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CAMELINA SATIVA OIL AND CAMELINA CAKE AS SOURCES OF POLYUNSATURATED FATTY ACIDS IN THE DIETS OF LAYING HENS: EFFECT ON HEN PERFORMANCE, FATTY ACID PROFILE OF YOLK LIPIDS, AND EGG SENSORY QUALITY*

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Abstract

The present study aimed to determine the effect of the use of *Camelina sativa* oil as a dietary ingredient for laying hens on their growth performance, fatty acid profile of yolk lipids, and egg quality parameters. In the experiment, 72 Hy-Line laying hens aged 26 weeks were randomly assigned to three groups with four treatments. Control group (I) was fed the diet containing 4% rapeseed oil (RO group). Experimental groups were fed diets containing 4% camelina oil (CSO group) and 10% camelina cake (group CSC). Feed consumption was measured for each group. The number of laid eggs and their weight were recorded every day. Eggs for the assessment of quality parameters were collected in the last 3 days of the experiment. Egg quality, chemical composition of yolk, and fatty acid profile were determined. Organoleptic evaluation was performed on boiled eggs. The inclusion of *C. sativa* oil or camelina cake in the laying hen diet did not affect egg weight, albumen quality, or taste and flavor. The experimental groups also showed a tendency toward an increase in the proportion of yolk in the egg (%). Addition of 4% camelina oil or 10% camelina cake to the diet of laying hens reduced monounsaturated fatty acid level in yolk lipids and significantly increased *n-3* PUFA content, in particular ALA, EPA, and DHA, compared to the control group.

Key words: laying hens, camelina oil, camelina cake, polyunsaturated fatty acids, laying performance, egg quality

The last 30 years have witnessed a surge of studies concerning the effect of the diet of laying hens on the increase in *n-3* fatty acid content in yolk lipids. Consumers have recently been more interested in products containing polyunsaturated fatty acids (PUFAs) that play a very important biological role in ensuring proper physiologi-

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cal functioning of human body. These health-promoting properties include the cardioprotective, anticancer, blood pressure lowering, and immune-enhancing effects of *n-3* fatty acids and their important roles in the growth and development of the nervous system (Simopolous, 2011; Jump et al., 2012). Currently, eggs are thought to be an alternative source of these acids in the human diet. Previous studies have proved that the consumption of eggs enriched in *n-3* PUFA contributes to the reduction of risk of cardiovascular diseases and prevents the development of these diseases (Cherian and Quezada, 2016; Stupin et al., 2018). It was found that the fatty acid profile of egg yolk could be easily modified by dietary inclusion of oils rich in *n-3* fatty acids (Ehr et al., 2017). However, the efficacy of incorporation of *n-3* PUFA into egg yolk lipids is different among various dietary *n-3* PUFA sources (Cherian and Quezada, 2016). Among the available dietary *n-3* sources for laying hens, marine oil, fish oil, and flaxseed oil are the most effective oils in increasing *n-3* fatty acid content of egg yolk lipids (Lemahieu et al., 2013; Ao et al., 2015; Ehr et al., 2017). Because of limited availability, shorter shelf life, and a high risk of changing aroma of eggs as well as a higher cost of these feed supplements, alternative sources of *n-3* PUFA are being intensively investigated.

Considering the preferences of consumers and expectations of egg producers, there is an increased interest for finding nontraditional, low-cost components to enrich egg yolk in *n-3* fatty acids. *Camelina sativa* is characterized by higher disease and drought tolerance and lower input cost (Matthäus and Zubr, 2000). Furthermore, camelina has lower soil requirements than other oil crops, matures early, and is frost resistant. *Camelina sativa* contains a high concentration of PUFAs, especially α-linolenic fatty acid which is a precursor of long-chain fatty acids such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). Camelina is also a rich source of vitamin E, a natural antioxidant, which prolongs its shelf life (Matthäus and Zubr, 2000). Camelina cake, the by-product after oil extraction, has crude protein content of approximately 35% and fat content of 10% to 20% (Nain et al., 2015). Previous studies indicate that both camelina oil and by-products of oil pressing can be used for the production of eggs enriched in *n-3* fatty acids, but the inclusion level depends on the concentration of antinutritional substances whose levels vary among the different varieties of camelina and also on soil and climate (Matthäus and Zubr, 2000; Woyengo et al., 2010). Like other oilseed crops from the *Brassicaceae* family, *Camelina sativa* variety Borowska contains antinutritional factors such as glucosinolate that may affect thyroid and liver function (Tripathi and Mishra, 2007). In addition, they reduce feed consumption, suppress growth and fertility of animals, and cause mucosal irritation in the gastrointestinal tract, resulting in local necrotic foci (Bell et al., 1991; Clarke, 2010). Glucosinolate content in camelina cake ranges from 20.3 to 24.4 μmol/g (Pekel et al., 2009; Aziza et al., 2010; Pekel et al., 2015) and is higher than that observed in rapeseed cake where it ranges from 1.55 to 24 μmol/g (Woyengo et al., 2010). However, camelina cake contains less tannins and saponins than rapeseed cake (Woyengo et al., 2010). Synapin contents in camelina and rapeseed seeds vary from 5 to 17 μmol/kg and 22 to 41.8 μmol/kg, respectively (Matthäus and Zubr, 2000). Camelina cake does not contain progoitrin and sinigrin (Matthäus and Zubr, 2000). It contains the largest amounts of 10-methylsulfanylde-

cyl glucosinolate (glucocamelina), 9-methyl-sulfinylnonyl glucosinolate (glucoarabin), and 11-methylsulfinylundecyl glucosinolate (Ryhänen et al., 2007; Pekel et al., 2009; Aziza et al., 2010; Pekel et al., 2015). These glucosinolates exhibit anticancer properties (Fahey et al., 2001; Berhow et al., 2013) and improve hepatic metabolism (Meadus et al., 2014).

The present study aimed to determine the effect of incorporation of *C. sativa* oil or cake in the diet of laying hens on their performance parameters and chemical composition, fatty acid profile of yolk lipids, and selected parameters of egg quality.

Material and methods

Experimental design, birds, and diets

The experiment was conducted according to the guidelines of the Ethics Committee for the Use of Animals in Research. No explicit approval of the committee was required because the hens were only fed different diets and none of these diets were toxic (the Regulation 68/2013 of the European Union Commission allows the use of *C. sativa* seeds and products obtained by their processing, including oil and camelina meal, as a feed component in animal diets), and no invasive procedures were performed on them. The experiment was conducted on 72 Hy-Line brown laying hens obtained from a commercial source and housed in battery cages, 2 birds per cage; they were exposed to a 14 L:10 D lighting schedule during the experiment, with a light intensity of 10 lux. Before the experiment, from week 18 to 24, the hens were fed a standard diet. At week 25, the hens were randomly assigned to 3 experimental groups with 12 replicates each (one replicate included 1 cage with 2 laying hens). Layers were fed the diets containing the tested ingredients. At week 26, the main experimental period had begun and lasted for 7 weeks. Hens were provided feed *ad libitum* with free access to water. Control group (RO) hens were fed a standard diet containing 4% rapeseed oil. Experimental groups were fed diets with 4% camelina oil (group CSO) or 10% camelina cake (group CSC). Composition and nutritional value of these diets are shown in Table 1. Diets were formulated to provide nutrients according to the guidelines of the Nutrition Requirements of Poultry (2005) and computed using WinPaszePro (2006) software, considering the chemical composition and metabolizable energy value of the experimental components used in the present study (Jansen, 1989). All diets were formulated to be isonitrogenous and isocaloric relative to the basal control diet. The crude fiber content in the experimental feed mixtures did not exceed 4%.

During the experiment, feed consumption and the number and weight of the laid eggs were recorded, and production performance, daily egg weight, daily feed intake, and feed conversion ratio (g of feed/g of eggs) were calculated. To determine the egg yolk fatty acid profile and chemical composition, yolks from three eggs from each cage (n=36 per treatment) were separated, pooled (n=12 per treatment), and then lyophilized using Christ Beta lyophilizer. The dry weight of egg yolk was determined by the weighing method. The raw protein analysis was performed using

the Kjeldahl method. The nitrogen content when expressed as protein was calculated by multiplying the value with 6.25. Crude fat was estimated using a Tecator Soxtec apparatus (HT system) in accordance with the procedures established by the Central Laboratory of the National Research Institute of Animal Production based on the ASN 3165 applications of the Tecator company "The Extraction of Lipids from Egg." Fat substances were extracted from the lyophilized samples of yolks with a 1:1 mixture of toluene and ethanol. The abovementioned method was performed following the methodology described in laboratory protocol PN-75/A-04018.

Table 1. Composition and nutritional value of the diets of laying hens

Ingredients	Treatment Group		
	RO	CSO	CSC
Corn meal	30.58	30.58	32.00
Wheat meal	28.00	28.00	27.55
Soybean meal (46% CP)	26.00	26.00	16.00
Rapeseed oil	4.00	–	2.00
Camelina sativa oil	–	4.00	–
Camelina cake	–	–	10
Ground limestone	8.90	8.90	8.90
Dicalcium phosphate	1.60	1.60	1.63
NaCl	0.30	0.30	0.30
DL-Methionine	0.12	0.12	0.12
Vitamin-mineral premix (0.5%)[1]	0.50	0.50	0.50
Calculated contents of nutrients:			
Metabolizable energy (MJ/kg)	11.6		
Total protein	17.0		
Lysine	0.82		
Methionine	0.36		
Ca	3.65		
P assimilable	0.37		

[1]The premix provided per kg of diet included the following components: retinyl acetate, 10,000 IU; cholecalciferol, 2,000 IU; tocopheryl, 20 IU; menadione sodium bisulfite, 1.5 mg; thiamine, 1 mg; riboflavin, 4 mg; pyridoxine, 1.5 mg; cyanocobalamin, 0.01 mg; Ca-pantothenate, 8.7 mg; niacin, 20 mg; folic acid, 0.8 mg; choline chloride, 200 mg; manganese, 85 mg; zinc, 60 mg; iron, 45 mg; copper, 8 mg; iodine, 1 mg; selenium, 0.25 mg.

Higher fatty acids were determined as methyl esters by gas chromatography. Fat was extracted from samples by using a mixture of chloroform and methanol (2/1) according to the modified method of Folch et al. (1957). The extract was evaporated at 65°C under nitrogen. The residue was saponified with 0.5N NaOH in methanol (20 min, 80°C) and then esterified with BF_3 in methanol (Morrison and Smith, 1964) for 10 min at 80°C, followed by the addition of hexane. After salting out with saturated NaCl solution, the hexane layer was collected in a chromatographic vial and

analyzed using a gas chromatograph VARIAN 3400 (CP-Wax-58, 25 m, 0,53 mm, 1 μm, FID, Hel, 6 ml/min) with an autosampler 8200 CX. Software Varian Star 4.5 was used for data processing. Conjugated linoleic acid (CLA) was determined by mass spectrometry using a gas chromatograph linked to a mass spectrometer (GC-MS-QP 2010 Plus, Shimadzu). In addition, the presence of CLA was confirmed with the same equipment using the derivatization procedure with 4-methyl-1,2,4-triazoline-3,5-dione (MTAD) (Reaney et al., 2001; Dobson, 1998). At week 32, one egg from each cage (12 eggs per treatment) was collected to determine internal egg and eggshell quality by using the Egg Quality Measurements (EQM) system (Technical Services and Supplies, York, England); the following parameters were analyzed: egg weight, Haugh units, yolk color, yolk percentage, eggshell weight, eggshell thickness, and density. At week 32, one egg from each cage was collected to determine internal egg quality. The chosen parameters of egg and eggshell quality, such as egg weight, yolk color, yolk percentage, eggshell weight, thickness, and density, were determined using the EQM system. Eggshell breaking strength was evaluated on the apparatus TA.XTPlus Texture Analyzer (Stable Micro Systems, Godalming, Surrey, UK) fitted with a 30 kgf load cell and a 77-mm compression plate (P/75). The eggs were compressed at a constant test speed of 2 mm/min, and the breaking strength was determined at the time of eggshell fracture.

At week 32, one egg from each treatment (n=12) was collected for sensory analysis. The sensory test evaluates the characteristics of boiled eggs and uses a response scale where the obtained numerical values indicates the quality of the studied sensory properties. Sensory evaluation was conducted by eight internal panelists who received boiled eggs of the control group and two experimental groups. The eggs were boiled for 10 min and cooled to room temperature. After separation of shells, the eggs were cut into eight quarters and given to each panelist on a plastic plate divided into three sections. Each panelist evaluated the flavor and palatability of the eggs on a 4-point scale according to the extent they enjoyed them (2: unacceptable, 3: acceptable, 4: good, 5: very good). Between each testing, the panelists used unsalted bread and water to refresh their senses.

Statistical analysis

The obtained results were analyzed using one-way ANOVA. The significance of differences between the experimental groups was evaluated using the multiple range Duncan test. Statistical significance was considered at $P<0.05$. Statistical data analyses were carried out using the SAS statistical package (version 9.2), procedure GLM.

Results

Chemical composition of oils

Table 2 shows the results of determination of fatty acid contents in oils used as dietary ingredients for hens. The addition of 4% camelina oil or 10% camelina cake into the diets increased the contents of PUFAs of *n-3* series (*n-3* PUFA) and reduced *n-6*/*n-3* PUFA ratio.

Table 2. Contents of fatty acid groups in the diets

Fatty acid group	Treatment Group		
	RO	CSO	CSC
SFA	16.65	15.58	15.00
MUFA	48.69	29.83	44.86
PUFA	34.65	54.59	40.14
PUFA *n-6*	29.10	33.05	30.87
PUFA *n-3*	4.79	19.58	8.00
PUFA *n-6/n-3*	6.15	1.70	3.87
CLA	0.82	1.28	1.71

Production performance of laying hens

The inclusion of 4% CSO or 10% CSC had no significant effect on egg performance parameters in comparison to the hens fed with control diet containing RO (Table 3). The other parameters such as egg weight, feed consumption, and feed conversion ratio were similar in all treatment groups.

Table 3. Effect of dietary CSO and CSC on the performance of 26- to 32-week-old hens

Parameter	Treatment Group			SEM	P-value
	RO	CSO	CSC		
Laying rate (%)	91.05	91.00	89.83	0.628	0.391
Egg weight (g)	61.00	61.11	61.30	1.074	0.816
Daily mass of eggs (g per hen)	57.98	58.28	58.46	0.876	0.718
Daily feed consumption (g per hen)	116.00	116.00	118.00	2.119	0.149
Feed conversion (g of feed per g of eggs)	1.99	1.99	2.02	0.002	0.206

Quality of eggs and shell

Yolks from laying hens fed with the diet containing 4% camelina oil or 10% camelina cake were characterized by a significantly higher color index compared to the control group. The inclusion of *C. sativa* oil or cake from the oil extract of *C. sativa* seeds in the diets of laying hens did not significantly affect eggshell weight, thickness, density, or proportion of eggshell in the egg (%) (Table 4).

No statistically significant effect of camelina oil or cake was observed on the sensory traits of eggs. According to the evaluation of the panelists, both flavor and palatability of eggs from hens belonging to the CSO and CSC treatment groups did not differ from those of the control RO group (Table 5).

Table 4. Effect of 32-day dietary treatment on the egg quality of laying hens

Parameter	Treatment Group			SEM	P-value
	RO	CSO	CSC		
Yolk color (DSM)	2.74 b	2.90 a	2.93 a	0.002	0.0001
Yolk proportion (%)	26.84	27.15	27.00	2.68	0.978
Eggshell proportion (%)	12.73	12.64	12.66	1.24	0.949
Eggshell thickness (mm)	0.37	0.38	0.38	0.004	0.854
Eggshell weight (g)	7.02	7.44	7.13	0.57	0.247
Eggshell density (mg/cm^2)	94.21	95.47	93.95	8.89	0.292
Eggshell breaking strength (N)	48.28	48.69	50.62	5.07	0.068

a, b – mean values with different letters indicate statistically significantly differences at P≤0.05.

Table 5. Effect of 32-day dietary treatments on the organoleptic quality of eggs

Parameter	Treatment Group			SEM	P-value
	RO	CSO	CSC		
Flavor of boiled egg (points)	4.31	4.55	4.10	0.337	0.240
Palatability of boiled egg (points)	4.57	4.50	4.30	0.194	0.280

Effect of camelina oil on the chemical composition of yolk

There was no significant effect of the tested dietary ingredients on the basic chemical composition of egg yolk. All the experimental treatment groups showed comparable levels of dry mass, total protein, and crude fat contents (Table 6). Dietary CSO or CSC also did not have a significant effect on the cholesterol level in eggs.

Table 6. Effect of *Camelina sativa* oil on the basic chemical composition of yolk

Parameter	Group			SEM	P-value
	RO	CSO	CSC		
Dry mass (%)	47.23	46.31	47.08	0.88	0.068
Total protein (%)	15.81	15.88	15.95	0.34	0.083
Crude fat (%)	32.13	33.26	33.18	0.89	0.106
Cholesterol (g/kg)	9.63	9.34	9.76	0.91	0.617

Fatty acid profile of yolk

The analysis of fatty acid profile of yolk showed that the inclusion of 4% CSO or 10% CSC in the layer diet reduced monounsaturated fatty acid (MUFA) content in yolk lipids and significantly elevated (P<0.05) *n-3* PUFA level as compared to that of the control group fed 4% rapeseed oil (RO) (Table 7). The content of α-linolenic acid belonging to the *n-3* series (ALA C18:3) was noted to be significantly increased in yolk lipids of eggs from hens fed the diet containing CSO or CSC. A significant increase in the level of the long-chain fatty acids EPA (P<0.01) and DHA (P<0.05) was also observed in yolk lipids from hens fed with dietary CSO and CSC as compared to the control group (RO). Percentage contents of linoleic acid (LA C18:2) and

arachidonic acid (ARA C20:4) – both belonging to the *n-6* series – fluctuated around the same level in all groups. The *n-6*/*n-3* PUFA concentration ratio was significantly (P<0.01) reduced in yolk lipids in eggs from hens receiving experimental diet with CSO or CSC. The level of CLA significantly increased in yolk lipids from the hens of the CSO and CSC groups.

Table 7. Effect of dietary CSO and CSC on the fatty acid profile of egg lipids

Fatty acid (%)	Treatment Group			SEM	P-value
	RO	CSO	CSC		
C12:0	0.04	0.05	0.03	0.001	0.112
C14:0	0.48	0.52	0.48	0.053	0.278
C16:0	28.68	27.85	27.98	1.807	0.228
C16:1	3.37 AB	2.99 B	3.80 A	0.169	0.002
C18:0	6.76 B	7.24 A	7.22 A	0.048	<.0001
C18:1	43.09	42.22	42.21	0.840	0.079
C18:2 LA	11.64	11.91	11.69	0.259	0.485
γ-C18:3	0.11	0.12	0.12	0.011	0.718
C20:0	0.04 B	0.06 A	0.06 A	0.008	0.003
C18:3 ALA	2.11 C	2.86 A	2.65 B	0.130	0.0006
C20:4 ARA	1.57	1.58	1.55	0.013	0.906
C22:1	0.04	0.05	0.05	0.016	0.654
C20:5 EPA	0.03 B	0.05 A	0.05 A	0.005	0.0003
C22:6 DHA	1.44 b	1.75 a	1.63 a	0.027	0.002
SFA	36.18	35.70	35.77	1.750	0.697
UFA	63.82	64.30	64.23	1.326	0.697
MUFA	46.49 Aa	45.05 Bb	45.26 Bb	0.632	0.009
PUFA	17.33 B	19.04 A	18.87 A	1.080	0.006
PUFA-*6*	13.31	13.60	13.36	0.322	0.523
PUFA-*3*	2.58 c	4.65 a	4.14 b	0.229	0.0003
MUFA/SFA	1.29	1.27	1.29	0.004	0.783
PUFA/SFA	0.48 b	0.53 a	0.51 ab	0.002	0.048
PUFA *6/3*	5.26 A	2.93 B	3.17 B	0.110	<.0001
CLA	0.43 B	0.79 A	0.68 A	0.029	0.0004

A, B, C – mean values with different letters indicate statistically significantly difference at P≤0.01.
a, b, c – mean values with different letters indicate statistically significantly difference at P≤0.05.

Discussion

Studies conducted to date on the effect of camelina oil and cake on the quality and composition of eggs indicate that yolk composition can be positively modified

by including camelina oil in the diet of laying hens (Rokka et al., 2002; Aziza et al., 2013; Cherian and Quezada, 2016). The results of the present study also showed that *C. sativa* oil and camelina cake obtained after extraction of cold pressed oil modify the fatty acid composition of yolk into the desired direction from the point of view of human diet, and neither produces a detrimental effect on the production performance of laying hen eggs nor do they worsen the morphological and sensory qualities of the eggs. Cherian et al. (2009) also observed that the inclusion of *C. sativa* meal in the layer diet at the level not higher than 10% elevated the *n-3* PUFA content of yolk lipids and did not affect the production parameters or quality of eggs. Correspondingly, Kakani et al. (2012) did not observe a negative effect of the inclusion of 10% camelina meal in the diet of laying hens; however, it should be mentioned that these authors used extruded *C. sativa* meal. Aziza et al. (2013) confirmed a beneficial effect of 10% camelina meal on production performance and increase in the *n-3* PUFA content of egg yolk. These authors observed a significant effect of *C. sativa* meal on laying rate and egg weight. In addition, Cherian et al. (2009) showed a beneficial effect of camelina meal on the enhancement of the laying rate, but they did not observe increased egg weight. In contrast, Kakani et al. (2012) noted that 10% extruded camelina meal did not influence the laying rate and egg weight. The results of the present study did not confirm that the incorporation of 10% camelina cake in the laying hen diet improved the laying rate. Furthermore, no effect was observed on egg weight which was comparable in all the treatment groups; this finding is in line with the data reported by Cherian et al. (2009) and Kakani et al. (2012). Pietras et al. (2012) indicated that inclusion of 1.5% or 3% camelina oil in the diet did not affect the production parameters of hens or egg weight. These data agree with the results of the present study, which indicated that hen diet enrichment with 4% CSO and 10% CSC did not significantly affect production performance or egg weight. CSO and CSC also did not lead to higher proportion of yolk in the eggs, and there was also no negative effect on the other parameters of egg quality; however, these results did not agree with the studies of Pietras et al. (2012), Aziza et al. (2013), and Cherian et al. (2009). Pietras et al. (2012) noted that camelina oil induced an increase in the proportion of yolk in the egg, while Cherian et al. (2009) and Aziza et al. (2013) demonstrated that eggs from hens fed 10% dietary camelina meal showed significantly reduced proportion of yolk. The authors have explained that the major lipoprotein of dry yolk mass is triacyloglycerol-rich very low-density lipoprotein whose secretion is dependent on the activity of stearoyl-coenzyme A desaturase and whose activity in turn is dependent on the levels of *n-3* fatty acids. Higher proportion of *n-3* fatty acids decreases the activity of stearoyl-coenzyme A desaturase, thus reducing the synthesis of very low-density proteins, which leads to a lower yolk mass and lipid content (Cherian et al., 2009). The difference in the results of the present study and the earlier studies may be due to different variety and the level of *n-3* PUFA in camelina meal, cake, or oil. Moreover, Cherian et al. (2009) also proved that camelina meal decreased the proportion of albumen in the egg, which was not observed in the present study. However, the present study showed the positive effect of the inclusion of camelina oil and camelina cake in hen diet on yolk color as compared to yolks from hens fed diet containing RO. The obtained results contradict

those of Cherian et al. (2009) and Aziza et al. (2013) who found that camelina meal as a diet ingredient for laying hens impaired yolk color of eggs. These differences in the conclusion regarding the effect on yolk color may be due to the fact that the tested feed ingredients contained varying level of carotenoids, which are absorbed by the hen's digestive system and deposited in the yolk, thus influencing the intensity of color. Cold pressed camelina oil contains a high level of carotenoids, especially β-carotene, lutein, and zeaxanthine (Kurasiak-Popowska et al., 2017). It is thought that camelina oil and camelina cake obtained after extraction of cold pressed oil have higher level of carotenoids than RO and camelina meal or oil obtained after oil extraction (Cherian et al., 2009). Yolk pigments are associated with antioxidant and visual health-promoting properties (Fiedor and Burda, 2014). The higher yolk color score obtained in eggs from hens fed on diet with camelina oil or camelina cake may be because these components are rich in fat-soluble pigments such as carotenoids.

Cherian et al. (2009) and Aziza et al. (2013) did not observe an effect of camelina meal on shell thickness, which agrees with the findings of the present study. However, according to Kakani et al. (2012), the inclusion of 10% extruded camelina meal in the hen diet significantly increased eggshell breaking strength as compared to the control group. There was, no detrimental effect of CSC or CSO on eggshell parameters. Likewise, Pietras et al. (2012) did not record any changes in eggshell parameters for eggs produced by layers fed 1.5% or 3.0% CSO-containing diets.

The present study revealed that dietary treatment of hens with camelina oil or camelina cake significantly increased the contents of PUFA of *n-3* series, especially α-linolenic acid (C18:3 ALA), EPA (C20:5), and DHA (C22:6) in yolk lipids. Pietras et al. (2012) also noted a significant elevation in the levels of the abovementioned fatty acids in yolk lipids from eggs produced by hens of experimental groups fed the diets containing 1.5% or 3% of *C. sativa* oil. Probably, the highly significant increase of DHA (C22:6) or EPA (C20:5) content in the CSO and CSC treatment groups was caused by desaturation and elongation process of ALA in the liver of laying hens (Cherian, 2015). These results were similar to those obtained by Cherian et al. (2009) in experiments on layers fed the diet containing 5%, 10%, and 15% camelina meal. They observed a significant increase in ALA and DHA in yolk lipids. On the other hand, Aziza et al. (2013) showed that camelina meal increased the percentage of ALA content but did not elevate EPA and DHA content (%). Moreover, a highly significant increase in the *n-3* PUFA content was noted in yolk lipids in the CSO and CSC treatment groups as compared to that in the control group. The obtained results were consistent with the findings of Rokka et al. (2002).

The *n-6*/*n-3* PUFA ratio was lower in yolk lipids of eggs laid by hens of the CSO and CSC groups, which is beneficial from the viewpoint of human dietetic requirements. The inclusion of *C. sativa* oil in the feed at the level of 5% (Rokka et al., 2002) or 3% (Pietras et al., 2012) or 10% camelina cake (Cherian et al., 2009; Kakani et al., 2012; Aziza et al., 2013) as a source of PUFAs also increased *n-3* PUFA content and favorably reduced the *n-6*/*n-3* PUFA ratio in egg yolk lipids. Rokka et al. (2002), Pietras et al. (2012), Cherian et al. (2009), and Aziza et al. (2013) observed reduced arachidonic acid (AA) levels in the yolk lipids, which was not observed in

the present study. The AA content in yolk lipids in the CSO and CSC groups was comparable, which agrees with the result of Kakani et al. (2012) who also did not find significant changes in the level of this acid in yolk lipids in eggs from hens fed 10% camelina meal. Some authors presumed that the reduction of *n-6* fatty acid AA level results from the higher content of *n-3* PUFA, in particular ALA that inhibits AA synthesis from linoleic acid (LA C18:2) of *n-6* series (Souza et al., 2008; Cherian, 2015). However, according to Milinsk et al. (2003), the AA content in egg yolk did not depend on the PUFA level in the laying hen diet. Similarly, Cobos et al. (1995) did not observe an increase in AA content in yolk lipids from eggs produced by hens fed soybean, flax, or sunflower oil in the diet. Yolks of eggs from hens of the CSO and CSC groups were characterized by a significantly lower content of MUFA than those from the control group (RO). However, no significant influence of CSO and CSC treatment was observed on the level of saturated fatty acids (SFA). Pietras et al. (2012) revealed that 3% inclusion level of camelina oil in the layer diet reduced MUFA and increased SFA level. On the other hand, according to Cherian et al. (2009) and Aziza et al. (2013), 10% camelina meal as a dietary ingredient lowered both MUFA and SFA contents in egg yolk lipids. Aziza et al. (2013) showed that 10% camelina meal did not affect MUFA and SFA levels, which may suggest that the efficiency of camelina meal depends on fatty acid profile and chemical composition. The discrepancy between the results of our studies and those of the abovementioned authors is probably due to the use of different *C. sativa* varieties cultivated in different climatic conditions. Waraich et al. (2013) confirmed that the contents of fatty acids, vitamins, and glucosinolates in grains substantially depend on camelina variety, climate, and fertilization. In addition, according to Cherian and Sim (1991), PUFAs are distinguished by a higher efficacy in reducing MUFA content than SFA content in egg yolk because they inhibit Δ-9 reductase, which is an essential enzyme for MUFA formation (Souza et al., 2008), thereby reducing their content in yolk lipids.

Yolks of eggs from the CSO and CSC groups were also found to contain higher amounts of CLA dienes, which show beneficial effect on human health. Discussion on CLA increase in egg yolks from CSO- or CSC-fed hens is hindered by the lack of data on the effect of the tested fatty acid ingredients on CLA level. It is thought that the elevated CLA level in yolks of the CSO and CSC experimental treatment groups resulted from increased CLA level in the diets.

It is worth noting that the beneficial changes caused by camelina oil or cake in the fatty acid profile of egg yolk, as observed in the present study, did not worsen the sensory quality of the eggs.

On the basis of the obtained results, it can be concluded that the inclusion of *C. sativa* seed oil or cake in the layer hen diet may be an efficient approach to modify the fatty acid profile of egg yolk lipids while maintaining the sensory quality of eggs, particularly the yolk color, in order to meet consumer preference for a distinct color intensity of the egg yolk and to comply with sensory traits, especially a pleasant flavor together with good palatability. The addition of camelina cake did not exert any detrimental effects on feed intake, hen body weight, and egg production; thus, it can be an effective strategy to reduce the cost of feed mixtures and to increase *n-3* PUFA content in egg yolk lipids.

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