29.3^{a}	27.9^{b}	0.50	0.47^{b}
2013		26.6^{b}	29.7^{a}	0.48	0.54^{ab}
2014		25.8^{b}	31.2^{a}	0.48	0.58^{a}

Note. The mean marked by the same letter do not differ significantly

Table 7: The content of macroelement and microelement in seeds (average of years)

Experience factor		P	K	Ca	Mg	Fe	Cu	Mn	Zn
sowing density (psc. m^{-2})	nitrogen fertilization (N kg·ha^{-1})	G kg DM				mg kg DM			
200	50	4.12	10.44	2.58	2.39	67.53	4.67	20.07	33.08
	100	3.99	10.50	2.44	2.35	68.26	5.42	21.05	35.08
300	50	3.64	10.47	2.57	2.05	69.23	4.79	19.61	30.54
	100	3.77	10.88	2.52	2.01	73.46	4.91	16.30	32.53
400	50	3.89	11.67	2.06	3.96	61.75	4.57	15.54	29.24
	100	3.39	13.91	2.12	2.71	77.58	5.09	17.04	36.42
200		4.06	10.47[b]	2.51	2.37[b]	67.90[b]	5.05	20.56[a]	34.08[a]
300		3.71	10.68[b]	2.55	2.03[b]	71.35[a]	4.85	17.96[b]	31.54[b]
400		3.64	12.79[a]	2.09	3.34[a]	69.67[a]	4.83	16.29[b]	32.83[b]
50		3.88	10.8[6]	2.40	2.80	66.17[b]	4.68	18.41	30.95[b]
100		3.72	11.7[6]	2.36	2.36	73.10[a]	5.14	18.13	34.68[a]
2012		3.72	10.55	2.38	2.40	54.94[c]	4.75	17.07	30.80[b]
2013		4.04	11.60	2.33	2.32	69.07[b]	4.96	20.44	33.01[a]
2014		3.64	11.79	2.44	3.02	84.89[a]	5.02	17.30	34.63[a]

Note. The mean marked by the same letter do not differ significantly

Table 8: Content of fatty acid (%) in seeds (average of years)

Fatty acids	Sowing density (psc. m^{-2})			Nitrogen fertilization (N kg·ha^{-1})		Years		
	200	300	400	50	100	2012	2013	2014
Myristic C 14:0	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.07
Palmitic C 16:0	6.10	6.12	6.23	6.21	6.09	6.14	6.09	6.22
Palmitoleic C16:1	0.14	0.16	0.18	0.17	0.15	0.17	0.16	0.15
Stearic C 18:0	2.95	3.01	3.15	3.12	2.95	2.83b	3.34[a]	2.94[b]
Oleic C18:1	16.56	17.47	17.52	19.55[a]	14.81[b]	19.80[a]	16.65[b]	15.10[b]
Linoleic C 18:2	18.53	18.72	18.91	15.65[b]	21.79[a]	18.90	19.01	18.25
Linolenic C 18:3	29.61	31.82	32.09	29.09[b]	33.27[a]	29.90[c]	32.12[a]	31.52[b]
Arachidic C 20:0	1.76	1.92	1.98	1.99	1.78	1.88b	2.02[a]	1.76[c]
Gondoic C 20:1	16.95	17.53	17.94	17.69	17.25	16.10[b]	16.84[b]	19.48[a]
Behenic C 22:0	0.37	0.43	0.46	0.44	0.40	0.42	0.45	0.39
Erucic C 22:1	3.75	3.81	3.91	3.93	3.72	3.61	3.77	4.09

Note. The mean marked by the same letter do not differ significantly

Authors' contributions

Designed and conducted all of the experiment (M.Cz. and D.B.J). Collected data, data analysis, laboratory analysis (M.Cz. and W.J.). Statistical analysis of the data (W.J.) and wrote the manuscript (M.Cz. and W.J.). All authors have read and approved the final manuscript.

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