LINSEED CAKE IN RABBIT NUTRITION: EVALUATION OF ANIMAL WELFARE, LIVESTOCK PERFORMANCES AND MEAT QUALITY

Zuzana Formelová[1], Ľubica Chrastinová[1†], Mária Polačiková[1], Matúš Rajský[1], Mária Chrenková[1], Zuzana Mlyneková[1], Anna Kalafová[3], Ondřej Bučko[3], Stanislav Baxa[2], Ľubomír Ondruška[1], Rastislav Jurčík[1], Aneta Kišová[3], Francesco Vizzarri[1].

[1]*National Agricultural and Food Centre, Research Institute for Animal Production Nitra, Hlohovecká 2, 951 41 Lužianky, Slovak Republic; † ad memoriam*
[2]*National Agricultural and Food Centre, Food Research Institute Bratislava, Hlohovecká 2, 951 41 Lužianky, Slovak Republic*
[3]*Slovak University of Agriculture in Nitra, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovak Republic.*

Keywords: *rabbit, meat quality, functional product, flaxseed, feed additive.*

Abstract. *A total of 66 post-weaned rabbits (35th day of age meat line M91 a P91 hybrid) were randomly divided into 3 groups for a fattening experiment and kept in standard metal cages with two animals per cage. Rabbits were fed a commercial diet (control group, CG) or a diet supplemented with 5% of agricultural by-products linseed cake (EG1), or a diet supplemented with 10% linseed cake (EG2). The experiment lasted 42 days, until the animals attained the slaughtering weight ≈2.5 kg. Individual blood was sampled from a total of 30 rabbits, and five animals from each group were slaughtered at the end of the experiment, for the evaluation of animal welfare and meat quality. Feeding linseed cake substances to rabbits did not negatively influence zootechnical parameters, growth performance and slaughter traits; it had no negative effect on the rabbit's blood biochemical profile either. Experimental diets with 5% linseed cake improved feed conversion ratios, without significantly impacting the final weight of animals. The dietary supplementation positively influenced the meat fatty acids profile, in particular polyunsaturated fatty acids (linoleic acid and CLA), indicating enhanced nutritional quality of the meat as a functional food. Overall, the use of linseed cake, a sustainable agricultural by-product, is a promising dietary strategy to improve the nutritional value of rabbit meat and support efficient, welfare-conscious rabbit production.*

Introduction

Oilseeds and the residues of seed processing in the fat and oil industry have a high energy value and a high protein content, leading to different physiological effects and dietetic properties in relation to the types of compressed and extracted scraps. Two specific properties must be considered when feeding extracted linseed meal and cake, namely the laxative effect and the effect on fat consistency. For constipation in animals, the laxative effect of linseed cake or crushed steamed linseed can be successfully used (Abdel-Magid et al., 2009). Linseed meal does not soften animal fats. Considering the mentioned properties, extracted flax meal and cakes can be used in feed mixtures for all species and categories of animals. Linseed and linseed-derived products have been given to rabbits to enhance their fertility, prolificacy, survival and meat quality (Agradi et al., 2023). Recently, Savietto et al. (2025) have evaluated the nutritional composition of linseed-based ingredients in rabbit nutrition, concluding that novel ingredients may improve the feed quality of growing rabbits when included up to 10% in feed formula. Earlier research (Halle and Schöne, 2013; Abdel-Magid et al., 2009) reported an evaluation of nutritional aspects of linseed dry meal cake containing an average of 89.7% dry matter (DM) of the total, including crude proteins (32.2%), crude lipid (13.0%), crude ash (5.2%), neutral detergent fibre (19.4%), acid detergent fibre (13.0%), and lignin (5.0%). Linseed cake (*Linum usitatissimum*) contains a high proportion of polyunsaturated fatty acids (PUFA) and other bioactive components. One of the richest plant sources of omega-3 polyunsaturated fatty acids is linseed, containing 9% saturated fatty acids, 18% monounsaturated fatty acids and up to 73% of PUFA. Among the total amount of PUFA, 43–56% are alpha-linolenic acid (ALA) (Ribeiro et al., 2013). Linseed is a rich source of both soluble and insoluble fibre and has the highest content of plant lignans, which act as phytoestrogens and antioxidants, among plants used in human and animal nutrition (Patade et al., 2008). The fibre content of flaxseed is significantly influenced by the variety; the highest total fibre levels (60–70%) are found in Agriol, Astella, CDC Bethune, Libra, and Lola, whereas Agram, Flanders, and Raciol contain moderate amounts (50–60%), and Natural

Corresponding author: francesco.vizzarri@nppc.sk

has the lowest content (below 50%). Soluble fibre, primarily in the form of mucilage, is predominant, ranging from 40.5% in Natural to 63.0% in Lola, while insoluble fibre remains minimal, from 1.6% in Natural to 8.3% in Astella (Kučka, 2024). Linseed is a source of vitamins A, B, C, D, E and minerals, such as potassium, phosphorus, magnesium, calcium, sulphur, iron, zinc, and sodium.

Flaxseed continues to be the richest known dietary source of lignans, particularly secoisolariciresinol diglucoside (SDG). A comparative assessment of 40 flaxseed varieties revealed a significant variability in SDG content (Wu et al., 2023).

In literature, several studies (Abdel-Magid et al., 2009) reported that the dietary application of linseed meal in rabbit nutrition (replacing 50% of crude protein from soybean meal with linseed meal) serves as a good alternative source of protein, improving all digestion coefficients and nutritive values and, thus, resulting in increased total body weight gain and average daily gain of growing animals. Aggoor et al. (2007) recommended the dietary use of linseed meal up to 50% of soybean meal protein replacement in rabbit, without adverse effects on reproductive performance and biochemical constituting blood plasma, also underlining advantages in the nutritional and economical aspects. In similar research experience (Halle and Schöne, 2013) on poultry, the dietary inclusion up to 10% of linseed cake did not negatively influence the laying performance of hens, and it was able to enrich yolk fat with polyunsaturated fatty acids.

The aim of the study was to evaluate the effects of dietary use of linseed cake in growing rabbits on growth performance, animal welfare, and selected chemico-physical, nutritional and quality traits of meat.

Materials and methods

Experimental design

A total of 66 post-weaned rabbits (aged 35 days; meat line M91 a P91; both sexes) were randomly divided into 3 groups (22 animals in each group, divided in control CG, experimental group EG1, and experimental group EG2, respectively) kept in standard metal cages, two animals per cage. The rabbits were fed a commercial diet (KV; TEKRO Nitra, Ltd. Slovak Republic) pellet of 3.5 mm in diameter ad libitum. Water was also provided ad libitum using nipple drinkers. Experimental group EG1 was fed an enriched commercial diet with 5% of linseed cake, while experimental group EG2 was fed the same control diet with 10% of linseed cake. The diet formulation (complete granulated mixture) for all groups is presented in Table 1.

Experimental diets and animals

No anticoccidials, antibiotics or other medications were included in the diet. The feed additive was included in the mashed diets, and then the diets were pelleted. The chemical compositions of diets and feed additive were analysed in accordance with the methods of the Association of Analytical Chemists (AOAC, 2000), and data are reported in Table 2. A cycle of 16 hours of light and 8 hours of dark was used throughout the experiment. The temperature and humidity in the building were recorded continuously by a digital thermograph positioned at the same level as the cages. The heating and forced ventilation systems allowed the building air temperature to be maintained within 14 ± °C throughout the experiment. Relative humidity was about 60 ± 5%. The study was carried in the National Agricultural and Food Centre, Research Institute for Animal Production Nitra. The body weight of each experimental animal

Table 1. Ingredients of the control and experimental diets+

Feed ingredients in g/kg	Control group	EG1 (5% LC)	EG2 (10% LC)
Alfalfa meal	360	342	342
Sunflower meal	55	52	52
Rape-seed meal	55	52	52
Linseed cake	0	50	100
Wheat bran	90	85	81
Oats	130	124	117
Dry malting sprouts	150	143	134
Maize	50	47	43
Sodium chloride	3	3	3
Minerals and vitamins mixture*	17	17	15
Barley	80	75	52
Limestone	10	10	9

+ LC – linseed cake, experimental group EG1, experimental group EG2; *Provided per kg diet: Vit. A 6000 IU; Vit. D_3 1000 IU; Vit. E 50 mg; Vit. B_1 1.7 mg; Vit. B_2 8.0 mg; Vit. B_6 3.0 mg; Vit. B_{12} 0.01 mg; Vit. K_3 0.5 mg; biotin 0.2 mg; folic acid 0.5 mg; nicotic acid 45 mg; Se 0.2 mg; choline chloride 450 mg.

was recorded weekly during the whole study, and the data are reported in Table 3 with the following intervals: initial live weight (day 0), intermediate live weight (day 21), and final live weight (day 42). Feed intake was checked daily, and average daily weight gain and feed conversion ratios as well as mortality were calculated mathematically at the end of the experiment. For this study, institutional and national guidelines for the care and use of animals were followed and all experimental procedures involving animals were approved by the State Veterinary and Food Institute of Slovak Republic (Permission code: SK CH 17 021).

The experiment lasted for 42 days. Five animals from each group were slaughtered at the end of experiment day by cutting the jugular vein and the carotid artery after electroanaesthesia (90 V for 5 sec), according to guidelines established by the European Community (n. 86/609/EEC). Carcasses were prepared according to Blasco and Ouhayoun (1996).

Haemato-biochemical analysis

Individual blood was sampled from ten rabbits per each group on day 42 of experiment (n = 10 per group) from the marginal ear vein (*Vena auricularis*) into dry non-heparinized Eppendorf tubes for biochemical analyses. Blood serum was produced by centrifugation at 3000 × g for 10 min and stored frozen (at −18°C) in plastic vials until analysis. To test the biochemical parameters (total proteins (TP; g/L), albumins (g/L), urea (mmol/L), glucose (mmol/L), triglycerides (mmol/L), and total cholesterol (mmol/L)), commercial kit Dialab (Czech Republic) and an automated biochemical analyser ELLIPSE

Table 2. Chemical composition of experimental diets+ (expressed on DM) and of linseed cake

Chemical analysis* in g/kg	Control group	EG1 (5% LC)	EG2 (10% LC)	Linseed cake
Crude proteins	144.80	147.47	147.04	315.42
Crude fibre	138.45	135.97	129.36	118.35
Fat	22.30	37.46	39.54	225.29
Ash	93.48	73.72	74.36	53.56
Starch	204.57	189.22	183.11	nd
Organic matter	796.62	789.49	763.91	946.44
ADF	168.94	234.37	154.16	161.64
NDF	300.14	342.18	273.34	243.61
Calcium (Ca)	11.74	12.99	11.69	3.48
Phosphorus (P)	5.89	6.53	5.89	6.02
Magnesium (Mg)	3.34	2.84	2.93	4.44
Sodium (Na)	1.09	1.06	1.03	0.74
Potassium (K)	11.10	8.68	9.33	11.10
ME MJ.kg^{-1}	10.74	11.17	11.06	16.47

+ LC – linseed cake, experimental group EG1, experimental group EG2; *ADF – acid detergent fibre; NDF – neutral detergent fibre; ME – metabolizable energy; nd – not detected. Analyses were performed in triplicate.

Table 3. Effect of linseed cake on growing performance of rabbits+ (n = 22)

Parameter#	Control group	EG1 (5% LC)	EG2 (10% LC)	SEM	*P* value*
Initial live weight (0 d) g	1175	1178	1213	41.96	NS
Intermediate live weight (21 d) g	2040	2024	1976	14.80	NS
Final live weight (42 d) g	2654	2761	2751	26.27	NS
Feed Intake 0–42d (g/day)	153	149	150	2.96	NS
AFC 0–42 d (g/g)	4.35^{b}	3.95^{a}	4.37^{b}	0.06	*
Mortality (n)	2	1	0	-	NS
Daily weight gain, (g/d)	35.21	37.69	36.61	0.73	NS
Carcass yield at slaughter (%)	53.17	53.08	54.28	0.30	NS

+ LC – linseed cake, experimental group EG1, experimental group EG2; # AFC – average feed conversion ratio;
* Different letters in the same row mean statistical difference for $P < 0.05$, NS – not significant.

(AMS, Italy), based on turbidimetric clinical assay, were used according to the manufacturers' instructions and following the methods of serum parameter determination. The activities of blood gamma glutamyl transferase (GGT; U/L), aspartate aminotransferase (AST; μkat/L), and alanine aminotransferase (ALT; μkat/L) were determined by the colorimetric method (Spectrophotometer UV-2550 Shimadzu, Kyoto, Japan) using a commercial kit Randox RS 504 (Randox Laboratories Ltd. Crumlin, UK).

Meat chemical composition and nutritional traits

The samples from *musculus longissimus dorsi* (MLD; 30 g) were analysed for proximate composition, specifically, moisture, protein, intramuscular fat, amino acids and fatty acids using spectrometer Nicolet 6700; the data are expressed in g/100 g. The amino acid composition was analysed by ion-exchange chromatography on AAA (Ingos Prague, Czech Republic) after acid hydrolysis with 6M HCl, while methionine and cystine were determined after oxidation hydrolysis.

The samples of MLD were collected immediately after slaughter and stored at 5°C for 24 hours and then chemical-physical analyses were performed (AOAC, 2000). The samples of MLD were homogenised and analysed for individual nutrients. The pH at 24 hours postmortem was measured by a portable pH-meter (model OP-109, Radelkis) with a combined electrode penetrating 3 mm into the muscle. Colour measurements were taken on MLD surface of the carcass at 24 hours after slaughter and were expressed using the CIE L*a*b system (lightness-L*, 0: black and 100: white; redness and greenness-a*; yellowness and blueness-b*) using a Lab Miniscan (HunterLab, Reston, VA, USA).

The energy value was calculated according to the equation (Strmiska et al., 1988):

$$\text{Energy value (kJ/100 g)} = 16.75 \times \text{protein content} + 37.65 \text{ x fat content.}$$

The water holding capacity was determined by the compression method at constant pressure (Hašek and Palanská, 1976). The analysed samples (0.3 g in weight) were placed on filter papers (Schleicher and Schuell No. 2040B, Dassel, Germany) with tweezers previously weighed. Together with the papers, the samples were wedged between Plexiglass plates and then subjected to a pressure of 5 kg for 5 min. The results were calculated based on the difference in weight between the slips containing the aspirating spot and the pure filter paper.

Statistical analysis

The statistical analysis was performed using the SPSS statistical package (version 18.0, 2009, SPSS Inc., USA). Data on productive performance, slaughter parameters, meat chemical composition, meat values of pH and colour, and fatty acid profile of meat were processed with one-way analysis of variance (ANOVA), with the dietary treatment (CON, EG1, EG2) as the source of variation and with the post-hoc Tukey multiple comparison test. All measurements were made in duplicate and the results in tables are reported as means and pooled SEM. The experimental unit for the livestock performance was the cage, while for the blood parameter and meat quality traits, the experimental unit was the single animal. Mean values within the same row having different superscripts indicate significant difference for ($P \leqslant 0.05$).

Results and discussion

The experiment was performed at the National Agricultural and Food Centre (NPPC) – Research Institute for Animal Production Nitra. All animals were in good health throughout the trial.

The experimental diets, prepared with or without the linseed cake, were balanced for organic matter, mineral profile, and energy values. In similar previous experience, increasing flaxseed levels (2.5% to 10%) led to obtaining experimental rations balanced for crude protein and digestible energy (Omer et al., 2013).

Results regarding the growth parameters are shown in Table 3. During the fattening period, differences observed at the end of trial induced by the diet on final live weight and feed consumption were not significant. However, differences among treatments ($P < 0.05$) were detected in the average feed conversion ratio, where the lowest value was reported in the EG1 group and the highest in the EG2 group. The overall mortality at the end of the growing phase was 2 (CG) vs 1 rabbit (EG1) and was not related to the type of diet. The average daily weight gain was higher in the experimental groups compared with the control group (35.21 g CG vs 37.69 g EG1 vs 36.61 g EG2), but those differences did not reach the statistical significance. Contrary to our results, Rizwan Tariq et al. (2015) showed that enrichment with 7% flaxseed exerted a highly significant effect on weight gain of rabbits, when compared with the control group. The authors also reported the feed conversion ratio (FCR) of the low flaxseed dose (3.5%) as positively lower compared with the control group, increasing the performance of experimental rabbit's growth. Similarly, Abdel-Magid et al. (2009) reported that the replacement of conventional ingredients with linseed meal resulted in a significantly increased values in total body weight gain and average daily weight gain of growing rabbits.

Despite variations in the literature, the recorded biochemical blood values fall within the accepted physiological range for rabbit health and welfare (Table 4). The addition of linseed cake to feed mixtures reduced the value of selected indicators of lipid metabolism (triglycerides and cholesterol) in both experimental rabbit groups when compared with the control group, but those differences did not reach the statistical significance. Similar results were reported by Aggoor et al. (2007) with no effect on biochemical constituting blood plasma, after the dietary use of linseed meal up to 50% of soybean meal protein replacement in rabbit. Controversially, Ibrahim et al. (2021) found that feeding rabbits diets containing 4%, 6%, and 8% flaxseed significantly ($P < 0.05$) decreased serum triglycerides and total cholesterol levels compared with a control group. The reductions were attributed to the high soluble mucilage fibre and lignin content of flaxseed, which may attenuate cholesterol levels.

In Table 5, the chemical and physical parameters of rabbit MLD muscle samples are reported. No statistically significant differences were found in basic chemical indicators (moisture, proteins, cholesterol, ash, and energetic value), except for fat content. In both experimental groups (EG1 and EG2), the value of fat was statistically lower ($P < 0.05$) compared with the control group (1.39 EG1 and 1.59 EG2 g/100 g vs 1.73 g/100 g CON).

Similarly, Dalle Zotte (2014) reported MLD moisture content in rabbits was 74.6 g/100 g, protein content was 22.4 g/100 g, and fat content was around 1.8 g/100 g. The intramuscular fat content of MLD was higher in the Californian rabbit breed (1.10 g/100 g) compared with the French Lop breed (0.92 g/100 g). Differences in the intramuscular fat content were likely affected by the breed and the size of the body weight. Consistent with our findings, Martino et al. (2016) reported a water content of 75.3 g/100 g, a protein content of 22.9 g/100 g but a lower intramuscular fat content of 0.70 g/100 g. The mineral content of MLD in the French Lop breed was 0.99 g/100 g, and in the Californian rabbit breed, it was 1.07 g/100 g. Combes (2004) reported a higher mineral content in the rabbit MLD (1.2 g/100 g).

Physical parameters (pH, colour, water holding capacity) were not affected by the dietary treatment,

Table 4. Biochemical analyses on rabbit[+] blood serum (n = 10)

Parameter[#]	Control group	EG1 (5% LC)	EG2 (10% LC)	SEM	*P* value[*]
Total protein (g/L)	62.19	60.20	58.95	1.06	NS
Glucose (mmol/L)	6.67	7.68	6.97	0.24	NS
Triglycerides (mmol/L)	1.55	1.10	0.92	0.25	NS
Urea (mmol/L)	4.33	4.49	3.92	0.34	NS
Cholesterol (mmol/L)	2.28	1.29	1.67	0.22	NS
GGT (µkat/L)	0.24	0.22	0.22	0.01	NS
AST (µkat/L)	0.86	0.84	0.96	0.09	NS
ALT (µkat/L)	0.64	0.69	0.53	0.04	NS

[+] LC – linseed cake, experimental group EG1, experimental group EG2; [#] GGT – gamma glutamyl transferase; AST – aspartate aminotransferase; ALT – alanine aminotransferase; [*] NS – not significant.

Table 5. Chemical and physical parameters of rabbit[+] MLD muscles

Parameters	Control group	EG1 (5% LC)	EG2 (10% LC)	SEM	*P* value[*]
Content of water (g/100 g)	74.6	73.61	74.08	0.23	NS
Total proteins (g/100 g)	22.69	22.81	22.54	0.10	NS
Content of fat (g/100 g)	1.728[a]	1.586	1.394	0.20	*
Cholesterol (g/100 g)	0.38	0.39	0.30	0.01	NS
Ash (g/100 g)	0.64	0.66	0.73	0.04	NS
Energetic value (kJ/100 g)	445.12	441.75	430.10	7.56	NS
pH_{24}	6.06	5.96	6.09	0.03	NS
$Colour_{24}$ L	51.28	52.44	52.28	1.19	NS
$Redness_{24}$ (500–700 nm) a	2.02[a]	1.23	1.08	0.22	*
$Yellowness_{24}$ (445–578 nm) b	8.99	8.90	7.46	0.38	NS
Water holding capacity (g/100 g)	25.34	24.88	24.37	1.20	NS

[+] LC – linseed cake; experimental group EG1; experimental EG2; MLD – *musculus longissimus dorsi*; [*] Different letters in the same row mean statistical difference for $P < 0.05$, NS – not significant.

except for the meat redness (a). In both experimental groups (EG1 and EG2), lower values ($P < 0.05$) were observed in comparison with the control group. The colour of meat is the main attractive factor for the consumer at the time of purchase. Similar to our results, Pogany Simonova et al. (2010) detected lower colour measurement of redness (a*), mainly in the meat from the rabbits supplemented with a commercial feed additive mixture (XTRACT). Noia et al. (2020) reported that the red colour values were lower in rabbits treated with chitosan; in addition, the authors observed an increase in the yellowing and the luminosity of the meat in comparison with the control group. In contrast, Meng et al. (2010) reported that meat colour scores and redness values increased when pigs received a probiotic complex of *Bacillus subtilis* endospore and *Clostridium butyricum* endospore. In line with other here mentioned authors, Pelicano et al. (2003) also observed that the redness values in the meat of broilers increased in the groups treated with probiotics compared with the control group.

The effect of diet on a fatty acid profile in intramuscular fat is reported in Table 6. Grouped data indicate 35.3%, 36.8%, and 34.5% for saturated fatty acids (SFA), then 49.6%, 49.2%, and 50.3% for monounsaturated acids (MUFA), and 10.7%, 11.4%, and 11.1% for polyunsaturated acids (PUFA) in the control group, EG1 and EG2 groups, respectively. At the end of the dietary treatment, experimental rabbit meat (EG1 and EG2) presented higher values

Table 6. Fatty acid profile (g/100 g FAME) in the rabbit# MLD meat

Parameter+	Control group	EG1 (5% LC)	EG2 (10% LC)	SEM	*P* value*
C12:0 (Lauric acid)	0.117	0.123	0.120	0.002	NS
C14:0 (Myristic acid)	1.354	1.349	1.375	0.012	NS
C16:0 (Palmitic acid)	24.296	24.390	24.480	0.094	NS
C17:0 (Heptadecanoic acid)	0.308	0.332	0.327	0.016	NS
C18:0 (Stearic acid)	10.790	10.760	10.680	0.118	NS
Σ SFA fatty acids	35.298	36.840	34.474	0.623	NS
C18:1n-9c (Oleic acid)	37.596	36.750	35.360	1.965	NS
C18:1 11c/15t (Vaccenic acid)	4.848	4.754	4.878	0.055	NS
C20:1 (Eicosanoic acid)	0.601	0.484	0.550	0.033	NS
Σ MUFA fatty acids	49.602	49.154	50.282	0.429	NS
C18:2n-6 (Linoleic acid)	4.432^{b}	6.254^{a}	5.182^{b}	0.341	*
C18:2 9c/11t (Conjugated linoleic acid CLA)	0.116^{b}	0.142^{a}	0.133^{ab}	0.007	*
C18:3n-3 (α-Linolenic acid)	0.204	0.154	0.167	0.009	NS
Σ essential fatty acids	8.644	8.484	8.600	0.433	NS
C20:4n-6 (Arachidonic acid)	1.674	1.733	1.804	0.151	NS
C20:5n-3 (Eicosapentaenoic acid)	0.101	0.114	0.107	0.007	NS
C22:5n-3 (Docosapentaenoic acid)	0.130	0.145	0.139	0.009	NS
C22:6n-3 (Docosahexaenoic acid)	0.033	0.037	0.035	0.002	NS
Σ PUFA fatty acid	10.726	11.388	11.116	0.411	NS
PUFA/ SFA	0.304	0.309	0.322	0.004	NS
MUFA/SFA	1.401	1.334	1.459	0.028	NS
Omega 6 fatty acid	8.488	9.300	8.676	0.191	NS
Omega 3 fatty acid	0.466	0.452	0.432	0.067	NS
Saturated index	1.954	1.874	2.030	0.035	NS
Atherogenic index	0.555	0.494	0.489	0.016	NS

*Different letters in the same row mean statistical difference for $P < 0.05$, NS – not significant; +SFA: saturated fatty acids $C_{8:0}$, $C_{10:0}$, $C_{12:0}$, $C_{14:0}$, $C_{16:0}$, $C_{18:0}$, $C_{20:0}$, $C_{22:0}$, $C_{24:0}$; MUFA: monounsaturated fatty acids $C_{16:1\ n\text{-}7}$, $C_{18:1\ n\text{-}9c}$, $C_{22:1}$; PUFA: polyunsaturated fatty acids $C_{18:2\ n\text{-}6}$, $C_{18:3\ n\text{-}3}$, $C_{20:4\ n\text{-}6}$; AI: Atherogenic index = (C12 + 4C14 + C16) / (PUFA + C18:1 + other MUFA) (Ulbricht and Southgate, 1991); # experimental group EG1; experimental EG2; MLD – *musculus longissimus dorsi*; + LC – linseed cake; FAME – fatty acid methyl esters.

Table 7. Content of essential amino acid in rabbits[#] MLD (g/100 g)

Parameter[+]	Control group	EG1 (5% LC)	EG2 (10% LC)	SEM	*P* value[*]
Arginine	1.141	1.237	1.104	0.03	NS
Cystine	0.267	0.253	0.244	0.01	NS
Phenylalanine	0.735	0.798	0.701	0.02	NS
Histidine	0.783	0.908	0.727	0.02	NS
Isoleucine	0.698	0.690	0.660	0.03	NS
Leucine	1.426	1.402	1.346	0.04	NS
Lysine	1.524	1.507	1.450	0.05	NS
Methionine	0.575	0.595	0.553	0.02	NS
Threonine	0.834	0.788	0.758	0.02	NS
Valine	0.815	0.794	0.776	0.02	NS
ΣEAA	8.798	8.696	8.319	0.25	NS

[#] Experimental group EG1; experimental EG2; MLD – *musculus longissimus dorsi*; [+] LC – linseed cake; [*]NS – not significant; [+] Σ EAA – total essential amino acids.

($P < 0.05$) of linoleic acid and conjugated linoleic acid (CLA) in comparison with the control group. The increment of CLA in products of animal origin is considered a benefit, since bioactive compounds that play a significant role in promoting human health are the monounsaturated and polyunsaturated fatty acids. Rabbits, as monogastric animals, are unable to synthesise CLA, but thanks to the phenomenon of caecotrophy, they can deposit this acid in their muscles (Corino et al., 2007). Several biological properties are ascribed to CLA, such as antioxidant, antiatherosclerotic and antidiabetogenic properties (Sudiak and Kowalska, 2023). The average PUFA/SFA ratio ranged from 0.304 to 0.322 between the groups. The omega 6 fatty acid content was from 8.49 g/100 g FAME (CG) to 9.30 g/100 g FAME (EG1), and the omega 3 fatty acid content was between 0.43 g/100 g FAME (EG2) and 0.46 g/100 g FAME (CG).

The amino acid composition in MLD muscles is shown in Table 7. The essential amino acid composition is one of the most important nutritional qualities of proteins. Some of these amino acids can be synthesized by living organisms from other nitrogenous material. Other amino acids essential to the diet cannot be synthesized in vivo but must be ingested as such (Henchion et al., 2017). Hernández and Dalle Zotte (2010) reported higher contents of lysine (2.1 g/100 g), leucine (1.7 g/100 g), valine (1.1 g/100 g) and phenylalanine (1.04 g/100 g) in rabbit MLD compared with our results. Wognin et al. (2018) found lower content of phenylalanine (0.77 g/100 g) and a higher value of threonine (0.89 g/100 g) compared with our results.

Conclusion

Feeding linseed cake substances in rabbits did not negatively affect zootechnical parameters, growth performance and slaughter traits; it had no negative effect on a rabbit's blood biochemical profile either. Experimental diets with 5% linseed cake improved feed conversion ratios, without significantly affecting the final weight of animals. The dietary supplementation positively influenced the meat fatty acids profile, in particular polyunsaturated fatty acids (linoleic acid and CLA), indicating enhanced nutritional quality of the meat as a functional food.

Overall, the use of linseed cake, a sustainable agricultural by-product, is a promising dietary strategy to improve the nutritional value of rabbit meat and support efficient, welfare-conscious rabbit production.

Ethical statement

The authors confirm that they have followed EU standards for the protection of animals used for scientific purposes. All care and experimental procedures involving animals followed the guidelines stated in the Guide for the Care and Use of Laboratory Animals approved by the State Slovak Veterinary and Food Administration and the Ethics Committees of both institutions (Permission code: SK CH 17 021).

Acknowledgements

This publication was supported by the Slovak Research and Development Agency, Contract No. APVV-20-0037, and the Operational Programme Integrated Infrastructure within the project: Sustainable smart farming systems taking into account the future challenges 313011W112, co-financed by the European Regional Development Fund. The authors would like to thank to Dr. Vladimir Parkányi, Dr. Tomáš Sládeček, Mrs. Jana Zelenáková, Mr. Ján Pecho, and Mr. Peter Fridrich for their excellent technical assistance and co-operation in experiments.

References

1. Abdel-Magid S.S., Omer H.A.A., Abedo A.A., Mohamed M.I., Awadalla I.M. Partial substitution of soybean meal by linseed meal or sesame meal in growing rabbit's diet. Egyptian Journal of Nutrition and Feeds. 2009. T. 12. P. 503–518.
2. Agradi S., Sulce M., Menchetti L., Vigo D., Castrica M., Barbato O., Andoni E., Quattrone A., Munga A., Marongiu M.L., Curone G., Brecchia G. Dietary supplementation with n-3 polyunsaturated fatty acids: effects on reproductive and productive performance and meat quality in rabbit breeding. Animal Nutrition. 2023. T. 14. P. 70-78.
3. AOAC 2000. Official methods of analysis of AOAC *International, 17th ed.; AOAC: Arlington, VA, USA.*
4. Aggoor F.A.M., Abd El-Hady S.B., El-Mogazy E.M.E.A., Henesh N.A.Y.S. Effect of feeding different levels of linseed meal instead of soybean meal in the diets of Balady Black rabbit does: 2 – Effect on productive and reproductive performance and some blood parameters. Journal of Agricultural Science, Mansoura University. 2007. T. 32. P. 4299–4300.
5. Blasco A., Ouhayoun J. Harmonization of criteria and terminology in rabbit meat research. Revised proposal. World Rabbit Science. 1996. T. 4. P. 92–99. https://doi.org/10.4995/wrs.1996.278
6. Combes S. Nutritional value of rabbit meat: a review. Productions Animales. 2004. T. 17. P. 373–383.
7. Corino C., Lo Fiego D.P., Macchioni P., Pastorelli G., Di Giancamillo A., Domeneghini C., Rossi R. Influence of dietary conjugated linoleic acids and vitamin E on meat quality, and adipose tissue in rabbits. Meat Science. 2007. T. 76. P. 19–28. https://doi.org/10.1016/j.meatsci.2006.10.007
8. Dalle Zotte A. Rabbit farming for meat purposes. Animal Frontiers. 2014. T. 4. P. 62–67. https://doi.org/10.2527/af.2014-0035
9. Halle I., Schöne F. Influence of rapeseed cake, linseed cake and hemp seed cake on laying performance of hens and fatty acid composition of egg yolk. Journal für Verbraucherschutz und Lebensmittelsicherheit. 2013. T. 8. P. 185–193. https://doi.org/10.1007/s00003-013-0822-3
10. Hašek O., Palanská O. Determination of water holding capacity in meat by instruments at constant pressure. Poultry Industry. 1996. T. 18. P. 228–233.
11. Henchion M., Hayes M., Mullen A.M., Fenelon M., Tiwari B. Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. Foods. 2017. T. 6. P. 53. https://doi.org/10.3390/foods6070053
12. Hernández P., Dalle Zotte A. Influence of diet on rabbit meat quality. In: Blas C., Wiseman J. (eds): Nutrition of the Rabbit. UK: CAB International, 2010. P. 163–178.
13. Ibrahim Sh.A.M., El-Nomeary Y.A.A., Salman F.M., Bakry B.A. The effects of dietary inclusion of different levels of flaxseed on the digestibility, growth performance, blood parameters and fatty acid profile in growing New-Zealand White (NZW) rabbits. Egyptian Journal of Nutrition and Feeds. 2021. T. 24, No. 1. P. 95–105.
14. Kučka M., Harenčár Ľ., Ražná K., et al. Great potential of flaxseed mucilage. European Food Research and Technology. 2024. T. 250. P. 877–893. https://doi.org/10.1007/s00217-023-04429-0
15. Martino M., Mattioli S., Farkas P., Szendrő Zs., Dal Bosco A., Ruggeri S., Matics Zs., Castellini C., Gerencsér Zs. Carcass traits and meat quality of growing rabbits in pens with and without different multi-level platforms. World Rabbit Science. 2016. T. 24. P. 129–138. https://doi.org/10.4995/wrs.2016.3922
16. Meng Q.W., Yan L., Ao X., Zhou T.X., Wang J.P., Lee J.H., Kim I.H. Influence of probiotics in different energy and nutrient density diets on growth performance, nutrient digestibility, meat quality, and blood characteristics in growing-finishing pigs. Journal of Animal Science. 2010. T. 88. P. 3320–3326. https://doi.org/10.2527/jas.2009-2372
17. Noia M., Mahmoud A.F.A., El-Sayed S.A., El-Badawy A.A. Effects of edible chitosan coating containing Salvia rosmarinus essential oil on quality characteristics and shelf life extension of rabbit meat during chilled storage. Journal of Food Measurement and Characterization. 2023. T. 17. P. 1–12. https://link.springer.com/article/10.1007/s11694-023-01804-z
18. Omer H.A.A., Abedo A.A., Ahmed S.M., Badr A.M.M., Hasanin M.S.M. Utilization of flaxseeds (Linum usitatissimum L.) in rabbit rations. 1. Response of growing rabbits to diets containing different levels of flaxseeds. Life Science Journal. 2013. T. 10, No. 4. P. 2638–2646. https://www.researchgate.net/publication/286178892
19. Patade A., Devareddy L., Lucas E.A., Korlagunta K., Daggy B.P., Arjmandi B.H. Flaxseed reduces total and LDL cholesterol concentrations in Native American postmenopausal women. Journal of Women's Health. 2008. T. 17. P. 355–366. https://doi.org/10.1089/jwh.2007.0359
20. Pelicano E.R.L., Souza P.A. de, Souza H.B.A. de, Oba A., Norkus E.A., Kodawara L.M., Lima T.M.A. de. Effect of different probiotics on broiler carcass and meat quality. Revista Brasileira de Ciência Avícola. 2003. T. 5. P. 207–214. https://www.scielo.br/j/rbca/a/7f4MGRsPpRGZNBDv5cZx4zN/
21. Pogány Simonová M., Chrastinová Ľ., Mojto J., Lauková A., Szabóová R., Rafay J. Quality of rabbit meat and phyto-additives. Czech Journal of Food Sciences. 2010. T. 28. P. 161–167. https://doi.org/10.17221/49/2008-CJFS
22. Ribeiro L.F., Peralta-Zamora P., Ramos L.P., Pereira-Netto A.B. Prediction of linolenic and linoleic fatty acids content in flax seeds and flax seeds flours through the use of infrared reflectance spectroscopy and multivariate calibration. Food Research International. 2013. T. 51. P. 848–854. https://doi.org/10.1016/j.foodres.2013.01.061
23. Savietto D., Bannelier C., Colin M., Guillevic M., Abdel-Kafy E.S.M., Failla S., Dal Bosco A., Jemmali B., Ben Salem I., Brecchia G., Gidenne T. Nutritional evaluation of two composite linseed-based ingredients for growing rabbits. World Rabbit Science. 2025. T. 33. P. 63–71.
24. Siudak Z., Kowalska D. Dietary supplements used in rabbit nutrition and their effect on the fatty acid profile of rabbit meat – a review. Journal of Animal and Feed Sciences. 2023. T. 32. P. 385–399. https://doi.org/10.22358/jafs/163632/2023
25. Strmiska F., Holčíkova K., Simonová E., Mrázová E., Hodeková J., Votaššaková A., Pristašová M., Strmiska J., Strmisková G., Krupařová M., Gola J., Pappajová H., Mareš J., Kostkanová E., Ehrenhaft B. Požívatinové tabuľky I – Potravinárske suroviny, Food tables I – primary foods (in Slovak with English summary and register). Výskumný ústav potravinársky (Food Research Institute), Bratislava. 1988. P. 189.
26. Tariq M.R., Khan M.I., Sameen A., Nisa M. Enrichment of flaxseed for developing functional rabbit meat. Sarhad Journal of Agriculture. 2015. T. 31. P. 70–74. https://researcherslinks.com/current-issues/Enrichment-of-Flaxseed-for-Developing-Functional-Rabbit-Meat/14/1/99/html
27. Wognin L.R.M.F., Otchoumou K.A., Yao K.F., Niamké S. Improving the nutritive value and sensory quality of rabbit meat by using leafy vegetables as feedstuffs. Journal of Animal and Plant Sciences. 2018. T. 36. P. 5812–5824. https://doi.org/10.35759/JAnmPlSci.v36-1.5
28. Wu Z., Li Y., Qiu H., Long S., Zhao X., Wang Y., Guo X., Baitelenova A., Qiu C. Comparative assessment of lignan, tocopherol, tocotrienol and carotenoids in 40 selected varieties of flaxseed (Linum usitatissimum L.). Foods. 2023. T. 12. P. 4250. https://doi.org/10.3390/foods12234250