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Effect of dehulled lupin seed meal in feed mixture on muscle fat quality of Cherry Valley ducks

Eva Straková[1], Lucie Všetičková[2], Pavel Suchý, Martin Kutlvašr*

[1]*Department of Animal Husbandry, Animal Nutrition and Biochemistry, Faculty of Veterinary Hygiene and Ecology, University of Veterinary Sciences Brno, Brno, Czech Republic*
[2]*Department of Zoology, Fisheries, Hydrobiology and Apiculture, Faculty of AgriSciences, Mendel university in Brno, Brno, Czech Republic*

**Corresponding author: strakovae@vfu.cz*

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Abstract: The experiment was done on 180 (2 × 90) Cherry Valley ducks that were fattened until 42 days of age with parity of females and males in the group. The aim of the study was to examine the effect of substituting dehulled lupin seed meal, Zulika variety, for soybean meal and its impact on the fatty acid content of breast and thigh muscle fat. Feeding lupin diets resulted in a significant ($P \leq 0.05$) increase in monounsaturated fatty acids (MUFA) in Cherry Valley ducks, as well as significant ($P \leq 0.05$) increase in polyunsaturated fatty acids n-3 (PUFA n-3) in breast and thigh muscle fat. There was no effect of the tested diets on PUFA n-6 content in muscle fat. The results confirm that lupin meal in the diet enhances the dietary value of Cherry Valley duck muscle due to the higher proportion of unsaturated fatty acids, with respect to the use of duck meat for human consumption.

Keywords: fattening; fatty acids; *Lupinus albus*; poultry

By growing the white lupin (*Lupinus albus*) in the European conditions it is possible to strengthen the self-sufficiency in protein sources and minimise the amount of imported soy products for the production of feed mixtures. On the other hand, we can use lupin products as a source of high-quality oil in animal nutrition. Lupin oil has an optimal composition and ratio of PUFA n-3 and PUFA n-6 polyunsaturated fatty acids, when their variability and profile were investigated by Rybinski et al. (2018). Also, Zapletal et al. (2015) confirmed that lupin seed oil is an important source of polyunsaturated fatty acids. From a nutritional point of view, the seeds of cultivated species of the genus *Lupinus* can be evaluated as a protein raw material usable in diets and feed mixtures intended for the nutrition of practically all livestock species and categories. For these reasons, the field area for the production of this crop is expanding in Europe.

Currently, much attention is paid to the production of not only safe but also functional and healthful foods (Carmona et al. 2019; Nowak et al. 2019). As reported by Strakova et al. (2023), animal nutrition for human sustenance is currently directed towards maintaining the good health of animals, while taking advantage of their high production capacity. This is determined mainly by genetic potential and nutrition, leading to the production

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of nutritionally high-value and safe raw materials and food of animal origin. Tyl et al. (2025) studied the effects of two protein levels on the performance of chicken males with different growth intensities, where genetic selection programs produce chicken genotypes with different growth intensities, which might have variable requirements for dietary protein. Zapletal et al. (2024) expected that by providing high-quality feed components and essential nutrients in poultry feed mixtures, poultry production will be crucial for improving the nutrition of the human population in countries around the world. Hajji et al. (2025) note that in products of animal origin produced for human consumption, nutritional characteristics, especially the fatty acid profile, are increasingly receiving attention because the quality of meat depends on the genotype and nutrition of the animals. The nutritional value of lupin seeds can be increased by dehulling, when, depending on the variety, a 20–30% increase in crude protein can be achieved (Strakova et al. 2006). From this perspective the dietary use of lupin meal in fattening poultry categories can enhance white lupin production. Improvement of the nutritional value of lupin seeds by dehulling was confirmed by Rubio et al. (2003). Precise breeding work has resulted in white lupin varieties that can safely be used in the feed and food industry due to their almost zero content of undesirable antinutritional substances, mainly from the group of quinolizidine alkaloids. From a dietary point of view, lupin products have the advantage of being free of antinutritional substances such as trypsin inhibitors and saponins. According to Sujak et al. (2006), cultivated lupin varieties, compared to e.g. peas or soybeans, generally contain less antinutritional substances. Suchy et al. (2010) studied the dietary effect of replacing soybean meal with white lupin seed meal on the performance parameters and carcass value of broiler chickens and ducks. The results of the study showed that the complete replacement of soybean meal with white lupin seed meal of the Amiga variety did not worsen the growth performance or carcass composition of fattened ducks during fattening up to 42 days of age.

The effect of genotype on the quality of muscle fat in ducks was investigated by Chartrin et al. (2006) as well as Zhang et al. (2022); they both found out the effect of different breeds on the fatty acid composition of meat and the expression of genes related to lipid metabolism in duck muscle. Witak (2008) and Qiao et al. (2017) investigated carcass composition and muscle quality including fatty acid content in ducks depending on age. The results of the study by Strakova et al. (2021) showed that replacing soy protein with white lupin protein did not negatively affect the health status of laying hens, where the observed molar concentration of inorganic elements in blood plasma of the groups fed lupin meal did not differ from the molar concentration of the control group. Only calcium values were slightly lower in the blood plasma. A statistically significant reduction of cholesterol and triacylglycerides in the blood plasma of laying hens was considered as a positive result. Timova et al. (2020) confirmed that feeding lupin also reduced cholesterol levels in egg yolk.

Therefore, the aim of the study was to verify the possibility of using dehulled lupin seed meal in optimised complete diets (50% and 100% replacement of soybean meal) and to assess the effect of these diets on selected yield parameters and the quality of muscle fat in ducks.

MATERIAL AND METHODS

The experiment with 180 (2 × 90) Cherry Valley broiler ducks was conducted in the accredited barn of the University of Veterinary Sciences Brno, Czech Republic. For the experiment, dehulled white lupin seeds, Zulika variety, were used. The Zulika variety was selected as the most promising variety of white lupin suitable nutritionally and for possible cultivation in the soil and climatic conditions of Central Europe. The seed of white lupine was industrially (mechanically) „dehulled" on the principle of grinding off. The supplier of fattening ducks was PERENA, s r.o. (Chlumec nad Cidlinou, Czech Republic), which supplies the English breeding material Cherry Valley. The Cherry Valley ducks were fattened up to 42 days of age on deep litter (wood shavings) according to the technological instructions for fattening Cherry Valley ducks in a temperature regime of 31–21 °C.

Experimental ducks were divided into three groups of 60 ducks (2 × 30), with 30 males (2 × 15) and 30 females (2 × 15) in each group with two replicates. The control group of ducks (C) was fed a complete feed mixture based on soybean meal. In the experimental group with 50% replacement (E_{50}) and 100% replacement (E_{100}), soybean meal was replaced by lupin meal based on dehulled lupin seeds ($VKCH_{Start}$,

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$VKCH_1$, $VKCH_2$, $VKCH_3$). Nutrient and energy balanced and optimised complete feed mixtures for duck fattening were industrially produced as commercial feed mixtures including additives by ZZN Pelhřimov a.s., Czech Republic. Commercially produced complete feed mixtures and drinking water were given to broiler ducks *ad libitum* throughout the fattening period via tube feeders and drinkers. Commercially produced feed mixtures were given to the broiler ducks in a crushed form ($VKCH_{Start}$) and then in a granular form ($VKCH_1$, $VKCH_2$, $VKCH_3$). For the preparation of complete feed mixtures, the following feed components were used: soybean meal ($VKCH_{Start}$ C = 38.0 kg/q, E_{50} = 25.3 kg/q, E_{100} = 0 kg/q; $VKCH_1$ C = 32.0 kg/q, E_{50} = 16.0 kg/q, E_{100} = 0 kg/q; $VKCH_2$ C = 21.4 kg/q, E_{50} = 8.6 kg/q, E_{100} = 0 kg/q; $VKCH_3$ C = 6.1 kg/q, E_{50} = 2.5 kg/q, E_{100} = 0 kg/q), lupin meal, maize, wheat, rapeseed meal, partially dehulled sunflower meal, soybean oil and feed additives based on synthetic amino acids, vitamins and minerals. The studied groups received complete feed mixtures according to the following schedule: day 1–10 of fattening ($VKCH_{Start}$), day 11–20 of fattening ($VKCH_1$), day 21–35 of fattening ($VKCH_2$) and day 36–42 of fattening ($VKCH_3$).

Nutritional composition of white lupin and complete feed mixtures

For exact comparison, the nutritional parameters of each feed mixture were expressed in g per 1 kg of dry matter. Dry matter was determined by drying the sample at 105 °C and weighing under prescribed conditions. Feed mixtures were analysed in accordance with the analytical procedures of the Central Institute for Supervising and Testing in Agriculture, Czech Republic.

Performance indicators and selected breast and thigh muscle indicators

Fattening finished on 42^{nd} day of age of the ducks (according to current farming practice). Ducks were slaughtered and breast and thigh muscles were collected from 10 males and 10 females per group for further analysis. Total muscle fat was determined by direct ether extraction according to Soxhlet. Extraction of fat from meat for FA determination was performed by hexane-isopropanol extraction (Hara and Radin 1978). Fatty acids (g/100 g of fat) were determined by gas chromatography using a GC 2010 Gas Chromatograph Shimadzu instrument (Shimadzu Company, Japan) with an automated injection system, flame ionisation detector. In the SFA group, the analysis was focused on FAs: caprylic (C8:0), capric (C10:0), lauric (C12:0), tridecanoic (C13:0), myristic (C14:0), palmitic (C16:0), heptadecanoic (C17:0), stearic (C18:0), arachidic (C20:0), tricosanoic (C23:0) and lignoceric (C24:0). In the MUFA group, the analysis was focused on FAs: myristoleic (C14:1), *cis*-10-pentadecanoic (C15:1), palmitoleic (C16:1), *cis*-10-heptadecanoic (C17:1), oleic/elaidic (C18:1n9t + C18:1n9c), *cis*-11-eicosenoic (C20:1n9), erucic (C22:1n9) and nervonic (C24:1n9). In the n-6 group of PUFAs, the analysis was focused on FAs: linoleic/linoleic (C18:2n6c 1C18:2n6t), γ-linolenic (C18:3n6), *cis*-11,14-eicosadiene (C20:2n6), *cis*-8,11,14-eicosatriene (C20:3n6), arachidonic (C20:4n6), *cis*-13,16-docosadiene (C22:2n6) and docosatetraenoic (C22:4n6). In the n-3 group of PUFAs, the analysis was focused on FAs: α-linolenic (C18:3n3), *cis*-11,14,17-eicosatrienoic (C20:3n3), *cis*-5,8,11,14,17-eicosapentaenoic (C20:5n3), *cis*-4,7,10,13,16,19-docosahexaenoic (C22:6n3) and docosapentaenoic (C22:5n3).

Welfare statement

When calculating the number of individuals per unit area, the standard of 15, 10 and 5 individuals/1 m^2 area was respected. The experiment was carried out in an accredited stable of the University of Veterinary Sciences Brno in accordance with current legislative rules and approved by the Ethics Committee of the Central Commission for Animal Welfare at the Ministry of Agriculture of the Czech Republic.

Statistical methods

The obtained results were processed by statistical methods, using the Unistat v5.6 program for Excel (Unistat Ltd., UK). Evaluation of mean values and their differences was performed by multiple comparisons using Tukey's HSD test at a significance level of $P \leq 0.05$. Each indicator is characterised by the value of mean (x) ± standard deviation (SD).

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RESULTS

Effect of machine dehulling on the essential nutrient content of white lupin

For the purpose of the experiment, the seeds of white lupin, Zulika variety, were dehulled by a dehulling machine on the principle of grinding off. Dehulling decreased crude fibre content and increased crude protein and crude fat contents and the content of the studied fatty acids (∑ SFA, ∑ MUFA, ∑ PUFA n-6 and ∑ PUFA n-3) (Table 1).

Changes in the nutrient composition of feed mixtures after replacing soybean meal with dehulled lupin seed meal

In feed mixtures, the increase in crude fat (Table 2) can be attributed mainly to the use of lupin meal (E_{50}, E_{100}), except for $VKCH_{Start}$ (E_{50}). The crude fat content in the experimental feed mixtures (E_{50}, E_{100}) increased with the proportion of lupin. Conversely, a decrease in crude protein content was observed for the feed mixtures (E_{50}, E_{100}), except for the mixtures $VKCH_{Start}$ (E_{100}) and $VKCH_1$ (E_{50}). A decrease

Table 1. Nutrient content of white lupin seed, Zulika variety (before and after dehulling)

Parameter	Unit	Before dehulling	After dehulling	Difference
Crude protein	g/kg	387	445	–58.0
Crude fat	g/kg	92.7	103	–10.3
Crude fibre	g/kg	95.6	30.9	64.7
∑ SFA	g/100 g of fat	2.10	2.33	–0.23
∑ MUFA	g/100 g of fat	20.9	25.3	–4.40
∑ PUFA n-6	g/100 g of fat	11.6	13.5	–1.90
∑ PUFA n-3	g/100 g of fat	9.30	9.86	–0.56

Table 2. Content of selected nutrients in feed mixtures for Cherry Valley ducks

Parameter	Unit	$VKCH_{Start}$			$VKCH_1$		
		C	E_{50}	E_{100}	C	E_{50}	E_{100}
Crude protein	g/kg	250	243	274	221	224	215
Crude fat	g/kg	40.2	37.3	67.3	37.5	45.7	53.5
Crude fibre	g/kg	26.3	24.5	17.4	27.2	27.0	22.7
ME	MJ/kg	12.9	12.9	13.8	12.9	12.9	13.2
∑ SFA	g/100 g of fat	5.12	5.05	6.77	7.16	7.90	6.70
∑ MUFA	g/100 g of fat	6.32	8.17	24.6	7.67	13.2	15.7
∑ PUFA n-6	g/100 g of fat	16.1	13.5	15.3	8.79	9.84	9.20
∑ PUFA n-3	g/100 g of fat	1.73	1.73	3.48	0.76	1.63	2.27

Parameter	Unit	$VKCH_2$			$VKCH_3$		
		C	E_{50}	E_{100}	C	E_{50}	E_{100}
Crude protein	g/kg	191	181	187	179	164	174
Crude fat	g/kg	35.1	42.1	51.1	38.3	45.4	51.2
Crude fibre	g/kg	27.1	25.1	27.3	32.8	27.9	28.6
ME	MJ/kg	12.7	13.0	13.1	12.8	13.0	13.0
∑ SFA	g/100 g of fat	6.94	5.57	5.64	6.62	8.00	8.91
∑ MUFA	g/100 g of fat	7.13	10.5	14.3	6.95	13.0	17.0
∑ PUFA n-6	g/100 g of fat	8.84	8.44	7.92	8.53	8.93	9.61
∑ PUFA n-3	g/100 g of fat	0.79	1.20	1.96	0.90	1.62	2.07

Diets: $VKCH_{Start}$ day 1–10 of fattening; $VKCH_1$ day 11–20 of fattening; $VKCH_2$ day 21–35 of fattening; $VKCH_3$ day 36–42 of fattening

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal; ME = metabolisable energy

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in crude fibre content was also observed for the E_{50} and E_{100} experimental groups compared to the control (C). No significant differences in ∑ SFA content were observed between control (C) and experimental (E_{50}, E_{100}) diets. The highest content in the SFA group was observed for C16:0 in the control (C) and experimental (E_{50}, E_{100}) diets ($VKCH_{Start}$ 3.74, 3.82, 4.89 g/100 g of fat; $VKCH_1$ 4.84, 5.28, 4.57 g/100 g of fat; $VKCH_2$ 4.75, 3.93, 3.91 g/100 g of fat; $VKCH_3$ 4.60, 5.42, 6.03 g/100 g of fat). For ∑ MUFA, the results confirm the effect of lupin meal in the diet (copying the volume of lupin meal content in the diet) in both E_{50} and E_{100} groups. The total ∑ MUFA content in these diets increased, with C18:1n9 being the dominant MUFA in feed mixtures ($VKCH_{Start}$ 6.12, 7.72, 22.0 g/100 g of fat; $VKCH_1$ 7.07, 11.9, 14.1 g/100 g of fat; $VKCH_2$ 6.58, 9.45, 12.7 g/100 g of fat; $VKCH_3$ 6.37, 11.7, 15.2 g/100 g of fat).

For ∑ PUFA n-6, the obtained results cannot clearly confirm the effect of administered lupin meal in the experimental diets by the differences in PUFA n-6 content between the control (C) and experimental groups (E_{50}, E_{100}). The most abundant PUFA n-6 in all three diets was C18:2n6 ($VKCH_{Start}$: 15.8, 13.4, 15.1 g/100 g of fat; $VKCH_1$ 8.72, 9.72, 9.09 g/100 g of fat; $VKCH_2$ 8.76, 8.37, 7.54 g/100 g of fat; $VKCH_3$ 8.47, 8.82, 9.48 g/100 g of fat). The results for the ∑ PUFA n-3 group demonstrate that replacing soybean meal with lupin meal increased their content in the experimental diets. It can be assumed that the PUFA n-3 content of the experimental diets increased significantly along with the volume of lupin meal in the diet. The predominant PUFA n-3 in all feed mixtures (C, E_{50}, E_{100}) was C18:3n3 ($VKCH_{Start}$ 1.63, 1.54, 3.38 g/100 g of fat; $VKCH_1$ 0.71, 1.40, 1.78 g/100 g of fat; $VKCH_2$ 0.74, 1.16, 1.62 g/100 g of fat; $VKCH_3$ 0.81, 1.37, 1.75 g/100 g of fat).

Production parameters

The average live weight of Cherry Valley ducks (30 males + 30 females/group) on day 42 of fattening was 3.22 ± 0.29 kg (C), 3.40 ± 0.27 kg (E_{50}) and 3.48 ± 0.28 kg (E_{100}). There was a significant ($P \leq 0.05$) difference in the mean live weight between C and E_{50} and between C and E_{100}. During the fattening period, 4 ducks died in C group and one duck died both in E_{50} group and E_{100} group. The feed conversion ratio was 2.33 (C), 2.27 (E_{50}) and 2.71 (E_{100}) kg/kg.

Fat quality of breast and thigh muscles

The results of dry matter and fat content in the dry matter of breast and thigh muscles are shown in Table 3. The results indicate that in the experimental groups of ducks there were not any significant differences in dry matter and fat in the dry matter content of breast muscle compared to the control. In the thigh muscle, a significant difference ($P \leq 0.05$) in dry matter and fat was revealed between E_{50} and E_{100} groups.

Saturated fatty acids (SFA)

The results of the SFA content of the breast and thigh muscle fat are presented in Table 4. C14:0, C16:0 and C18:0 were present in the breast and thigh muscle fat. For the other SFAs, no values were detected or they were below the limit of detection of the analyser (the content was very low, i.e. not nutritionally significant). In duck breast fat, the mean values of SFAs (C16:0, C18:0) were higher in the experimental groups (E_{50}, E_{100}) compared to the control (C), except for C14:0, where the lowest value was found in E_{50}. For SFA, a statistical significance ($P \leq 0.05$) for C16:0 and C18:0 was observed between C and E_{100} group and also between E_{50} and E_{100} group; for C14:0 only between E_{50} and E_{100}. The results of SFA content in duck thigh muscle fat are presented in Table 4. For SFA C14:0 and C18:0, there was no significant relationship between the mean values of control and experimental group. Inconsistently, significant ($P \leq 0.05$) results were found for the fatty

Table 3. Mean values of dry matter and fat in the dry matter of breast and thigh muscles of ducks in g/kg (n = 20)

Parameter	Group	Breast muscle	Thigh muscle
Dry matter	C	234 ± 7.15	275^{c} ± 14.7
	E_{50}	236 ± 8.73	279^{a} ± 18.3
	E_{100}	236 ± 6.34	266^{b} ± 10.9
Fat	C	86.2 ± 19.8	245^{c} ± 38.2
	E_{50}	91.8 ± 24.2	264^{a} ± 41.4
	E_{100}	88.2 ± 13.3	226^{b} ± 37.6

[a–c]Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

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Table 4. Mean values of saturated fatty acids (SFAs) in breast and thigh fat of ducks (g/100 g of fat; n = 20)

Parameter	Group	Breast muscle	Thigh muscle
C14:0	C	$0.53^c \pm 0.13$	0.69 ± 0.11
	E_{50}	$0.48^b \pm 0.15$	0.69 ± 0.06
	E_{100}	$0.63^a \pm 0.13$	0.64 ± 0.07
C16:0	C	$19.8^b \pm 4.70$	$24.2^b \pm 2.20$
	E_{50}	$20.2^b \pm 5.58$	$27.2^a \pm 1.71$
	E_{100}	$24.9^a \pm 4.68$	$24.5^b \pm 1.83$
C18:0	C	$6.10^b \pm 1.42$	5.78 ± 0.80
	E_{50}	$6.21^b \pm 1.14$	6.09 ± 1.52
	E_{100}	$7.49^a \pm 1.39$	5.60 ± 0.52

$^{a-c}$Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

acid C16:0, although the mean values of this acid were higher in the experimental groups E_{50} and E_{100} compared to C group. This fatty acid was a dominant SFA in the thigh fat of fattened ducks.

Monounsaturated fatty acids (MUFA)

The results of the MUFA content in duck breast and thigh muscle fat are presented in Table 5. The MUFAs C16:1 and C18:1n9 were found in the breast muscle fat. For the other MUFAs, no values were detected or they were below the detection limit of the analyser (the content was very low, i.e. nutritionally insignificant). For MUFA C16:1, a statistical significance ($P \leq 0.05$) was revealed between experimental groups E_{50} and E_{100}. C18:1n9 was the most abundant MUFA in duck breast muscle fat. A statistically insignificant difference between control (C) and experimental group (E_{50}, E_{100}) was observed for C16:1 in duck thigh fat while C18:1n9 was the most abundant acid among MUFAs with a significant difference ($P \leq 0.05$) between C and E_{50} groups and between C and E_{100} groups.

Table 5. Mean values of monounsaturated fatty acid (MUFA) content in breast and thigh fat of ducks (g/100 g of fat; n = 20)

Parameter	Group	Breast muscle	Thigh muscle
C16:1	C	$2.72^c \pm 0.81$	4.41 ± 0.06
	E_{50}	$2.52^b \pm 0.99$	4.49 ± 0.48
	E_{100}	$3.23^a \pm 0.85$	4.20 ± 0.36
C18:1n9	C	23.1 ± 6.28	$27.1^b \pm 3.02$
	E_{50}	25.1 ± 5.65	$30.4^a \pm 2.04$
	E_{100}	25.4 ± 2.88	$30.8^a \pm 1.72$

$^{a-c}$Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

Polyunsaturated fatty acids from the PUFA n-6 group

The average values of the individual PUFA n-6 fatty acids detected in the muscle fat of fattened ducks are presented in Table 6. The results show that the lupin diets fed to the experimental groups of ducks (E_{50}, E_{100}) had no significant effect on the PUFA n-6 content of the duck breast muscle fat. A lower mean value in the E_{50} group, compared to the control, was found for C18:2n6, C20:4n6 and C22:4n6. Significant differences ($P \leq 0.05$) in C20:4n6 were demonstrated between groups. Significantly higher ($P \leq 0.05$) mean values in duck thigh muscle were confirmed for C18:2n6 in E_{100} group. An insignificant difference in the mean values was observed for C22:4n6 comparing experimental groups with the control. Ambiguous differences between

Table 6. Mean values of polyunsaturated fatty acids (PUFAs n-6) in duck muscle fat (g/100 g of fat; n = 20)

Parameter	Group	Breast muscle	Thigh muscle
C18:2n6	C	$9.82^c \pm 2.25$	$11.9^b \pm 1.33$
	E_{50}	$9.21^b \pm 2.48$	$12.1^c \pm 1.08$
	E_{100}	$11.4^a \pm 1.99$	$12.9^a \pm 0.93$
C20:4n6	C	$2.34^a \pm 0.68$	$0.82^a \pm 0.18$
	E_{50}	$1.88^b \pm 0.33$	$0.90^a \pm 0.21$
	E_{100}	$2.28^a \pm 0.43$	$0.44^b \pm 0.43$
C22:4n6	C	1.21 ± 0.48	12.1 ± 1.08
	E_{50}	1.00 ± 0.16	12.9 ± 0.93
	E_{100}	1.07 ± 0.30	10.1 ± 0.01

$^{a-c}$Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

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groups were observed for C20:4n6. The fatty acid C18:2n6 showed the highest content in thigh muscle fat, regardless of the group and duck sex.

Polyunsaturated fatty acids from the PUFA n-3 group

The positive effect of the lupin diets on the increase of PUFA n-3 in muscle fat is indicated by their higher values in the E_{50} and E_{100} experimental groups (Table 7). In the muscle fat of ducks, C18:3n3 was the most abundant acid regardless of the group. The results presented in Table 7 clearly show that the average content of each acid increased in both breast and thigh muscle fat of the experimental groups in relation to the diets containing lupin meal. For most of the PUFAs n-3 this increase was tested as significant ($P \leq 0.05$) compared to the control.

Content of individual FA groups in duck muscle fat

Table 8 shows the average contents of the individual FA groups in the muscle fat of fattened ducks. The results show that in the experimental groups the sum of Σ SFA increased significantly ($P \leq 0.05$) in breast muscle between C and E_{100} groups and between E_{50} and E_{100}. For thigh muscle, results were inconsistent, although significance ($P \leq 0.05$) was noted between E_{50} and E_{100} groups. For the total Σ MUFA content, a certain tendency of increasing trend could be observed in both breast and thigh muscle of ducks in the experimental groups. Differences between fatty acid groups in breast muscle were not significant, while in thigh muscle, significance ($P \leq 0.05$) was shown between C and E_{50} groups and between C and E_{100} groups. For the total Σ PUFA n-6 content, inconsistent results were observed in breast muscle fat with a significant difference ($P \leq 0.05$) between E_{50} and E_{100} groups. In thigh muscle fat, an increasing trend of Σ PUFA n-6 was apparent with increasing addition of lupin meal to duck diets, but the differences were not significant. The greatest effect of diets containing lupin meal could be observed for the total Σ PUFA n-3 content. The total Σ PUFA n-3 content of muscle fat increased with the lupin content of the diet in experimental groups. The results show that the experimental ducks had significantly higher ($P \leq 0.05$) Σ PUFA n-3 content in both breast and thigh fat which significantly increased with the dietary content of lupin meal.

Table 7. Mean values of polyunsaturated fatty acids (PUFAs n-3) in duck muscle fat (g/100 g of fat; n = 20)

Parameter	Group	Breast muscle	Thigh muscle
	C	$0.70^{b} \pm 0.15$	$0.95^{bd} \pm 0.11$
C18:3n3	E_{50}	$0.93^{b} \pm 0.33$	$1.38^{bc} \pm 0.13$
	E_{100}	$1.76^{a} \pm 0.51$	$2.21^{a} \pm 0.20$
	C	$0.03^{b} \pm 0.01$	0.02 ± 0.01
C20:3n3	E_{50}	$0.03^{b} \pm 0.01$	0.03 ± 0.01
	E_{100}	$0.05^{a} \pm 0.02$	0.02 ± 0.02
	C	$0.11^{b} \pm 0.03$	$0.04^{d} \pm 0.01$
C20:5n3	E_{50}	$0.12^{b} \pm 0.02$	$0.06^{bc} \pm 0.01$
	E_{100}	$0.22^{a} \pm 0.05$	$0.11^{a} \pm 0.01$
	C	$0.68^{b} \pm 0.20$	$0.41^{bd} \pm 0.10$
C22:5n3	E_{50}	$0.75^{b} \pm 0.09$	$0.57^{c} \pm 0.12$
	E_{100}	$1.41^{a} \pm 1.28$	$0.71^{a} \pm 0.13$

[a–d]Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

Table 8. Mean values of groups of fatty acids (Σ SFA, Σ MUFA, Σ PUFA n-6 and Σ PUFA n-3) in duck muscle fat (g/100 g of fat; n = 20)

Parameter	Group	Breast muscle	Thigh muscle
	C	$27.2^{b} \pm 6.25$	$31.2^{c} \pm 2.98$
Σ SFA	E_{50}	$27.4^{b} \pm 7.29$	$34.5^{a} \pm 2.80$
	E_{100}	$33.9^{a} \pm 6.11$	$31.3^{b} \pm 2.28$
	C	26.6 ± 6.80	$32.3^{b} \pm 3.68$
Σ MUFA	E_{50}	28.5 ± 6.60	$36.2^{a} \pm 2.38$
	E_{100}	30.2 ± 3.86	$36.8^{a} \pm 1.83$
	C	$13.9^{c} \pm 3.17$	13.9 ± 1.68
Σ PUFA n-6	E_{50}	$12.7^{b} \pm 2.55$	14.2 ± 1.42
	E_{100}	$15.6^{a} \pm 2.53$	14.5 ± 0.89
	C	$1.52^{b} \pm 0.34$	$1.41^{bd} \pm 0.21$
Σ PUFA n-3	E_{50}	$1.93^{b} \pm 0.38$	$2.10^{bc} \pm 0.24$
	E_{100}	$3.65^{a} \pm 1.13$	$3.14^{a} \pm 0.30$

[a–d]Different superscripts denote statistically significant differences ($P < 0.05$)

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

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Table 9. Ratio of PUFA n-3 to PUFA n-6 fatty acids in breast and thigh muscle of Cherry Valley ducks

Ratio of FA	Breast muscle			Thigh muscle		
	C	E_{50}	E_{100}	C	E_{50}	E_{100}
PUFA n-6	13.9	12.7	15.6	13.9	14.2	14.5
PUFA n-3	1.52	1.93	3.65	1.41	2.10	3.14
n-3 : n-6	1 : 9.14	1 : 6.58	1 : 4.27	1 : 9.86	1 : 6.76	1 : 4.62

C = control; E_{50} = 50% replacement of soybean meal with dehulled white lupin meal; E_{100} = 100% replacement of soybean meal with dehulled white lupin meal

Ratio of PUFA n-3 to PUFA n-6

As shown in Table 9, the experimental diets (E_{50}, E_{100}) significantly affected the ratio of PUFA n-3 to PUFA n-6. The amount of substitution of dehulled lupin seed meal for soybean meal resulted in a narrowing of the PUFA n-3/PUFA n-6 ratio in both breast and thigh muscle fat of Cherry Valley ducks, which can be considered beneficial to the breast and thigh muscle quality in dietary terms.

DISCUSSION

Jeroch et al. (2016), who investigated the increasing importance of lupin (*Lupinus* spp.) in poultry nutrition, reported that lupin has a positive effect on muscle composition and is suitable for poultry. Also, Rubio and Molina (2016), who studied legumes from an animal nutrition perspective, recommended partial, but also complete replacement of traditional protein sources with legumes, which include lupin. The aforementioned Jeroch et al. (2016) stated that the recommended lupin content in complete feed mixtures for poultry can be defined on the basis of alkaloid content, crude protein quality and energy value, taking into account the age of the poultry and the purpose of production (laying hens, breeding hens, broiler chickens, broiler ducks). Recommended limits should take into account variations in the quality and content of antinutritional factors in order to minimise their adverse effects on growth performance and health status of poultry or egg quality. However, the use of lupin in poultry nutrition is determined also by its price, compared to soya meal and fat concentrates, as well as its availability on the market.

The authors Karel et al. (2016) considered that a major advantage of lupin meal, in contrast to soybean and soy products which contain a number of antinutritional substances, is that it does not require any heat treatment and can be fed in its natural state, which also represents certain energy and economic savings. In view of the above, in this study lupin was only dehulled, no further treatment was used and the results show that from the content of the individual fatty acid groups (Σ SFA, Σ MUFA, Σ PUFA n-6 and Σ PUFA n-3) it can be concluded that feeding diets with lupin meal had an effect on the content of the individual FA groups in duck muscle fat. This effect was significant ($P \leq 0.05$) for Σ SFA in the muscle fat of the experimental groups. For Σ MUFA, their content in the fat of the breast muscle increased in the experimental groups compared to the control, but the differences in the mean values were statistically insignificant. In the experimental groups (E_{50}, E_{100}), there was an increase in Σ PUFA n-3 in duck breast fat (1.93 g/100 g of fat and 3.65 g/100 g of fat, respectively) compared to the control (1.52 g/100 g of fat). The same result was obtained by Kutlvasr et al. (2022) for fattening broiler chickens. Based on their results, it can be stated that lupin meal had a nutritionally positive effect on the composition of breast muscle fat by increasing the MUFA and PUFA n-3 content in the breast fat of the chickens. A significant ($P \leq 0.05$) reduction (12.7 g/100 g of fat) was observed in Σ PUFA n-6 in the breast muscle fat of the experimental duck groups (E_{50}) compared to the experimental group E_{100} (15.6 g/100 g of fat). The differences between group C (13.9 g/100 g of fat) and the experimental groups were insignificant, suggesting that lupin meal in the experimental diets did not have a significant effect on the content of Σ PUFA n-6 in duck breast fat. From the summary results of the content of each fatty acid group (Σ SFA, Σ MUFA, Σ PUFA n-6 and Σ PUFA n-3) in duck thigh muscle fat, it can be concluded that the diets with lupin meal had an effect on the content of each fatty acid group in thigh muscle fat. This effect was manifested by an increase in Σ SFAs in the thigh muscle fat of the experimental E_{50} group of ducks (34.5 g/100 g

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of fat) compared to C group (31.2 g/100 g of fat), but also to E_{100} group (31.3 g/100 g of fat); a significant ($P \leq 0.05$) increase in ∑ MUFA in E_{50} and E_{100} groups (36.2 g/100 g of fat and 36.8 g/100 g of fat) compared to C group (32.3 g/100 g of fat) and a significant ($P \leq 0.05$) increase in ∑ PUFA n-3 (2.10 g/100 g of fat and 3.14 g/100 g of fat) compared to C group (1.41 g/100 g of fat) were also observed.

For ∑ PUFA n-6, there was no statistically significant difference in thigh muscle fat in the experimental groups of E_{50} and E_{100} ducks (14.2 g/100 g of fat and 14.5 g/100 g of fat, respectively) compared with C group (13.9 g/100 g of fat). Based on the obtained results, it can be stated that lupin meal had a nutritionally positive effect on the fat composition of the thigh muscle of ducks, due to the increased content of MUFA and especially PUFA n-3. Our results are in agreement with Chartrin et al. (2006), who reported an increased proportion of MUFA (mainly oleic acid) in duck muscle fat compared to PUFA and SFA. Woloszyn et al. (2006) compared the amino acids and fatty acids in the breast muscle of the original Pekin duck population and two breeding flocks of ducks at 7 weeks of age. In both studied duck flocks, there was a predominance of unsaturated fatty acids (UFA) in the muscle fat of the ducks. Our results demonstrate the predominance of MUFA in muscle fat of Cherry Valley ducks at 6 weeks of age. We consider as very important that the fed experimental diets caused positive changes in the muscle fat quality mainly related to the increase of MUFA and PUFA n-3 in muscle fat in the experimental groups (E_{50}, E_{100}). The significant increase of PUFA n-3 in muscle fat of ducks fed a diet based on dehulled lupin meal can be considered highly positive. The results showed that along with the increasing portion of lupin meal in the diet, the levels of PUFA n-3 also increased. However, the improvement of PUFA n-3 was declared by Swiatkiewicz et al. (2015), who added microalgae as one of the ingredients to broiler and layer diets, where microalgae are a rich source of long-chain n-3 fatty acids and their use as an additive resulted in a beneficial effect, i.e. higher levels of mainly eicosapentaenoic and docosahexaenoic acids. According to Witak (2008), with the increasing age of ducks, the better nutritional and processing value of duck muscle was observed with a higher proportion of unsaturated fatty acids and the author pointed out the more favourable PUFA n-6/n-3 ratio in duck breast muscle. Qiao et al. (2017) investigated the intramuscular fat composition and polyunsaturated fatty acid content in ducks; the authors concluded that polyunsaturated fatty acids were involved in the production of intense aroma and flavour in duck meat.

CONCLUSION

From the results, it can be concluded that in the feed mixtures for fattening Cherry Valley ducks, soybean meal can be replaced with dehulled lupin seed meal, both 50% and 100%. According to the results of this study 50% replacement is optimal, which in practice provides better optimisation of the feed mixture formulation due to the combination of two protein sources. The dehulling of lupin seeds can increase the quality of fat content (mainly unsaturated fatty acids). The replacement of soybean meal with dehulled lupin seed meal affected the nutrient composition of the feed mixture, which was reflected in increased fat content and increased content of polyunsaturated fatty acids (PUFA n-3). Diets containing lupin meal did not negatively affect duck performance. Contrarily, experimental diets improved breeding performance of the ducks, there was higher growth rate, lower mortality and minimal differences in feed conversion ratio. In general, it can be summarised that feeding diets based on lupin meal led to an increase of muscle fat content and changed the muscle fat quality, manifested by a significant increase in MUFA and especially PUFA n-3.

Conflict of interest

The authors declare no conflict of interest.

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