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Dietary inclusion of extruded flaxseed-pulse mixture increases the content of omega-3 fatty acids in broiler chicken meat

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ABSTRACT

The effects of extruded flaxseed-pulse mixture (LinPRO-24) on growth performance, tissue fatty acid composition, carcass traits, and meat quality in broilers were investigated. A total of 540-day-old male 308 Ross chicks were placed in pens (30 chicks/pen) and allocated to three diets ($n = 6$) in a completely randomized design. The diets were: CON (basal corn-soybean meal diet); LPA (CON+2.5% LinPRO-24); and LPB (CON+ 5.0% LinPRO-24). Diets were isocaloric and isonitrogenous, formulated for starter (day 1-10), grower (day 11-24), and finisher (day 24-34). Feed intake and body weight (BW) were recorded daily, and mortalities as they occurred to calculate average daily gain (AWG) and FCR. On day 34, visceral organs, breast tissue, and leg tissue were sampled. The CON group exhibited higher overall BW, AWG, and AFI than LPB ($P < 0.05$). Breast and leg tissues of birds fed LPB had the highest concentration of Alpha-linolenic acid (ALA) and total ω-3 PUFA followed by LPA; both had a higher ALA concentration than the CON group ($P < 0.05$). Thus, the ω-6:ω-3 ratio in these tissues was lower for LPA and LPB groups ($P < 0.05$). Additionally, both LPA and LPB groups had lower Docosatetraenoic acid (DTA, C22:4 ω-6), higher Docosapentaenoic acid (DPA, C22:5 ω-3) and total PUFA content, resulting in a reduced SFA:PUFA ratio in leg tissue compared with the CON group ($P < 0.05$). However, LPB negatively affected the water-holding capacity (WHC) in breast meat compared with the CON and in leg tissue compared with LPA treatment ($P < 0.05$). Moreover, LPB increased muscle hardness and gumminess in the breast compared with the CON group ($P < 0.05$), thereby negatively affecting meat textural qualities. Overall, both LPA and LPB diets increased the ω-3 PUFA content in poultry meat, thereby reducing the ω-6:ω-3 ratio. However, the current study suggests that the use of LinPRO-24 at 2.5% may be more appropriate for improving the fatty acid profile of broiler meat without compromising production performance and meat quality.

Introduction

There is growing interest in supplementing the diet with omega-3 (ω-3) long chain polyunsaturated fatty acids (LC-PUFAs) for their role in reducing inflammation, thereby improving cardiovascular health and supporting brain function. Recently, certain international organizations and European countries recommended maintaining a dietary ω-6:ω-3 fatty acids ratio of 4:1 to address lifestyle-related health conditions (Kumar et al., 2020). However, modern food practices typically involve higher consumption of plant oils and animal fats, which are predominantly rich in ω-6 PUFAs and contain low amount of ω-3 PUFAs, such as alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) (Gibbs et al., 2010). These dietary habits have resulted in an increased ω-6:ω-3 PUFA ratio, which is significantly higher than the recommended level for optimal human health (Mir et al., 2018a). Nevertheless, higher dietary intake of ω-3 PUFA can presumably reduce the ω-6:ω-3 PUFA ratio and lead to increased health benefits in humans (Del Gobbo et al., 2016).

Several strategies, including, enriching animal-derived foods, particularly poultry meat, with LC-PUFAs through land-based, sustainable feed-ingredients represents a promising method to improve the functional value of food products and increase the ω-3 intake in human diets. Flaxseed is one of the richest terrestrial sources of ω-3 fatty acids, particularly ALA, which constitutes approximately 40–50% of its dry

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matter (Apperson and Cherian, 2017; Thanabalan et al., 2020, 2024). In monogastric animals, like poultry, where no biohydrogenation of dietary fatty acids occurs, the ALA from flaxseed is directly deposited in their tissues, making poultry an ideal species for ALA enrichment (Kouba and Mourot, 2011; Mir et al., 2018a; Kumar et al., 2020). Several studies have also demonstrated that increasing levels of ground flaxseed in poultry diets results in higher ω-3 fatty acid content, particularly ALA, in broiler meat (Konieczka et al., 2017; Mir et al., 2017b, 2018b; Kumar et al., 2019). Furthermore, Kumar et al. (2019) reported that broiler chickens can convert some dietary ALA to EPA and DHA. A study by Kumar et al. (2020) reported that supplementing broiler diets with 10% flaxseed meal significantly reduced total fat content and ω-6 PUFA, while significantly increasing ω-3 PUFA, including EPA, DPA, and DHA, in broiler meat.

However, feeding flaxseed increases the degree of unsaturation in muscle tissue, making it more prone to lipid peroxidation and subsequent free-radical-induced protein denaturation, which influences carcass traits in broilers (Kumar et al., 2020). Moreover, they can go rancid easily due to their high PUFA content and have a limited shelf life, which is a downside for long-term storage (Kajla, 2020). Additionally, the presence of several anti-nutritional factors (ANFs), particularly non-starch polysaccharides (NSPs), is associated with reduced nutrient digestibility and compromised growth performance in broilers (Apperson and Cherian, 2017; Leung et al., 2018). To mitigate these challenges, advanced methods, such as extrusion technology, have proven effective in reducing or inactivating ANFs. It has been reported that extrusion cooking enhances the degradation of ANFs while disrupting the compact fiber structure of flaxseed, thereby improving digestive and absorption functions and enhancing growth performance in birds (Wu et al., 2010; Pirmohammadi et al., 2019). Sepehr et al. (2021) summarized that extruded flaxseed (3, 6, and 9%) outperformed whole and milled flaxseed by enhancing the feed intake, egg production, egg mass contents, and egg weight in layer birds. Nevertheless, higher extruded flaxseed concentrations (5, 10, and 15%) still negatively affected blood and meat antioxidant activities, and meat sensory acceptability in broilers (Anjum et al., 2013).

The initial body weight of chicks affects subsequent broiler growth, as the first week accounts for approximately 17% of the total growth cycle (Akram et al., 2024; Tsementzis et al., 2025). Therefore, excessive inclusion of flaxseed-based ingredients during this period may compromise overall performance. Konieczka et al. (2017) reported that incorporating flaxseed at levels below 6% in the diet did not adversely affect broiler growth performance. Although, numerous studies have investigated the effects of raw flaxseed, flaxseed oil, or extruded flaxseed alone as ω-3 sources at moderate to high inclusion levels in poultry nutrition. To the best of our knowledge, no study has evaluated the effects of extruded flaxseed-pulse mixture on fatty acid deposition, meat quality, and growth performance in broilers. Thus, the current hypothesized that lower inclusion levels of extruded flaxseed-pulse mixture (LinPRO-24) would improve the meat fatty acid profile to recommended levels while avoiding potential growth suppression associated with higher inclusion rates. Therefore, this study aimed to investigate the effects of LinPRO-24 at 2.5 and 5.0% on growth performance, fatty acid profile, relative organs weight, carcass quality, and meat quality in broiler chickens.

Materials and methods

Ethical statement

All experimental protocols in the present study were reviewed and approved by the Institute Animal Care and Use Committee of the National Pingtung University of Science and Technology (NPUST), Pingtung, Taiwan (NPUST-114-041).

Birds and housing

A total of 540-day-old Male Ross 308 broiler chicks, which were vaccinated against Marek's disease, Newcastle disease, and infectious bronchitis in according to the standard vaccination procedure, were purchased and randomly allocated based on initial body weight (41.33 ± 0.03 g) using a complete randomized design into 18 floor pens (2 m × 1.7 m × 2 m). These birds were assigned to three dietary treatment groups; each group comprised 6 replicate pens, and each pen had 30 chicks. Birds were housed in a broiler barn equipped with tunnel ventilation and water-cooling pads. Each pen had a feeder and a drinker with rice hull as the bedding material. Feed and water were provided *ad libitum* under a 24 h lighting scheme during the 34-day experimental period. The experiment was divided into three feeding phases: a starter (day 1 to 10), a grower (day 11 to 24), and a finisher (day 25 to 34). Temperature and relative humidity were recorded four times in a day, where the average temperature and relative humidity were maintained at 28.00°C ± 2.03°C and 63.01% ± 3.16% in the starter phase, 26.72°C ± 2.77°C and 62.28% ± 6.87% in the grower phase, and 25.89°C ± 1.93°C and 70.37% ± 11.22% in the finisher phase, respectively.

Experimental treatments

The commercially available extruded full-fat flaxseed and pulse mixture (1:1 wt/wt) as a source of alpha-linolenic acid (LinPRO-24, O&T Farms Ltd., SK, Saskatchewan, Canada), was included in the experimental diets as previously described by Thanabalan et al. (2020). The manufacturing process of LinPRO-24 combines flaxseed with pulse flour, forming a protein–starch matrix that may provide structural protection to polyunsaturated fatty acids, thereby improving the nutritional consistency and stability of dietary ω-3 sources. The current study consisted of three dietary treatment groups: CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; and LPB, basal diet with 5.0% LinPRO-24. The basal diet was based on corn-soybean meal and experimental diets were formulated in accordance with Ross 308 standard nutritional guidelines (Table 1). Mash feed was provided during the starter phase and switched to pelletized feed in the following phases.

Growth performance and sampling

The amount of feed offered and the residue for each pen were measured daily to calculate the average feed intake per treatment in each phase (AFI; g/bird). In addition, group body weight measurement for each pen was performed on day 1, 11, 25, and 34 without pre-measurement feed restriction for determining body weight (BW; g/bird) and average weight gain (AWG; g/bird). The feed conversion ratio (FCR) was further calculated using the ratio of average feed intake (AFI; g/bird) to average body weight gain (AWG; g/bird) in each phase. The body weight of dead birds was recorded to adjust BW, AFI, and FCR accordingly. Moreover, birds uniformity was calculated as the percent individuals within 10% of the mean BW using total number of birds within 10% range of mean to total number of birds as described by Vasdal et al. (2019).

Each diet (3 treatments × 3 phases = 9) was sampled and sent to the Tropical Agriculture Research Center (CAAPIC, NPUST, Taiwan) for proximal analysis according to the International (2000) and for fatty acid analysis using gas chromatography with a flame ionization detector (GC–FID; Shimadzu GC-2010, Shimadzu Corporation, Japan) equipped with an SP-2560 fused silica capillary column (100 m × 0.25 mm × 0.20 μm; Supelco, Cat. No. 24056, Sigma-Aldrich, USA). At the end of the feeding trial (day 34), 12 birds from each treatment group were selected based on average weight of the treatment, weighed, and electrically stunned by using an electric stunner. Birds were euthanized, and the absolute weights of the organs, including liver, gizzard (flushed), heart, spleen, and visceral fat were measured after collection ($n = 12$) (Gorenz et al., 2024). Furthermore, 10 birds from each treatment group were

Table 1
Composition of experimental diets, as fed basis.

Item	Starter			Grower			Finisher		
	CON[1]	LPA	LPB	CON	LPA	LPB	CON	LPA	LPB
Corn	59.40	58.60	58.00	63.90	63.10	62.40	66.00	65.30	64.50
Soybean meal, 47%	29.50	28.30	27.00	24.70	23.50	22.20	22.40	21.10	19.90
Corn gluten meal, 60%	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
LinPRO-24[2]	-	2.50	5.00	-	2.50	5.00	-	2.50	5.00
Soybean oil	1.70	1.20	0.65	2.55	2.05	1.55	3.00	2.50	2.00
Mono-Dicalcium phosphate	1.10	1.10	1.10	0.86	0.85	0.85	0.75	0.75	0.75
Limestone	1.40	1.40	1.40	1.20	1.25	1.25	1.15	1.15	1.15
L-Lysine HCl, 79.8%	0.60	0.61	0.62	0.57	0.57	0.58	0.53	0.54	0.55
DL-Methionine, 99%	0.47	0.47	0.47	0.44	0.44	0.45	0.41	0.42	0.42
Sodium chloride	0.28	0.27	0.27	0.28	0.28	0.27	0.28	0.28	0.28
L-Threonine	0.21	0.22	0.22	0.19	0.19	0.19	0.17	0.17	0.18
Choline chloride 60%	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Vitamins premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace minerals premix[4]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Phytase(500 FTU)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	100	100	100	100	100	100	100	100	100
Calculated provisions									
Dry matter, %	88.20	88.30	88.40	88.20	88.30	88.40	88.20	88.30	88.40
Apparent metabolizable energy, kcal/kg	3152	3152	3150	3252	3250	3252	3300	3301	3301
Crude protein, %	22.00	22.00	22.00	20.00	20.00	20.00	19.00	19.00	19.00
Crude fat, %	4.29	4.35	4.36	5.18	5.24	5.30	5.65	5.71	5.76
Crude fiber, %	2.60	2.78	2.96	2.51	2.69	2.87	2.47	2.65	2.83
Calcium, %	0.96	0.96	0.95	0.83	0.84	0.84	0.78	0.78	0.78
Total Phosphorous, %	0.75	0.75	0.75	0.68	0.68	0.68	0.65	0.65	0.65
Available Phosphorous, %	0.48	0.48	0.48	0.42	0.42	0.42	0.39	0.39	0.39
Lysine, %	1.53	1.53	1.53	1.37	1.37	1.37	1.28	1.28	1.28
Methionine %	0.81	0.80	0.80	0.75	0.75	0.76	0.71	0.72	0.72
Methionine + Cysteine, %	1.15	1.15	1.15	1.08	1.07	1.08	1.02	1.03	1.03
Threonine, %	1.02	1.03	1.02	0.92	0.92	0.92	0.87	0.86	0.87
Tryptophan, %	0.25	0.25	0.25	0.22	0.22	0.22	0.2	0.2	0.2
Sodium, %	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Potassium, %	0.75	0.75	0.74	0.67	0.67	0.67	0.64	0.63	0.63

[1] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.
[2] LinPRO-24; co-extruded full-fat flaxseed and pulse mixture (1:1 wt/wt) as a source of alpha-linolenic acid (O&T Farms Ltd., SK, Saskatchewan, Canada).
[3] Vitamin premix provided per kilogram of diet: vitamin A, 10,000,000 IU; vitamin D3, 1,000,000 IU; vitamin E, 20 g; vitamin K3, 1.5 g; Vitamin B, 2 g; vitamin B2, 4 g; vitamin B6, 3 g; vitamin B12, 15 mg; biotin, 60 mg; pantothenic acid, 15 g; folic acid, 1 g; and niacin: 35 g.
[4] Mineral premix provided per kilogram of diet: cobalt, 100 mg; copper, 5 g; iodine, 400 mg; iron, 40 g; manganese, 60 g; selenium, 300 mg; zinc, 40∼44 g; lead, 50 ppm; mercury, 0.5 ppm; cadmium, 10 ppm; and arsenic, 12 ppm.

additionally selected, weighed, transported, and slaughtered in the slaughterhouse production line. After collection, the right breast (*pectoralis major*) and right leg (*biceps femoris*) were used for fatty acid analysis, whereas left breast and left leg meat were used to assess carcass qualities and sensory attributes ($n = 10$).

Sample processing and analyses

Carcass weight was recorded at 1 and 24 h post-slaughter and used to calculate dressing percentage as the ratio of carcass weight to live body weight ($n = 10$). In addition, each carcass was stored at 4°C for 24 h in plastic bag, and the difference in initial and final weight was calculated to measure the drip loss (DL) and expressed as a percentage. Furthermore, each carcass was divided into various commercial cuts, including head and neck, breast, legs, wings, feet, breast, and bone frame. Each carcass cut was recorded and presented as a percentage of live weight to determine carcass yield.

Approximately 100–150 g of right breast and right leg meat samples, including skin, were collected and submitted to the Center for Agricultural and Aquacultural Product Inspection and Certification (CAAPIC), NPUST, Taiwan, for analysis. Fatty acids in chicken meat were determined as fatty acid methyl esters (FAMEs) that were analyzed using gas chromatography with a flame ionization detector (GC–FID; Shimadzu GC-2010, Shimadzu Corporation, Japan) equipped with an SP-2560 fused silica capillary column (100 m × 0.25 mm × 0.20 μm; Supelco, Cat. No. 24056, Sigma-Aldrich, USA). Helium was used as the carrier gas at a constant flow rate of 1 mL/min. The injector temperature was set at 250°C, and 1 μL of sample was injected in split mode with a split ratio of 200:1. The detector temperature was maintained at 300°C. The oven temperature program was as follows: an initial temperature of 150°C, increased to 170°C at 2°C/min, then to 190°C at 1°C/min, and finally to 240°C at 5°C/min, followed by a final hold for 30 min. Moreover, the pH, meat color, water-holding capacity (WHC), cooking loss (CL), and textural properties of left breast and leg meat at 24 h post-slaughter were analyzed as described by Bhattarai et al. (2025). Briefly, the pH of each meat sample was measured using a pH meter (Model SP-2100; Suntex, Taiwan), with the electrode inserted 2 to 3 cm into the meat sample. Each measurement was performed in triplicate, and the mean value was used for analysis. Meat color, expressed as lightness (L*), redness (a*), and yellowness (b*), was determined using a Chroma Meter (CR-400; Konica Minolta, Japan) at three different locations on the proximal surface of each meat cut, and the average value was recorded. For WHC analysis, 1 g of each meat sample was placed on No. 1 filter paper (Adventec), covered with acetate film, and subjected to a pressure of 3000 psi for 1 min using a pressure device (Model C; Carver, USA). After drying, the surface areas of the inner and outer rings were measured using a planimeter (KP-90 N; KOIZUMI, Japan). Lastly, the WHC was calculated as the ratio of the difference between the outer and inner ring areas to the inner ring area and expressed as a percentage. The breast and leg meat samples were cooked in a water bath (80°C) to an internal core temperature of 75°C (40 min), and the weight difference before and after cooking was recorded to determine the CL and expressed as a percentage. Cooked breast and leg meat samples were further trimmed into three pieces (4 cm × 4 cm × 2 cm) for texture profile analysis. Shear

force was measured using a texture profile analyzer (TA.XTplusC; Stable Micro Systems, Surrey, UK) equipped with an A/MORS blade. The instrument was operated at a trigger force of 50 g, a compression depth of 10 mm, and a test speed of 5 mm/s. Other textural parameters, including hardness, springiness, cohesiveness, gumminess, and chewiness, were measured using the same texture profile analyzer fitted with a P/1S spherical probe, operated at a trigger force of 30 g, a compression depth of 10 mm, and a test speed of 5 mm/s. Measurements were performed on three pieces per sample and the mean value was recorded. Moreover, sensory evaluation was performed using left breast and leg meat, with a sensory panel comprising 14 semi-trained persons ($n = 14$). The analyzed sensory traits were hardness, flavor, juiciness, color, and overall acceptance. The sensory profiling was carried out by the same trained panel for each sample, and the terms were scored on a scale from 1 to 7, where a low number corresponded to a low intensity of the specific parameter and a high number to a high intensity (Rybarczyk et al., 2020).

Statistical analysis

All experimental data were subjected to analysis using one-way analysis of variance using SPSS (Version 22.0; IBM, Armonk, NY, USA). The pen was considered the experimental unit for growth performance parameters, while the individual bird was considered the experimental unit for carcass, meat quality, and organ weight measurements. Tukey's honestly significant difference test was used to compare means among treatments and significant differences were considered at $P < 0.05$. Results in tables were presented as means of treatments and the pooled standard error of the means (SEM).

Results

Experimental diets

The analyzed chemical composition of the diets (Table 2) was comparable to the formulated values (Table 1). Fatty acid analysis of the experimental diets at different growth stages illustrated no marked differences in SFAs among experimental diets (Table 3). Regarding MUFAs, the treatment diets (LPA and LPB) had higher oleic acid content than the CON diet during the starter and grower phases, but not in the finisher phase. Moreover, Linoleic acid (LA; C18:2 ω-6) content was highest in the CON diet and decreased linearly with increasing LinPRO-24 inclusion across all growth phases. Consequently, the total ω-6 PUFA content reduced as LinPRO-24 concentration increased. In contrast, the LPA and LPB diets had considerably higher ω-3 fatty acid content than the CON diet throughout all phases. Particularly, ALA content increased progressively with higher LinPRO-24 inclusion. As a result, the ω-6:ω-3 ratio was lowest in the LPB diet, followed by the LPA diet and highest in the CON diet across all growth stages. Additionally, the SFA:PUFA ratio was lower in the treatment diets, particularly in LPB, than in the CON diet. Notably, the fatty acid concentrations progressively increased across all experimental diets with growth stages.

Growth performance

Supplementation with LPA and LPB negatively affected the BW and AWG compared with the CON group during the starter phase ($P = 0.001$ each; Table 4). As a result, the starter FCR was higher in treatment groups than the CON group ($P = 0.008$). In contrast, birds fed with LPA and LPB exhibited improved FCR compared with the CON group during the grower phase ($P = 0.004$), with no alterations on grower BW, AWG, and AFI among treatments. During finisher phase, the LPB treatment had lower BW and AWG compared with the CON group ($P = 0.036$ and ($P = 0.018$, respectively).

Overall, inclusion of LPB reduced overall BW, AWG, and AFI compared with the CON group ($P = 0.034$, $P = 0.036$, and $P = 0.016$, respectively). Nevertheless, no significant differences were observed on BW, BWG, AFI, FCR, and uniformity between the CON and LPA treatments.

Fatty acid profile in breast meat

Birds supplemented with LPB exhibited the highest ALA content in breast meat, followed by those supplemented with LPA; both were higher than the CON group ($P < 0.001$; Table 5). Consequently, the total ω-3 PUFA content was increased in the LPA and LPB treatments compared with the CON group ($P < 0.001$). Moreover, the Arachidonic acid (ARA, C20:4 ω-6) content was lowered in the LPB treatment compared with the LPA and CON treatments ($P = 0.001$). In turn, LPB treatment had lowest ω-6:ω-3 ratio in breast meat, followed by the LPA treatment; both were lower than the CON group ($P < 0.001$).

Fatty acid profile in leg meat

A linear increase in absolute ALA content was observed in leg meat of treatment groups, with the highest level in the LPB, followed by the LPA; both were higher than the CON group ($P < 0.001$; Table 6). Additionally, both LPA and LPB treatments had higher Docosapentaenoic acid (DPA, C22:5 ω-3) than the CON group ($P < 0.001$), resulting in higher total ω-3 PUFA content in the supplemented treatments ($P < 0.001$). Moreover, birds in LPB treatment had higher Eicosadienoic acid (EDA, C20:2 Ω-6) compared with the CON group ($P = 0.004$). On the other hand, both ARA and Docosatetraenoic acid (DTA, C22:4 ω-6) were lowered in the LPB treatment compared with the CON group ($P = 0.005$ and $P < 0.001$, respectively). Both LPA and LPB treatments had higher total PUFA content compared with the CON group ($P = 0.024$). As a result, the ratio of SFA:PUFA was lower in the LPA and LPB treatments than the CON group ($P = 0.017$). Moreover, both LPA and LPB markedly reduced the ω-6:ω-3 ratio in leg meat compared with the CON group ($P < 0.001$).

Relative organ weight

LPB treatment had significantly higher visceral fat compared to the CON group ($P = 0.018$; Fig. 1). However, no significant differences were observed on liver, spleen, heart, and gizzard weights among the treatments.

Table 2
Analyzed chemical composition of experimental diets.

Items	Starter			Grower			Finisher		
	CON[1]	LPA	LPB	CON	LPA	LPB	CON	LPA	LPB
Dry matter, %	88.20	88.50	88.60	87.20	87.20	87.40	87.80	88.40	88.00
Gross energy, kcal/kg	3470	3590	3600	3560	3570	3590	3630	3650	3640
Crude protein, %	22.70	22.30	21.40	20.30	20.70	20.20	18.40	18.60	18.30
Crude fat, %	4.60	4.50	4.80	4.50	4.80	4.90	5.40	5.60	5.40
Crude ash, %	4.60	4.40	4.50	3.90	3.90	3.80	3.70	4.10	3.70

[1] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Table 3
Analyzed fatty acid composition of experimental diets.

Items, g/100 g[1]	Starter			Grower			Finisher		
	CON[2]	LPA	LPB	CON	LPA	LPB	CON	LPA	LPB
TFA	3.56	3.93	3.89	4.33	4.61	4.95	5.41	5.41	5.44
SFAs									
C14:0 Myristic acid	-	-	-	-	-	-	-	0.01	0.01
C16:0 Palmitic acid	0.41	0.45	0.42	0.51	0.5	0.53	0.61	0.62	0.56
C18:0 Stearic acid	0.11	0.11	0.11	0.13	0.14	0.14	0.17	0.17	0.17
C20:0 Arachidic acid	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
C22:0 Behenic acid	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C24:0 Lignoceric acid	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MUFAs									
C18:1 Oleic acid	1.04	1.13	1.11	1.09	1.13	1.20	1.48	1.47	1.48
C20:1 Eicosenoic acid	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
PUFAs, ω-6									
C18:2 Linoleic acid	1.80	1.70	1.59	2.32	2.32	2.30	2.77	2.56	2.42
C18:3 Gamma-linolenic acid	-	-	-	-	-	0.01	0.01	0.01	0.01
PUFA, ω-3									
C18:3 Alpha-linolenic acid	0.12	0.37	0.60	0.17	0.40	0.65	0.21	0.41	0.67
Others	0.03	0.03	0.03	0.06	0.07	0.06	0.09	0.08	0.07
Total SFA	0.56	0.59	0.56	0.68	0.68	0.71	0.82	0.84	0.78
Total MFA	1.05	1.14	1.12	1.10	1.14	1.21	1.49	1.48	1.50
Total PUFA	1.92	2.07	2.19	2.49	2.72	2.96	2.99	2.98	3.10
ω-6 PUFAs	1.80	1.70	1.59	2.32	2.32	2.31	2.78	2.57	2.43
ω-3 PUFAs	0.12	0.37	0.60	0.17	0.40	0.65	0.21	0.41	0.67
SFA:PUFA	0.29	0.29	0.26	0.27	0.25	0.24	0.27	0.28	0.25
ω-6:ω-3	15.00	4.59	2.65	13.65	5.80	3.55	13.24	6.27	3.63

[1] TFA, total fatty acids content; SFA, saturated fatty acids; MUFAs, mono-unsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA:PUFA: ratio of saturated fatty acids to unsaturated fatty acids; and ω-6:ω-3: ratio of omega-6 polyunsaturated fatty acids to omega 3 polyunsaturated fatty acids.
[2] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Table 4
Effects of co-extruded flaxseed and pulse mixture on growth performance of Ross 308 broiler chickens[1].

Items[2]	Treatments			SEM	P-value
	CON[3]	LPA	LPB		
BW, gm/bird					
Day 1	41.32	41.32	41.34	0.006	0.293
Day 10	307.33 ^{a}	295.39 ^{b}	297.35 ^{b}	1.663	0.001
Day 24	1367.34	1399.46	1361.61	9.599	0.232
Day 34	2498.59 ^{a}	2474.54 ^{ab}	2401.61^{b}	16.723	0.036
AWG, gm/bird					
Day 1-10	266.01 ^{a}	254.07 ^{b}	256.01 ^{b}	1.665	0.001
Day 11-24	1060.00	1104.07	1064.25	10.338	0.160
Day 25-34	1131.25 ^{a}	1075.08 ^{ab}	1040.00 ^{b}	14.1796	0.018
Day 1-34	2457.27 ^{a}	2433.22 ^{ab}	2360.26 ^{b}	16.726	0.036
AFI, gm/bird					
Day 1-10	327.63	323.14	326.77	1.438	0.426
Day 11-24	1375.64	1383.40	1342.40	9.255	0.159
Day 25-34	1628.22	1628.11	1548.92	14.881	0.031
Day 1-34	3331.49 ^{a}	3334.66 ^{a}	3218.09 ^{b}	20.208	0.016
FCR					
Day 1-10	1.23 ^{b}	1.27 ^{a}	1.28 ^{a}	0.007	0.008
Day 11-24	1.30 ^{a}	1.25 ^{b}	1.26 ^{b}	0.006	0.004
Day 25-34	1.44	1.51	1.49	0.016	0.139
Day 1-34	1.36	1.37	1.40	0.008	0.090
Uniformity, %					
Day 34	25.14	27.98	18.18	2.377	0.233

[1] n=6; SEMs: Standard error of means for each item. ^{ab}Mean values in the same row with a different superscript differ significantly at $P < 0.05$.
[2] BW, body weight; ABWG, Average weight gain; AFI, Average feed intake; FCR, Feed conversion ratio.
[3] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Table 5
Effects of co-extruded flaxseed and pulse mixture on fatty acid profile in breast meat of Ross 308 broiler chickens[1].

Items, g/100g[2]	Treatments			SEM	P-value
	CON[3]	LPA	LPB		
TFA	4.41	4.70	4.93	0.225	0.662
SFA					
C14:0 Myristic acid	0.03	0.02	0.02	0.003	0.476
C16:0 Palmitic acid	0.91	0.87	0.99	0.058	0.663
C18:0 Stearic acid	0.23	0.22	0.24	0.011	0.784
MUFA					
C16:1 Palmtoleic acid	1.59	1.66	1.76	0.013	0.903
C18:1 Oleic acid	0.01	0.01	0.03	0.083	0.700
C20:1 Eicosenoic acid	1.11	1.17	1.14	0.006	0.417
PUFA, ω-6					
C18:2 Linoleic acid	1.11	1.17	1.14	0.054	0.916
C18:3 Gamma-linolenic acid	0.01	0.01	0.01	0.001	0.034
C20:2 Eicosadienoic acid	0.01	0.01	0.02	0.001	0.116
C20:4 Arachidonic acid	0.04^{a}	0.04^{a}	0.03^{b}	0.001	0.001
PUFA, ω-3					
C18:3 Alpha-linolenic acid	0.07^{c}	0.17^{b}	0.26^{a}	0.016	<0.001
C22:5 Docosapentaenoic acid	0.01	0.01	0.01	0.000	0.422
Total SFA	1.16	1.11	1.25	0.067	0.704
Total MUFA	1.81	1.90	2.02	0.098	0.700
Total PUFA	1.28	1.44	1.51	0.064	0.348
Total ω-6 PUFA	1.20	1.25	1.22	0.055	0.925
Total ω-3 PUFA	0.08^{c}	0.19^{b}	0.29^{a}	0.018	<0.001
SFA:PUFA	0.903	0.765	0.834	0.027	0.111
ω-6: ω-3	14.56^{a}	6.58^{b}	4.16^{c}	0.835	<0.001

[1] n=10; SEMs: Standard error of means for each item. ^{ab}Mean values in the same row with a different superscript differ significantly at $P < 0.05$.
[2] TFA, total fatty acids content; SFA, saturated fatty acids; MUFAs, mono-unsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA:PUFA: ratio of saturated fatty acids to unsaturated fatty acids; and ω-6:ω-3: ratio of omega-6 polyunsaturated fatty acids to omega 3 polyunsaturated fatty acids.
[3] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Carcass yield and carcass quality

Birds fed with LPB exhibited lower the pH value in breast meat at 24 h post-slaughter compared with the CON group ($P = 0.029$; Table 7). Moreover, LPB treatment had lower breast WHC compared with the CON group ($P = 0.02$) and lower leg WHC than the LPA treatment ($P = 0.049$). In addition, both LPA and LPB treatments had greater CL in leg

Table 6
Effects of co-extruded flaxseed and pulse mixture on fatty acid profile in leg meat of Ross 308 broiler chickens[1].

Items, g/100g[2]	Treatments			SEM	P-value
	CON[3]	LPA	LPB		
TFA	8.99	10.38	10.31	0.306	0.112
SFA					
C14:0 Myristic acid	0.04	0.04	0.04	0.001	0.931
C16:0 Palmitic acid	1.86	2.06	2.02	0.061	0.369
C18:0 Stearic acid	0.44	0.47	0.49	0.013	0.243
MUFA					
C16:1 Palmtoleic acid	0.45	0.51	0.49	0.018	0.425
C18:1 Oleic acid	3.21	3.67	3.71	0.115	0.141
C20:1 Eicosenoic acid	0.03	0.03	0.03	0.001	0.350
PUFA, ω-6					
C18:2 Linoleic acid	2.31	2.65	2.40	0.079	0.196
C18:3 Gamma-linolenic acid	0.02	0.02	0.02	0.001	0.327
C20:2 Eicosadienoic acid	0.019[b]	0.022[ab]	0.026[a]	0.001	0.004
C20:3 gamma-eicosatrienoic acid	0.02	0.02	0.02	0.001	0.339
C20:4 Arachidonic acid	0.07[a]	0.07[a]	0.059[b]	0.002	0.005
C22:4 Docosatetraenoic acid	0.02[a]	0.01[b]	0.01[b]	0.001	<0.001
PUFA, ω-3					
C18:3 Alpha-linolenic acid	0.16[c]	0.39[b]	0.57[a]	0.033	<0.001
C22:5 Docosapentaenoic acid	0.01[b]	0.02[a]	0.02[a]	0.001	<0.001
Total SFA	2.34	2.57	2.55	0.074	0.364
Total MUFA	3.70	4.22	4.24	0.133	0.168
Total PUFA	2.64[b]	3.23[a]	3.15[a]	0.099	0.024
Total ω-6 PUFA	2.47	2.80	2.54	0.081	0.207
Total ω-3 PUFA	0.17[c]	0.42[b]	0.61[a]	0.036	<0.001
SFA:PUFA	0.89[a]	0.80[b]	0.81[b]	0.015	0.017
ω-6:ω-3	14.57[a]	6.61[b]	4.15[c]	0.828	<0.001

[1] n=10; SEMs: Standard error of means for each item. [ab]Mean values in the same row with a different superscript differ significantly at $P < 0.05$.
[2] TFA, total fatty acids content; SFA, saturated fatty acids; MUFAs, mono-unsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA:PUFA: ratio of saturated fatty acids to unsaturated fatty acids; and ω-6:ω-3: ratio of omega-6 polyunsaturated fatty acids to omega 3 polyunsaturated fatty acids.
[3] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

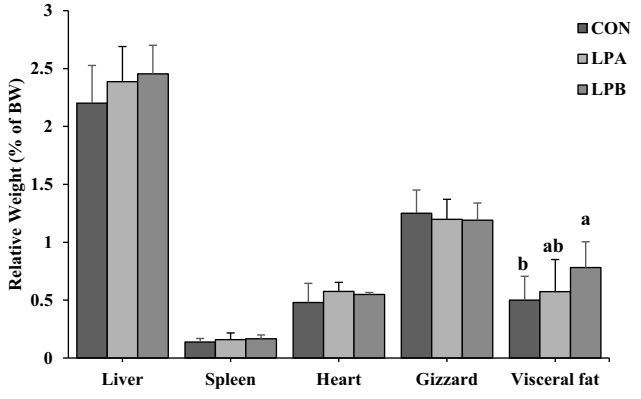

Fig. 1. Effects of co-extruded flaxseed and pulse mixture on relative organ weight of Ross 308 broiler chickens ($n = 12$). [ab]Mean values and standard error of the mean (SEM) with a different superscript differ significantly at $p < 0.05$. CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

meat than the CON group ($P = 0.003$). Moreover, the leg meat yellowiness (b*) was higher in the LPA treatment than in the CON and LPB treatments ($P = 0.003$).

Texture and sensory attributes

Inclusion of LPB in diet resulted in higher breast meat hardness and gumminess compared with the CON group ($P = 0.004$ and $P = 0.007$, respectively; Table 8). However, no significant differences were observed on other texture profile in breast and texture attributes in leg meat among the groups. In addition, inclusion of LinPRO-24 did not affect the sensory parameters in breast and leg meat in this study (Fig. 2).

Table 7
Effects of co-extruded flaxseed and pulse mixture on carcass yield and carcass quality of Ross 308 broiler chickens[1].

Items[2]	Treatments			SEM	P-value
	CON[3]	LPA	LPB		
Live wt, g	2348.30	2414.60	2342.40	16.413	0.136
Carcass wt 1 h, g	1894.50	1941.80	1886.50	14.656	0.258
Carcass wt 24 h, g	1865.70	1912.30	1853.40	13.551	0.176
Dressing %	80.69	80.41	80.55	0.322	0.942
DL, %	1.51	1.51	1.72	0.167	0.846
Carcass Yield, %					
Breast	26.34	26.62	26.86	0.288	0.774
Legs	25.78	25.74	25.85	0.205	0.975
Head and Neck	7.06	6.79	6.77	0.086	0.325
Medical Muscle	4.51	4.71	4.80	0.061	0.126
Wings	9.30	8.90	9.29	0.075	0.038
Feets	4.13	3.97	4.19	0.049	0.162
Thoracic Skeleton	22.55	23.15	22.17	0.204	0.142
Breast					
pH 24 h	6.15 [a]	6.02 [ab]	5.96 [b]	0.030	0.029
L*	53.97	55.12	55.02	0.502	0.602
a*	1.39	1.44	1.59	0.132	0.831
b*	6.58	8.67	7.72	0.369	0.063
CL, %	20.65	24.08	22.54	0.866	0.278
WHC, %	57.17 [a]	54.07 [ab]	48.09 [b]	1.391	0.020
Leg					
pH 24 h	6.34	6.19	6.19	0.030	0.046
L*	56.24	53.92	54.63	0.535	0.198
a*	3.43	3.90	3.96	0.134	0.217
b*	6.41 [b]	8.56 [a]	6.08 [b]	0.344	0.003
CL, %	22.59 [b]	28.34 [a]	26.3 [a]	0.742	0.003
WHC, %	63.88 [ab]	68.15[a]	61.17 [b]	1.192	0.049

[1] n=10; SEMs: Standard error of means for each item. abMean values in the same row with a different superscript differ significantly at $P < 0.05$.
[2] Live wt, live weight; carcass wt, carcass weight; DL, dripping loss; L*, lightness; a*, redness; b*, yellowiness; CL, cooking loss; and WHC, water holding capacity.
[3] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Table 8
Effects of co-extruded flaxseed and pulse mixture on sensory attributes of breast and leg meats in Ross 308 broiler chickens[1].

Items	Treatments			SEM	P-value
	CON[2]	LPA	LPB		
Breast					
Shear force, N	673.97	679.17	692.67	13.308	0.849
Hardness, N	758.09 [b]	908.29 [ab]	1015.42 [a]	33.821	0.004
Springiness, cm	0.91	1.04	0.94	0.041	0.420
Cohesiveness	0.82	0.82	0.80	0.005	0.557
Gumminess, N	616.28 [b]	732.38 [ab]	814.53 [a]	27.318	0.007
Chewiness, N cm	567.56	792.74	768.08	46.434	0.091
leg					
Shear force, N	469.71	561.47	546.76	16.723	0.049
Hardness, N	573.95	596.21	654.44	14.537	0.060
Springiness, cm	0.93	0.86	0.88	0.020	0.374
Cohesiveness	0.77	0.76	0.76	0.006	0.598
Gumminess, N	445.77	452.15	496.68	10.715	0.105
Chewiness, N cm	391.79	393.31	440.78	10.429	0.089

[1] n=10; SEMs: Standard error of means for each item. [ab]Mean values in the same row with a different superscript differ significantly at $P < 0.05$.
[2] CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

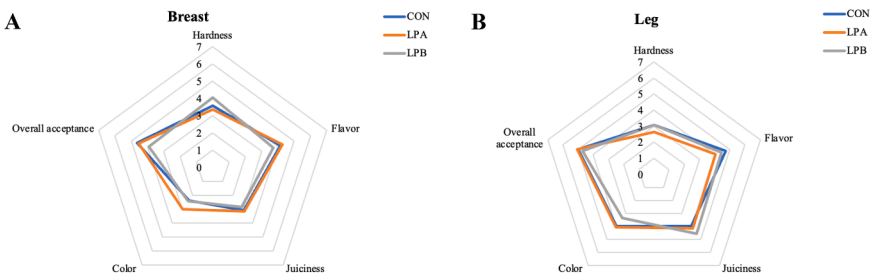

Fig. 2. Effects of co-extruded flaxseed and pulse mixture on sensory attributes of breast and leg meat at 24 h post-slaughter in Ross 308 broilers chickens ($n = 14$). CON, basal diet; LPA, basal diet with 2.5% LinPRO-24; LPB, basal diet with 5.0% LinPRO-24.

Discussion

The current experiment evaluated the effects of extruded flaxseed-based ingredient (LinPRO-24) supplementation at 2.5% and 5.0% on production parameters, fatty acids composition, carcass quality, and meat quality in broiler chickens. LinPRO-24 supplementation improved the ω-3 PUFA content in both breast and leg meat. However, 5.0% inclusion level (LPB) negatively affected the production parameters, physical and textural qualities of broilers meat. Nevertheless, incorporating LinPRO-24 at 2.5% (LPA) had no influence on growth performance and textural qualities of meat with minimal effects on physical characteristics of broiler meat in this study.

The gut integrity is still immature and developing with limited microbial abundance and diversity during the starter phase of the bird (Fuller, 1989). Thus, the presence of ANFs in diet, such as those in flaxseed, can increase the digesta viscosity and impair the nutrient absorption during an early stage of their development. Nevertheless, extrusion of flaxseed inactivates the heat-labile non-nutritive factors and improves the nutrient digestibility (Frías et al., 2011). Giacomino et al. (2013) reported that extrusion processing considerably reduces the trypsin inhibitor but does not influence phytic acid content. Taking together, the extrusion process does reduce ANFs, but residual levels may still negatively impact birds, particularly in the early stages of growth. The current study demonstrated that supplementation of LinPRO-24 (LPA and LPB) negatively affected the growth indices in birds during the starter phase. Overall, birds fed with higher inclusion of LinPRO-24 (LPB) treatment had compromised growth indices compared with CON group in this experiment. Consistent with our findings, Anjum et al. (2013) concluded the reduction in body weight gain, feed intake, and FCR with a linear increase in extruded flaxseed concentration from 5 to 15% in broilers diet. The impaired growth performance in birds may be attributed to reduced feed intake resulting from higher fat content in diet and presence of ANFs, which may limit energy availability (Rodriguez et al., 2001; Zuidhof et al., 2009). Nabati et al. (2025) reported that ANFs can impair protein synthesis and lipogenesis, thereby reducing nutrient digestibility and utilization, which ultimately leads to decreased growth performance in broilers. These findings suggest that the reduced performance observed in the LPB group may be partially associated with residual anti-nutritional components or altered nutrient utilization efficiency. However, the digestibility of LinPRO-24 within the broiler gastrointestinal tract was not evaluated in this study, which could be an area of research for future studies. However, incorporating lower concentration of LinPRO-24 did not alter overall growth performance and uniformity in this study. Konieczka and Smulikowska (2017)) proposed that supplementing lower concentration of flaxseed (< 6%) does not compromise overall growth performance in broilers. The current findings suggest incorporating LinPRO-24 at 2.5% could be an effective strategy during the grower and finisher phases of the poultry production.

The current study illustrated that the fatty acid composition of the diet was reflected in the fatty acid profile of the meat, which corresponds to previous findings (Taulescu et al., 2010; Kostadinović et al., 2016; Maina et al., 2023). There was a linear increase in ALA content in treatment diets. Consequently, birds fed with LPB diet exhibited the highest ALA contents in both breast and leg meat, followed by those fed with LPA diet, with both treatments exceeding the CON group. These results indicate that the increased dietary ALA provided by LinPRO-24 was efficiently absorbed in the gut and deposited in muscle tissues (Jia et al., 2010; Slominski et al., 2006; Mir et al., 2018a). Kostadinović et al. (2016) also reported that inclusion of 2.5 and 5.0% extruded flaxseed significantly enhanced the ALA deposition in broiler breast meat, supporting the current findings. The report from Lyon Heart Study revealed positive health benefits of ALA consumption and meat products enriched in ALA may positively contribute to human health (De Lorgeril et al., 1999). Although dietary analysis indicated no detectable DPA and EPA in the treatment diets, their presence in meat suggests that dietary ALA supported the endogenous synthesis of long-chain ω-3 fatty acids, including DPA in breast meat and EPA in leg meat via desaturase enzymes of treatment birds (Sprecher, 2000). The recommended dietary ω-6:ω-3 ratio for improved health is below 4:1 (Kostadinović et al., 2016). Notably, the higher concentration of LinPRO-24 (LPB) met, and lower concentration (LPA) approached the recommended ω-6:ω-3 ratio in both breast and leg meat for optimal health benefits in this study. Consistent with these findings, previous studies have reported reduction in the ω-6:ω-3 ratio following flaxseed supplementation at 10% inclusion rate (Mir et al., 2017a, 2018a; Kumar et al., 2020). Collectively, these findings suggest that increasing dietary levels of LinPRO-24 linearly enhanced the ω-3 PUFA deposition in broiler muscle, thereby reducing the ω-6:ω-3 ratio and improving meat quality. Additionally, the total PUFA content in leg meat was higher in treatment groups, thereby resulting in a more favorable SFA:PUFA ratio. Previous studies also concluded that flaxseed supplementation markedly increases PUFA content in broiler meat (Jia et al., 2010; Anjum et al., 2013). Moreover, the differential incorporation of fatty acids between the breast and leg meat can be attributed to variations in phospholipid and triacylglycerol content between these muscles (Konieczka and Smulikowska, 2017). This study indicated that feeding LinPRO-24 enhances the deposition of ω-3 PUFA into the lipids of the leg meat than that of breast, likely because leg muscle has two to three times more total lipids. Additionally, linoleic acid is preferentially incorporated into the triacylglycerol fraction, which is more abundant in leg tissue (Apperson and Cherian, 2017; Konieczka and Smulikowska, 2017).

Supplementation with LPB promoted the visceral fat deposition in this experiment, indicating altered adipose accumulation in broilers. In contrast to our finding, previous studies have reported that incorporating flaxseed in diet reduces the fat accumulation due to increased lipid oxidation rate and reduced endogenous fatty acid synthesis in broilers (Rebolé et al., 2002; Zając et al., 2020). Nevertheless, Duarte et al. (2014) also observed that inclusion of flaxseed oil in an iso-caloric diet increased visceral fat percentage in 42-day-old broilers. The pH of the meat is an important indicator that influences various carcass traits, including water retention and meat texture (Devatkal et al., 2019). The standard pH range for broilers breast meat at 24 h post-slaughter falls in the range of 5.00 to 6.00 (Albergamo et al., 2022). In the current study,

the pH value of CON group was 6.15±0.15, indicating towards dark, firm, and dry (DFD) meat formation, which is associated with poor storage quality. However, the pH values in LPA and LPB treatments were reduced to 6.02 and 5.96, respectively, and were within the normal range, which denotes acceptable meat quality. The WHC is another crucial parameter reflecting the ability of meat to retain moisture, thereby directly influencing processing yield and meat quality. The current study demonstrated supplementing higher concentration of LinPRO-24 negatively affected the muscle water retention, as evidenced by lower WHC in breast meat, lower WHC and higher CL in leg meat. In addition, LPA treatment was also associated with elevated CL in leg meat. A decline in muscle pH can promote protein denaturation, protein solubility, and decrease the availability of reactive sites for water binding, which collectively led to lower WHC (Wismer–Perdersen, 1986). Thus, the lower muscle pH in treatment groups may have contributed to reduced water retention in meat of treatment birds. Tekin et al. (2025) also proposed that muscle pH is closely associated with WHC in broiler meat. Flaxseed-based diets have also been reported to influence water retention capacity, potentially due to increased lipid deposition and enhanced susceptibility to lipid oxidation in muscle tissues (Albergamo et al., 2022). However, oxidative status and protein denaturation were not directly assessed in this study. The reduced pH may partly explain the observed changes in WHC, the underlying mechanisms remain speculative. Future studies evaluating oxidative stability and protein structural changes would provide a comprehensive understanding of the effects of LinPRO-24 on meat quality. Moreover, the yellowish color in leg meat of LPA treatment was higher than other treatments, which is similar to the finding of Anjum et al. (2013). These data suggest that the LinPRO-24, particularly at 5%, affects the water retention of the meat, which could affect the meat quality and its shelf life. Nevertheless, no significant differences were observed on carcass yield and carcass quality among the groups.

It is desirable to retain as much water as possible in meat to improve juiciness, firmness, tenderness, and appearance for better meat quality and its economic value (Tekin et al., 2025). The texture profile analysis of breast meat showed that birds fed with LPB had lowered meat tenderness and inferior meat quality as evidenced by higher hardness and gumminess values. The lower WHC and higher DL observed in the breast meat of LPB treatment may have attributed to tougher meat formation likely due to poor water bounding to muscle proteins and shrinkage of myofibrils in this study (Mir et al., 2017a). Yu et al. (2025) reported that woody breast meat, which is characterized by higher muscle hardness and chewiness, is associated with reduced WHC, elevated lipid and protein oxidation, and impaired myofibrillar structures in broilers. However, LinPRO-24 did not alter texture attributes in leg meat along with sensory properties in both breast and leg meat in this study. Previous research on flaxseed meals also highlighted non-significant effects on the sensory qualities of breast meat in broilers (Mridula et al., 2011, 2015). In contrast, Albergamo et al. (2022) proposed that extruded flaxseed meal at $\geq$ 5% could negatively influence the sensory parameters of the breast meat and inclusion in between 2.5 and 3.13% could ameliorate sensory alterations in animal products. Collectively, the current findings highlight that inclusion of LinPRO-24 at 5.0% negatively affected carcass and meat qualities, while incorporating at 2.5% minimize the effects in broilers.

In conclusion, supplementation of extruded flaxseed-pulse mixture (LinPRO-24) at 2.5% did not affect the overall growth performance or meat texture profile of broilers, with minimal effects on the physical characteristics of meat. In contrast, a higher inclusion level of 5.0% negatively affected overall growth performance and reduced water retention in meat, ultimately diminishing the texture quality of the meat. Nevertheless, inclusion of LinPRO-24 in the diets linearly enhanced ω-3 PUFA deposition in muscle tissues, resulting in higher total ω-3 PUFA content and lower ω-6:ω-3 ratio in broiler meat. Notably, dietary inclusion of LinPRO-24 resulted in greater enrichment of the fatty acid profile in leg meat than in breast meat. Taking together, it can be concluded that formulating 2.5% LinPRO-24 in the diets appears to be an effective strategy to enhance ω-3 deposition in muscle tissue and promote consumer health without compromising growth performance or carcass quality in broilers. However, protein structural changes and oxidative stability in broiler meat were not evaluated in the present study, which represents a limitation of this experiment. Thus, this study provides a foundation for future research, and further studies assessing these indices are required to elucidate the effects of LinPRO-24 on meat quality of broiler chickens.

Data availability

Data will be made available upon request.

CRediT authorship contribution statement

Bishnu Prasad Bhattarai: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Chi Yu:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Conceptualization. **Chao-Wei Huang:** Writing – review & editing, Supervision, Resources, Methodology. **Elijah G. Kiarie:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Funding acquisition. **Jai-Wei Lee:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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