

Full Length Research Paper

## Fatty acid composition of *Camelina sativa* as affected by combined nitrogen and sulphur fertilisation

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**Camelina (false flax) oil is an important source of linolenic acid (C18:3). As agronomic treatments such as fertilization may affect seed quality parameters in oilseeds, fatty acid composition and oil content of *Camelina sativa* were investigated as affected by the combined application of nitrogen and sulphur in pot experiments. Nitrogen was applied as  $\text{NH}_4\text{NO}_3$  at rates of 0.6 ( $\text{N}_1$ ), 0.9 ( $\text{N}_2$ ) or 1.2 ( $\text{N}_3$ ) g per pot. To increase the natural soil  $\text{S-SO}_4^{2-}$  level of 25 mg/kg ( $\text{S}_0$ ) to 35 mg/kg ( $\text{S}_1$ ), 45 mg/kg ( $\text{S}_2$ ) and 55 mg/kg ( $\text{S}_3$ ) were supplied as  $(\text{NH}_4)_2\text{SO}_4$ . Results of this study show that seed oil content ranged from 37.01 to 41.23% of seed dry matter, and oil content was significantly reduced by N fertilizer application. The contents of palmitic acid (range 6.9 to 11.0%), oleic acid (range 12.8 to 16.3%) as well as arachidic and 11, 13-icosadienoic acids were also affected by fertilisation, whereas variations in linolenic acid content were not significantly influenced by the fertilizer treatments applied.**

**Key words:** Nitrogen, sulphur, fertilizer, *Camelina sativa*, seed, fatty acid, GC-FID.

### INTRODUCTION

Camelina (false flax, gold-of-pleasure, *Camelina sativa* [L.] Crtz.) belongs to the Brassicaceae family and is a flexible oilseed crop that can be grown under different climatic and soil conditions (Zubr, 2003). Agronomic interest in camelina as an oilseed crop is due to its low-input characteristics (Putnam et al., 1993). While its agronomic features have been considered to be quite acceptable, the oil content has been described as being in the low range of 320 to 440 g/kg seed dry matter (Vollmann et al., 1996; Zubr, 2003). Therefore, improvement of the seed oil content would undoubtedly enhance the competitiveness of camelina in comparison with other oilseed crops (Vollmann et al., 2005). In many

oilseed crops such as soybean, oilseed rape or linseed, selection for low linolenic acid content has been practised (Burton et al., 2004) in order to improve shelf life of the oil and to reduce the rate of trans fatty acid formation during oil processing, which has a negative health effect (Stender and Dyerberg, 2004).

However, as a polyunsaturated fatty acid (PUFA)  $\alpha$ -linolenic acid is a nutritionally valuable omega-3 fatty acid, reducing the incidence of cardiovascular disease as well as various other health risks in humans (Ruxton et al., 2007). Thus, vegetable oil from camelina appears as an important source of omega-3-fatty acids due to its high concentrations of linolenic acid (Hrastar et al., 2009) and good oxidative stability (Abramovic and Abram, 2005). The consumption of camelina oil can contribute to the desirable improvement of general health of the population (Zubr, 1997; Zubr and Matthäus, 2002; Rokka et al., 2002; Lu and Kang, 2008), and significantly reduces

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**Table 1.** Experimental layout of the nitrogen/sulphur fertilization experiments and oil content (%) as influenced by N-S-treatments (Lošák et al., 2010, 2011).

Treatment no.	Description	N – dose (g/pot)	S-SO <sub>4</sub> <sup>2-</sup> content in soil (mg/kg)	Oil content mean ± S.D.
1	N <sub>1</sub> S <sub>0</sub>	0.6	25	40.02 ± 3.569 <sup>ad</sup>
2	N <sub>1</sub> S <sub>1</sub>	0.6	35	40.49 ± 4.554 <sup>ac</sup>
3	N <sub>1</sub> S <sub>2</sub>	0.6	45	39.64 ± 6.382 <sup>ae</sup>
4	N <sub>1</sub> S <sub>3</sub>	0.6	55	41.23 ± 3.108 <sup>a</sup>
5	N <sub>2</sub> S <sub>0</sub>	0.9	25	39.05 ± 2.607 <sup>ab</sup>
6	N <sub>2</sub> S <sub>1</sub>	0.9	35	38.19 ± 2.876 <sup>bcd</sup>
7	N <sub>2</sub> S <sub>2</sub>	0.9	45	37.86 ± 2.054 <sup>bde</sup>
8	N <sub>2</sub> S <sub>3</sub>	0.9	55	38.84 ± 2.638 <sup>ab</sup>
9	N <sub>3</sub> S <sub>0</sub>	1.2	25	37.26 ± 4.638 <sup>be</sup>
10	N <sub>3</sub> S <sub>1</sub>	1.2	35	37.70 ± 4.726 <sup>bde</sup>
11	N <sub>3</sub> S <sub>2</sub>	1.2	45	37.01 ± 4.912 <sup>b</sup>
12	N <sub>3</sub> S <sub>3</sub>	1.2	55	37.72 ± 0.983 <sup>bde</sup>

<sup>a-e</sup> Means followed by the same letter in the column are not significantly different ( $P \leq 0.05$ ). S.D. – standard deviation.

serum cholesterol (Karvonen et al., 2002). Of all agricultural methods, balanced nutrition and fertilisation of camelina in particular predetermines the seed quality, oil yields and composition of fatty acids (Honermeier and Agegnehu, 1996; Zadernowski et al., 1999). Nitrogen is one of the most important nutrients involved in the production of oilseed crops (Urbaniak et al., 2008; Nuttall and Malhi, 1991). A number of research projects have evaluated N requirements in camelina with variable results.

According to studies conducted in Europe (Zubr, 1997), camelina can be successfully grown with N levels of 100 kg N/ha. Applications of nitrogen affect yield components (Agegnehu and Honermeier, 1997), seed yield, oil and protein content and fatty acid composition (Szczebiot, 2002; Urbaniak et al., 2008; Zheljzkov et al., 2008). Sulphur deficiency inhibits the plant use efficiency of N from fertilisers (Schnug et al., 1993) and may therefore increase N losses. If the sulphur supply is insufficient, increasing rates of nitrogen will intensify this shortage (Janzen and Bettany, 1984) and further reduce yields. The aim of the present study was to explore the effect of combined N and S fertilisation on fatty acid composition and oil content of camelina.

## MATERIALS AND METHODS

A pot trial with 4 replications of every treatment was set up outdoors on 20 March 2005, at the experimental site of Mendel University. A total of 6-L Mitscherlich pots were filled with 6 kg of fresh medium-heavy soil characterised as a fluvial. The pots were watered with demineralised water to a level of 60% of the maximum water-holding capacity and were kept free of weeds. The layout of the fertilizer treatments is shown in Table 1. On 18 July 2005, four plants from each pot were harvested at the stage of full maturity and the oil content and fatty acids composition of camelina seeds

were determined. Soil analyses and plant analyses were published in our previous studies (Lošák et al., 2010, 2011).

### Oil content

Sub-samples of about 15 g of dry seeds were analysed for oil content by near-infrared reflectance spectroscopy (NIRS) using an InfraAlyzer model 450 spectrometer and IDAS calibration software (Bran & Luebbe, Norderstedt, Germany). NIRS calibrations with validation  $r^2$  values of 0.90 for oil content had previously been developed with reference samples from eight different environments. All seed oil content data were expressed as % of oven-dried seed dry matter.

### Chemicals

Used chemicals as Dimethylformamide (DMF) puriss, disodium hydrogen citrate purum, sodium methoxide, methanol p.a., 1,4-dioxane p.a., n-hexane p.a. were purchased from Sigma-Aldrich. Food Industry FAME Mix standard was acquired from Restek.

### Determination of fatty acids (FA)

Determination of fatty acids was performed according to Suter et al. (1997). Briefly, 1 g of homogenous sample of camelina was accurately weighed. Then, the sample was heated in DMF: 2.5 ml of DMF were added and the slurry refluxed whilst it was stirring, for 15 min, as pretreatment before transesterification. Samples were cooled to ambient temperature and after that transesterification followed. Firstly, 5 ml of 1,4-dioxane was added and mixed to dissolve any solid fat. Then, 5 ml of methanol containing 5% methoxide were added (vortexed for 3 s) and allowed to stand for 90 s. Consequently, 25 ml of hexane were admixed. Immediately afterwards, the reaction (saponification) was stopped by addition of 10 ml of 15% disodium hydrogen citrate in water, reducing the pH to 7-8. The hexane phase was transferred to the 50 ml volumetric flask and 10 µl of cyclohexanone as an internal standard were added, and the volumetric flask was filled to the mark.

The hexane solution was used for GC-FID analysis, which was

**Table 2.** Fatty acid concentrations (%) of camelina oil depending on the fertilizer treatment.

Treatment	C16:0 mean ± S.D.	C18:0 mean ± S.D.	C18:1 mean ± S.D.	C18:2 mean ± S.D.	C18:3 mean ± S.D.	C20:0 mean ± S.D.	C20:1 mean ± S.D.	C20:2 mean ± S.D.
N <sub>1</sub> S <sub>0</sub>	7.78 <sup>bc</sup> ± 0.417	2.99 <sup>a</sup> ± 0.133	14.73 <sup>ab</sup> ± 1.356	19.49 <sup>a</sup> ± 1.341	34.69 <sup>a</sup> ± 3.130	1.94 <sup>bc</sup> ± 0.084	16.34 <sup>a</sup> ± 0.617	2.03 <sup>ab</sup> ± 0.139
N <sub>1</sub> S <sub>1</sub>	7.08 <sup>cd</sup> ± 0.081	2.80 <sup>a</sup> ± 0.021	14.86 <sup>ab</sup> ± 0.257	19.79 <sup>a</sup> ± 0.256	35.32 <sup>a</sup> ± 1.090	1.96 <sup>ab</sup> ± 0.024	16.14 <sup>a</sup> ± 0.313	2.04 <sup>ab</sup> ± 0.048
N <sub>1</sub> S <sub>2</sub>	7.53 <sup>bc</sup> ± 0.237	2.92 <sup>a</sup> ± 0.166	14.96 <sup>ab</sup> ± 0.245	19.69 <sup>a</sup> ± 0.265	34.52 <sup>a</sup> ± 1.862	2.07 <sup>ab</sup> ± 0.069	16.27 <sup>a</sup> ± 0.137	2.04 <sup>ab</sup> ± 0.049
N <sub>1</sub> S <sub>3</sub>	6.98 <sup>c</sup> ± 0.305	2.85 <sup>a</sup> ± 0.057	15.50 <sup>ac</sup> ± 0.337	18.70 <sup>a</sup> ± 0.218	35.67 <sup>a</sup> ± 0.620	1.98 <sup>ab</sup> ± 0.057	16.41 <sup>a</sup> ± 0.148	1.91 <sup>ab</sup> ± 0.079
N <sub>2</sub> S <sub>0</sub>	8.13 <sup>b</sup> ± 0.145	2.98 <sup>a</sup> ± 0.174	14.32 <sup>ab</sup> ± 0.098	18.22 <sup>a</sup> ± 2.298	36.45 <sup>a</sup> ± 0.237	1.91 <sup>b</sup> ± 0.219	15.78 <sup>a</sup> ± 0.349	2.21 <sup>a</sup> ± 0.182
N <sub>2</sub> S <sub>1</sub>	6.91 <sup>c</sup> ± 0.426	2.83 <sup>a</sup> ± 0.212	14.37 <sup>ab</sup> ± 0.383	19.90 <sup>a</sup> ± 0.197	35.26 <sup>a</sup> ± 0.732	2.12 <sup>ab</sup> ± 0.152	16.50 <sup>a</sup> ± 0.052	2.11 <sup>ab</sup> ± 0.101
N <sub>2</sub> S <sub>2</sub>	11.02 <sup>a</sup> ± 0.310	3.22 <sup>a</sup> ± 0.210	16.26 <sup>a</sup> ± 0.239	18.42 <sup>a</sup> ± 0.842	32.02 <sup>a</sup> ± 0.502	2.08 <sup>ab</sup> ± 0.070	15.15 <sup>a</sup> ± 0.284	1.83 <sup>ab</sup> ± 0.015
N <sub>2</sub> S <sub>3</sub>	7.67 <sup>bc</sup> ± 0.336	3.30 <sup>a</sup> ± 0.328	16.16 <sup>a</sup> ± 0.629	19.54 <sup>a</sup> ± 1.968	32.88 <sup>a</sup> ± 4.050	2.02 <sup>ab</sup> ± 0.152	16.42 <sup>a</sup> ± 0.792	2.01 <sup>ab</sup> ± 0.122
N <sub>3</sub> S <sub>0</sub>	7.92 <sup>bd</sup> ± 0.081	3.15 <sup>a</sup> ± 0.075	15.17 <sup>ac</sup> ± 0.359	19.24 <sup>a</sup> ± 1.263	34.25 <sup>a</sup> ± 3.088	2.32 <sup>ac</sup> ± 0.076	15.94 <sup>a</sup> ± 1.202	2.01 <sup>ab</sup> ± 0.222
N <sub>3</sub> S <sub>1</sub>	7.70 <sup>bc</sup> ± 0.216	3.17 <sup>a</sup> ± 0.116	12.82 <sup>b</sup> ± 1.201	19.71 <sup>a</sup> ± 0.723	37.49 <sup>a</sup> ± 0.290	2.15 <sup>ab</sup> ± 0.120	15.26 <sup>a</sup> ± 1.163	1.70 <sup>b</sup> ± 0.135
N <sub>3</sub> S <sub>2</sub>	7.33 <sup>bc</sup> ± 0.133	3.02 <sup>a</sup> ± 0.087	13.54 <sup>bc</sup> ± 0.069	19.45 <sup>a</sup> ± 1.344	36.62 <sup>a</sup> ± 1.141	2.34 <sup>a</sup> ± 0.086	15.94 <sup>a</sup> ± 0.943	1.75 <sup>ab</sup> ± 0.042
N <sub>3</sub> S <sub>3</sub>	7.98 <sup>bd</sup> ± 0.343	3.30 <sup>a</sup> ± 0.236	13.86 <sup>bc</sup> ± 0.776	20.26 <sup>a</sup> ± 1.008	34.80 <sup>a</sup> ± 0.422	2.26 <sup>ab</sup> ± 0.132	15.46 <sup>a</sup> ± 1.123	2.10 <sup>ab</sup> ± 0.263

<sup>a-d</sup> Means followed by the same letter in each column are not significantly different ( $P \leq 0.05$ ). S.D. – standard deviation.

performed with Shimadzu GC 2010 using L × I.D. 30 m × 0.25 mm, d<sub>i</sub> 0.20 μm capillary column SPB-PUFA. The injection volume was 1.0 μl with split ratio 1:100. During injection, the oven temperature was 50°C (1 min), then programmed at 20°C/min to 220°C; the total GC programme took about 30 min. Nitrogen 5.0 served as the mobile phase. Software GC solution was used for data analysis. Quantitative analysis of FA in camelina samples was accomplished by comparison with FAME Mix standard. The conversion from FAMES to fatty acids was performed using coefficient, which was calculated as the ratio of the molecular weight of fatty acid to the molecular weight of fatty acid methyl ester according to Pimentel et al. (2010).

#### Statistical analyses

The data were statistically analysed according to Zapletal et al. (2009) using the statistical programme Statistica CZ 9.0. (StatSoft, Inc., 2011), using analysis of variance (ANOVA) with N rate and S rate as fixed effects on fatty acid composition. The parametric Tukey's HSD test as a post hoc test was used for the determination of significant

differences. Statistically significant differences were tested at  $P \leq 0.05$ .

## RESULTS AND DISCUSSION

### Oil content

In the present study, the seed oil content ranged from 37.01 to 41.23% of seed dry matter (Table 1). This range corresponded to that reports in a number of previous studies (Vollmann et al., 1996, 2005; Zubr, 1997, 2003; Agegnehu and Honermeier, 1997). In our experiment (Table 1), the oil content significantly decreased with increasing rate of N fertilisation (N<sub>1</sub>, N<sub>2</sub> and N<sub>3</sub>). The highest N dose significantly reduced the oil content of seeds in comparison to the lowest one applied with the same S rate (N<sub>3</sub>S<sub>0</sub> compared with N<sub>1</sub>S<sub>0</sub>) or (N<sub>3</sub>S<sub>2</sub> compared with N<sub>1</sub>S<sub>2</sub>). This finding confirmed the conclusions of Agegnehu and

Honermeier (1997), who discovered that increasing the N doses from 0 to 120 kg N ha<sup>-1</sup> at a seed rate of 400 seeds m<sup>-2</sup> decreased the oil content of camelina from 41 to 39%. Urbaniak et al. (2008) arrived at the same conclusion. Rathke et al. (2005) suggested that this may be a consequence of reduced availability of carbohydrates for oil synthesis with increasing N availability. In our experiment, S fertilisation did not affect the oil content of camelina.

### Fatty acid (FA) composition

The results of the FA analysis of camelina seed oil are presented in Table 2. Generally, the analysis confirmed the known specific content of FA in camelina oil which was similar, but not the same as report for oils from camelina cultivated in the USA, Central and North Europe (Bonjean and

Le Goffic, 1999; Zubr and Matthäus, 2002; Abramovic and Abram, 2005; Peiretti and Meineri, 2007). The results (Table 2) showed that nitrogen/sulphur fertilization significantly influenced the concentration of palmitic (C16:0), oleic (C18:1), arachidic (C20:0) and 11, 13 – icosadienoic acid (C20:2). The content of palmitic acid ranged from  $6.9 \pm 0.43\%$  by  $N_2S_1$  application to  $11.0 \pm 0.31\%$  in the case of  $N_2S_2$  application. The fertilizer combinations  $N_2S_2$  and  $N_2S_3$  caused the highest contents of oleic acid ( $16.3 \pm 0.24\%$ ,  $16.2 \pm 0.63\%$ , respectively) while the lowest amount was determined in case of  $N_3S_1$  application ( $12.8 \pm 1.20\%$ ). The content of arachidic acid was highest after  $N_3S_0$  or  $N_3S_2$  treatments, rising to  $2.3 \pm 0.08$  and  $2.3 \pm 0.09\%$ , respectively, in contrast to the combinations  $N_1S_0$  and  $N_2S_0$  ( $1.9 \pm 0.08\%$  and  $1.9 \pm 0.22\%$ ). Significant differences were also found between  $N_2S_0$  and  $N_3S_1$  for 11, 13 – icosadienoic acid ( $2.2 \pm 0.18\%$  and  $1.7 \pm 0.14\%$ , respectively). The present findings are confirmed by Abramovic and Abram (2005) who find that the differences in the composition of the FA in seed oil can be caused not only by the different cultivars, but also by environmental conditions. Zubr (2003) similarly concluded that variations are due to the combined effects of climatic and soil conditions on the crop.

## Conclusion

Camelina is described as a crop requiring fewer inputs than other oilseed species and producing higher amounts of  $\alpha$ -linolenic acid. This study revealed an effect of nitrogen/sulphur fertilizer application on oil content and FA composition. The highest N dose significantly reduced the oil content of seeds in comparison to the lowest one applied with the same S rate. The  $N_2S_2$  fertilization caused the highest contents of both palmitic and oleic acids. The concentration of linolenic acid, which is the important fatty acid with respect to human nutrition, remained unaffected by the fertilizer treatments applied. With the view of seed yield, oil yield (Lošák et al., 2010, 2011) and fatty acids composition we could recommend for *C. sativa* growing, the  $N_2S_2$  fertilization, which means combination of  $0.9 \text{ g/pot}$  (approximately equal to  $95 \text{ kg} \cdot \text{ha}^{-1}$ ) of nitrogen and  $45 \text{ mg/kg}$  of  $S\text{-SO}_4^{2-}$ .

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## REFERENCES

Abramovic H, Abram V (2005). Physico-chemical properties,

- composition and oxidative stability of *Camelina sativa* oil. Food Technol. Biotech., 43: 63–70.
- Agegnehu M, Honermeier B (1997). Effects of seeding rates and nitrogen fertilization on seed yield, seed quality and yield components of false flax (*Camelina sativa* Crtz.). Bodenkultur, 4: 15–21.
- Bonjean A, Le-Goffic F (1999). False flax–*Camelina sativa* (L.) Crantz: an opportunity for European agriculture and industry. OCL, 6: 28–33.
- Burton JW, Miller JF, Vick BA, Scarth R, Holbrook CC (2004). Altering fatty acid composition in oil seed crops. Adv. Agron., 84: 273–306.
- Honermeier B, Agegnehu M (1996). Camelina has a future as a non-food crop. Neue Landwirtschaft, 12: 44–46.
- Hrastar R, Petrisic MG, Ogrinc N, Kosir IJ (2009). Fatty acid and stable carbon isotope characterization of *Camelina sativa* oil: Implications for authentication. J. Agric. Food Chem., 57: 579–585.
- Janzen HH, Bettany JR (1984). Sulfur nutrition of rapeseed: I. Influence of fertilizer nitrogen and sulfur rates. Soil Sci. Soc. Am. J., 48: 100–107.
- Karvonen HM, Aro A, Tapola NS, Salminen I, Uusitupa MIJ, Sarkkinen ES (2002). Effect of  $\alpha$ -linolenic acid-rich *Camelina sativa* oil on serum fatty acid composition and serum lipids in hypercholesterolemic subjects. Metabolism, 51: 1253–1260.
- Lošák T, Hlušek J, Martinec J, Vollmann J, Peterka J, Filipčík R, Varga L, Ducsay L, Martensson A (2011). Effect of combined nitrogen and sulphur fertilisation on yield and qualitative parameters of *Camelina sativa* [L.] Crtz. (false flax). Acta Agr. Scand. B-S P., 61: 313–321.
- Lošák T, Vollmann J, Hlušek J, Peterka J, Filipčík R, Prášková L (2010). Influence of combined nitrogen and sulphur fertilization on false flax (*Camelina sativa* [L.] Crtz.) yield and quality. Acta Aliment. Hung., 39: 431–444.
- Lu Ch, Kang J (2008). Generation on transgenic plants of a potential oilseed crop *Camelina sativa* by Agrobacterium-mediated transformation. Plant Cell Rep., 27: 273–278.
- Nuttall WF, Malhi, SS (1991). The effect of time and rate of N application on the yield and N uptake of wheat, barley, flax and four cultivars of rapeseed. Can. J. Soil Sci., 71: 227–238.
- Peiretti PG, Meineri G (2007). Fatty acids, chemical composition and organic matter digestibility of seeds and vegetative parts of false flax (*Camelina sativa* L.) after different lengths of growth. Anim. Feed Sci. Tech., 133: 341–350.
- Pimentel SA, Kus MMM, Kumagai EE, Ruvieri V, Zenebon O (2010). Comparison of gas chromatographic and gravimetric methods for quantization of total fat and fatty acids in foodstuffs. Quim. Nova, 33: 76–84.
- Putnam DH, Budin JT, Field LA, Breene WM (1993). Camelina: a promising low-input oilseed. in: Janick, J. & Simon, J.E. (Ed.), New Crops Exploration Research and Commercialization. Proceedings of the Second National Symposium Indianapolis. 6–9 Oct. 1991. John Wiley and Sons. Inc., New York, pp. 314–322.
- Rathke GW, Christen O, Diepenbrock W (2005). Effect of nitrogen source and rate on productivity and quality of winter oilseed rape (*Brassica napus* L.) grown in different crop rotations. Field Crops Res., 94: 103–113.
- Rokka T, Alen K, Valaja J, Ryhanen EL (2002). The effect of a *Camelina sativa* enriched diet on the composition and sensory quality of hen eggs. Food Res. Int., 35: 253–256.
- Ruxton CHS, Reed SC, Simpson MJA, Millington KJ (2007). The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence. J. Hum. Nutr. Diet., 20: 275–285.
- Schnug E, Haneklaus S, Murphy D (1993). Impact of sulphur fertilisation on fertiliser nitrogen efficiency. Sulphur Agric., 17: 8–12.
- Stender S, Dyerberg J (2004). Influence of trans fatty acids on health. Ann. Nutr. Metab., 48: 61–66.
- Suter B, Grob K, Pacciarelli B (1997). Determination of fat content and fatty acid composition through 1-min transesterification in the food sample; principles. Z. Lebensm. Unters. F. A., 204: 252–258.
- Szczepiot M (2002). Effect of mineral fertilization on yielding of spring false flax and crambe. Oilseed Crops (Poland), 23: 141–150.
- Urbaniak SD, Caldwell CD, Zheljzkov VD, Lada R, Luan L (2008). The effect of cultivar and applied nitrogen on the performance of *Camelina sativa* L. in the Maritime Provinces of Canada. Can. J. Plant Sci., 88: 111–119.
- Vollmann J, Damboeck A, Eckl A, Schrems H, Ruckenbauer P (1996).

- Improvement of *Camelina sativa*, an underexploited oilseed. in: Janick, J (eds.). Progress in New Crops. ASHS Press, Alexandria, pp. 357–362.
- Vollmann J, Grausgruber H, Stift G, Dryzhyruk V, Lelley T (2005). Genetic diversity in camelina germplasm as revealed by seed quality characteristics and RAPD polymorphism. *Plant Breed.*, 124: 446–453.
- Zadernowski R, Budzynski W, Nowak-Polakowska H, Rashed AA, Jankowski K (1999). Effect of fertilization on the composition of lipids from false flax (*Camelina sativa* L. Cr.) and crambe (*Crambe abissinica* Hochst.). *Oilseed Crops (Poland)*, 20: 503–510.
- Zapletal D, Chládek G, Šubrt J (2009). Breed variation in the chemical and fatty acid compositions of the Longissimus dorsi muscle in Czech Fleckvieh and Montbeliarde cattle. *Livest. Sci.*, 123: 28–33.
- Zheljazkov VD, Vick BA, Ebelhar MW, Buehring N, Baldwin BS, Astatkie T, Miller JF (2008). Yield, oil content, and composition of sunflower grown at multiple locations in Mississippi. *Agron. J.*, 100: 635–642.
- Zubr J (1997). Oil-seed crop: *Camelina sativa*. *Ind. Crop. Prod.*, 6: 113–119.
- Zubr J (2003). Qualitative variation of *Camelina sativa* seed from different locations. *Ind. Crop. Prod.*, 17: 161–169.
- Zubr J, Matthäus B (2002). Effect of growth conditions on fatty acids and tocopherols in *Camelina sativa* oil. *Ind. Crop and Prod.*, 15: 155–162.