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Different lines of camelina (*Camelina sativa* (L.) Crantz) in broiler quails' diets: effects on meat physicochemical traits and sensory profile

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ABSTRACT

The present study investigated the effect of *Camelina sativa* cake dietary inclusion on quail meat fatty acids (FA), amino acids (AA), and sensory characteristics. To this, 480 broiler quails were allocated to four dietary treatments (12 replicated cages/treatment): a control diet (Control) and three diets with 15% camelina cake, containing a commercial cultivar (Calena) and two improved lines (Pearl: low linoleic acid; Alan: low glucosinolates). After slaughter, breast meat FA and AA profiles and contents were analysed, alongside a sensory evaluation by trained panellists. The dietary inclusion modified breast meat FA profile and contents ($p < .001$), notably increasing α-linolenic acid (C18:3 *n*-3), which improved overall *n*-3 PUFA and reduced the *n*-6/*n*-3 ratio to recommended levels. Health indices improved in a line-dependent manner: atherogenicity lowered in Alan compared to Control and Calena ($p < .01$), while thrombogenicity reduced in all camelina treatments than the Control ($p < .001$). Camelina-fed groups showed an AA profile in line with the Control one, and Pearl displayed a higher essential AA content compared to Alan ($p < .05$). Sensory results indicated no substantial changes in meat attributes across treatments, except for tenderness and animal fat flavour: the first lowered in Alan meat compared to the Control ($p < .05$), while the latter was higher in the Control than in Alan and Calena groups ($p < .01$). In conclusion, the 15% dietary inclusion of different camelina cakes in quail diets positively influenced meat FA, enhancing product healthiness without negatively impacting its nutritional quality and sensory attributes. Findings indicated that camelina cake is an effective feedstuff to improve quail meat quality.

HIGHLIGHTS

- Once fed to quails, all tested camelina cakes increased meat *n*-3 PUFA and reduced the *n*-6/*n*-3 by about 5 and 7 times, respectively.
- Meat atherogenicity and thrombogenicity indices of camelina-fed quails improved, indicating enhanced product healthiness.
- Camelina inclusion did not alter quail meat sensory attributes compared to the control group.

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Camelina; quail; nutrition; meat quality; sensory

Introduction

One of the biggest challenges of modern poultry farming is to sustainably provide high quality meat, as sustainably as possible. In the last years the poultry sector has been experiencing an overall growing interest in novel feedstuffs to obtain healthier poultry products (i.e. enriched in *n*-3 PUFA). This because human's dietary intake of the long-chain, *n*-3 polyunsaturated fatty acids (PUFA), especially eicosapentaenoic acid (EPA; C20:5 *n*-3) and docosahexaenoic acid (DHA; C22:6 *n*-3), is implicated in growth development and preventing cardiovascular diseases, and arthritis (Simopoulos 2011). The α-linolenic acid (C18:3 *n*-3) serves as a precursor for the biosynthesis of EPA and DHA. Pertinently, it has been demonstrated that chickens fed diets enriched with C18:3 *n*-3 exhibit inhibition of hepatic fatty acid synthase activity (Cui et al. 2019), which is a pivotal enzyme in fatty acids (FA) biosynthesis. On the other hand, the activity level of Δ6-desaturase in the chickens' liver is significant, therefore making it capable of synthesising long-chain FA starting from dietary C18:3 *n*-3.

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Referring to the sustainability aspect of modern poultry production, the industry has been experiencing significant growth which has generated an increasing demand for feedstuffs, including high-quality protein sources (FAOSTAT 2023). Traditionally, soybean meal has been the primary protein ingredient in poultry feed (Babatunde et al. 2021) due to its high nutritional value, widespread availability, and relatively favourable cost. Despite these advantages, the industry's reliance on soybean as a singular protein source presents several challenges. These include price volatility, potential supply chain disruptions, and concerns over environmental sustainability (long transport due to imports and feed-food competition). Therefore, diversifying feed ingredient sources helps to mitigate the risks associated with fluctuating global markets and to reduce dependency on soybean. This would represent one first aspect to meet the demands of modern poultry production. In addition, there is an increasing need to explore alternative feed ingredients that are not only cost-effective, but also nutritionally adequate and sustainable (van Huis and Oonincx 2017).

Camelina (*Camelina sativa*) also known as false flax, is a *Brassicaceae* family oilseed crop like mustard, rapeseed and canola. Camelina crop can be grown in temperate regions, where it can be used as a spring and winter crop. It has a short growing season (70–250 d from sowing to maturity), it displays a certain tolerance to frost and drought, and it requires a very low pesticide and fertilising input, thus making it a resilient crop which is suitable for sustainable production systems (Matteo et al. 2020). Thanks to its positive features, including an interesting oil composition (rich in *n*-3 FA), it has been receiving increasing interest as an oilseed feedstock for bio-based products and biofuels (Zanetti et al. 2021; Mondor and Hernández-Álvarez 2022; Singh et al. 2023).

Camelina cake, a by-product of camelina seed pressing, is becoming increasingly more available for animal feeding, especially for poultry industry, because of its interesting nutritional profile: a high crude protein (35.2 ± 2%) content, source of essential amino acids such as arginine, cystine, lysine, methionine, and threonine (Aziza et al. 2014), and energy (16.9 ± 5 MJ/kg). Camelina cake has a residual 10–22% oil, whose FA are approximately constituted of a 30–35% C18:3 *n*-3 (Singh et al. 2023). In addition, it is also richer in antioxidants and phenolic compounds compared to common oilseed crops (Zanetti et al. 2021; Singh et al. 2023).

Parallel to its favourable nutritional aspects, camelina is known to contain also anti-nutritional compounds such as erucic acid (C22:1 *n*-9), glucosinolates, phytates, sinapine, and other related phenolic acids (Russo and Reggiani 2012). These constituents are associated in adverse effects on nutrient absorption and utilisation by elevating digesta viscosity, thereby lowering the nutrients and energy digestibility (Singh et al. 2023). Moreover, erucic acid is linked to myocardial lipidosis in cardiac muscle, while glucosinolates may affect thyroid and hepatic functions in livestock fed with camelina (Nain et al. 2015; Cullere et al. 2023). The negative effects associated to an excessive dietary intake of camelina cake have recently been demonstrated in a recent study (first part of the present research), where a 15% dietary incorporation of different camelina cakes can negatively affect the live performance of quails (Cullere et al. 2023). In the second part of the research, which is the topic of the present manuscript, a comprehensive evaluation of the effects of the different camelina cakes on detailed meat quality aspects and sensory attributes is carried out, which are relevant for both consumers' acceptance as well as for marketing purposes, ultimately allowing to assess the full potential of incorporating *Camelina sativa* into broiler quail's diet. This investigation is required also because, overall, limited research has been conducted to investigate the impact of camelina and its by-products on the quality of chicken (Juodka et al. 2022), and quail (Juodka et al. 2023) meat.

Materials and methods

Experimental design

The research was approved by the Ethical Committee of the University of Padova (Prot. n. 362845). Also, the study was carried out in accordance with article 2, DL 4 March 2014, No. 26 of the Official Journal of the Italian Republic, implementing the EC Directive 86/60963/2010 EU regarding the protection of animals used for experimental and other scientific purposes.

The *in vivo* trial was conducted in an educational farm located in the Padova province (Italy), which has a scientific agreement with the Department of Animal Medicine, Production and Health - MAPS (University of Padova, Italy). A detailed description of the origin, chemical composition, and energy content of camelina cakes, as well as dietary specifications, performance trial and *in vivo* data collection, slaughter

specifications, carcase dissection and samples preparation are reported in the manuscript presenting the first part of the research (Cullere et al. 2023).

Fatty acid profile of camelina cakes, diets, and meat

After quails' slaughtering, from each carcase, breasts were dissected and ground by 3 (within experimental group) with a Retsch® Grindomix GM 200 (7000 g for 10 s) in order to have enough sample to perform all the scheduled analyses. Afterwards, ground meat samples were freeze-dried and ground again to a fine powder. A total of $n = 12$ meat samples/treatment were dedicated to FA analysis. The lipid extractions were performed by Modified Accelerated Solvent Extraction, in which hexane (camelina cakes), petroleum ether (experimental diets) or a binary solvent mixture of chloroform/methanol 2:1 (meat) were the solvents used for extraction. The fat content of the sample was determined gravimetrically after vacuum-evaporation. Samples were trans-methylated using a methanolic solution of H_2SO_4 (4%) in order to determine fatty acid methyl esters (FAME). A biphasic separation was obtained by adding 0.5 mL of distilled water and 1.5 mL of n-heptane to each sample. FAME were quantified by gas chromatography (Shimadzu GC17A), equipped with an Omegawax (Sigma-Aldrich Co. LLC., Saint Louis, USA) 250 column (30 m × 0.25 μm × 0.25 μm) and flame ionisation detector. Helium was used as the carrier gas at a constant flow of 0.8 mL/min. The injector and detector temperatures were 260 °C. Peaks were identified based on commercially available FAME mixtures (37–Component FAME Mix; Supelco Inc., Bellefonte, PA, USA). Results were expressed as % of the total detected FAME. Furthermore, the quantitative determination of meat samples FA (mg/100 g meat) was also conducted by using the chromatographic peak area according to the internal standard (nonadecylic acid: C19:0) method and the total lipid content of the sample. The atherogenic index (AI) and thrombogenic index (TI) (Ulbricht and Southgate 1991), peroxidability index (PI; Arakawa and Sagai 1986) and hypocholesterolemic/hypercholesterolemic (hH; Santos-Silva et al. 2002) of meat samples were calculated.

Amino acid profile of camelina cakes, diets, and meat

A total of $n = 6$ meat samples/treatment (each sample was composed of $n = 3$ breasts) were dedicated to amino acid (AA) analysis. The AA composition of camelina cakes, experimental diets, and quail breast meat samples was assessed after acid hydrolysis and pre-column derivatisation using 6–aminoquinolyl-N-hydroxysuccinimidyl carbamate, separated by RP-HPLC and analysed by ultraviolet detection (Agilent 1260 Infinity, Agilent Technologies, Santa Clara, CA, USA) following an adapted method from European Pharmacopoeia (Council of Europe 2005), and by using 6 M HCl at 105 °C for 24 h to hydrolyse samples. Differently, cysteine was determined by the sum of cysteine and cystine, after reaction with dithiodipropionic acid, producing a mixed disulphide, which then underwent acid hydrolysis. After hydrolysis, samples were neutralised with 8 M NaOH, and volume was adjusted and filtered at 0.45 μm. Then, the derivatisation step was conducted according to the manufacturer's instructions (AccQ-Tag Ultra Derivatisation Kit; Waters, Milford, MA). The obtained results were expressed as g/100 g breast meat.

Meat sensory profile

Quail breasts were subjected to a descriptive sensory analysis, to detect possible differences among the dietary treatments (Control *vs* Calena *vs* Pearl *vs* Alan). A total of 14 breasts per treatment were used (3 breasts/treatment/panellist). Panellists underwent two pre-test training sessions of 1 h each to familiarise with the matrix and select appropriate descriptors, also drawn from the literature. Olfactory, gustative, and textural aspects were evaluated, and the final list of descriptors was the following one: odour intensity, animal fat odour, flavour intensity, liver flavour, animal fat flavour, off-flavour intensity, liver, mustard and rancid off-odours, off-flavours intensity, mustard, cabbage, rancid and onion off-flavours, juiciness and tenderness. The quail breast meat used for the training sessions was purchased at a supermarket and was processed, stored, handled and cooked in the same manner of the samples which were used for the subsequent sensory analysis.

After two months of frozen storage at −40 °C, quail breasts were allowed to thaw for 16 h at +4 °C. A random three-digit code was assigned to each breasts sample for identification. The breast samples were *vacuum*-packaged in food-grade bag and cooked in a water bath at +80 °C, samples were cooked until the core temperature of the heaviest sample reached +74 °C. At the end of cooking, the samples were cooled with crushed ice for 30 min to stop the cooking reaction. Samples were kept at room temperature for

20 min then samples were randomly served to six panellists.

The panel received the list of descriptors to score on numerical and continuous scales from 0 (the lowest score for each attribute) to 10 (the highest score for each attribute). All the evaluations were performed in a room where the temperature was set at +22 °C. Unsalted crackers and still water at room temperature were available to panellists throughout each sensory session.

Statistical analyses

AA and FA profile data were subjected to a one-way ANOVA with experimental diets as fixed effect following the General Linear Model (GLM) procedure of SAS (SAS® OnDemand for Academics—3.81 Enterprise Edition, SAS Institute Inc., Cary, NC, USA). For sensory traits (odour, texture, and flavours) normally distributed data were subjected to a one-way ANOVA with experimental diets as fixed effect following the GLM. The least square means were obtained using the Bonferroni correction. Whereas non-normally distributed data were converted into rank data by assigning rank order number to the evaluations. Ranking data were analysed with a Friedman's test. A chi-square test with Marascuilo (1966) procedure was performed on off-odours and off-flavours characterisation to detect the differences among the treatments. For all statistical analyses significance was considered at a 5% confidence level.

Results

Fatty acids and amino acids of the camelina cakes and the experimental diets

Camelina cakes showed to have an FA profile particularly rich in PUFA, which averagely accounted for more than 57% of total FA (Table 1). Among them, *n*-3 FA accounted for and average 39% of total FA, with C18:3 *n*-3 being the main one: 38.9, 38.7 and 36.6% for Calena, Pearl, and Alan cakes, respectively. This generated a *n*-6/*n*-3 ratio of 0.47. Considering the other FA classes, MUFA and SFA accounted for about 33% and 8.78% of total FA, respectively. Among single MUFAs, it is worth to highlight that camelina cakes displayed an average 2.95% erucic acid (C22:1 *n*-9).

Out of an average 24.7 g amino acids/100 g product, the three camelina cakes displayed an average 45.5% of essential AA (Table 2), which were mainly represented by Arginine (2.21 g/100 g), Leucine (1.72 g/100 g), Lysine (1.23 g/100 g), Phenylalanine (1.12 g/100 g), and Threonine (1.11 g/100 g).

The presence of 15% camelina cakes in the experimental diets positively impacted their FA profile (Table 3). The most notable outcome concerned the *n*-3 proportion that improved from 5.45% of the Control diet to an average 26.2% of the camelina diets; consequently, the *n*-6/*n*-3 ratio lowered from an 8.63 of the Control diet to an average 1.04 of the camelina ones. As a result of the

Table 1. Fatty acids profile (% of total FAME) of Calena, Pearl, and Alan *Camelina sativa* cakes.

	Camelina cakes		
	Calena	Pearl	Alan
C16:0 (Palmitic)	5.16	5.18	5.77
C18:0 (Stearic)	2.14	2.31	2.13
C20:0 (Arachidic)	1.32	0.99	1.37
ΣSFA	8.62	8.47	9.26
C16:1 (Palmitoleic)	0.08	0.10	0.11
C18:1 *n*-9 (Oleic)	12.4	19.1	12.5
C18:1 *n*-7	0.71	1.00	0.94
C20:1 *n*-9 (Eicosenoic)	14.6	14.5	14.6
C22:1 *n*-9 (Erucic)	3.37	2.10	3.37
ΣMUFA	31.2	36.8	31.5
C18:2 *n*-6 (Linoleic)	16.1	12.5	16.8
C20:2 *n*-6 (Eicosadienoic)	1.88	1.03	1.93
C20:4 *n*-6 (Arachidonic)	1.66	1.20	1.69
C22:2 *n*-6 (Docosadienoic)	0.15	0.00	0.25
C18:3 *n*-3 (α-Linolenic)	38.9	38.7	36.6
C20:5 *n*-3 (Eicosapentaenoic)	0.29	0.22	0.31
C22:6 *n*-3 (Docosahexaenoic)	0.64	0.62	0.66
ΣPUFA	59.6	54.2	58.2
ΣUFA/ΣSFA	10.5	10.7	9.69
Σ*n*-6	19.8	14.7	20.6
Σ*n*-3	39.8	39.5	37.6
Σ*n*-6/Σ*n*-3	0.50	0.37	0.55
Identified, %	99.4	99.5	99.0

FAME: Fatty acid methly esters; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated Fatty Acids.

Table 2. Amino acid concentration (g/100 g, as fed) of Calena, Pearl, and Alan *Camelina sativa* cakes.

	Camelina cakes		
	Calena	Pearl	Alan
Essential amino acids			
Arginine	2.20	2.09	2.34
Cysteine	0.59	0.59	0.63
Histidine	0.87	0.75	0.89
Isoleucine	0.70	0.60	0.70
Leucine	1.72	1.60	1.85
Lysine	1.16	1.09	1.44
Methionine	0.20	0.21	0.22
Phenylalanine	1.08	1.08	1.21
Threonine	1.06	1.01	1.27
Tryptophan	0.33	0.35	0.34
Valine	0.96	0.81	0.98
Non-essential amino acids			
Alanine	1.14	1.08	1.35
Aspartic acid	2.35	2.25	2.71
Glycine	1.28	1.27	1.52
Glutamic acid	5.29	5.12	5.87
Proline	1.39	1.26	1.50
Serine	1.28	1.27	1.52
Tyrosine	0.56	0.50	0.61

Table 3. Fatty acids profile (% of total FAME) of the experimental diets.

	Experimental diets			
	Control	Calena	Pearl	Alan
C14:0 (Myristic)	0.09	0.06	0.04	0.05
C16:0 (Palmitic)	12.6	7.91	7.86	7.85
C17:0 (Margaric)	0.09	0.06	0.05	0.05
C18:0 (Stearic)	3.52	2.60	2.76	2.47
C20:0 (Arachidic)	0.49	1.20	0.95	1.14
C23:0 (Tricosylic)	0.10	0.35	0.14	0.36
ΣSFA	17.3	14.8	13.5	14.4
C14:1 (Myristoleic)	0.02	0.06	0.06	0.04
C16:1 (Palmitoleic)	0.16	0.10	0.12	0.11
C18:1 *n*-9 (Oleic)	25.1	16.2	22.2	16.5
C18:1 *n*-7	1.29	0.79	1.16	1.01
C20:1 *n*-9 (Eicosenoic)	1.32	11.1	11.0	10.6
C22:1 *n*-9 (Erucic)	0.27	2.65	1.65	2.46
ΣMUFA	28.1	28.2	34.5	28.3
C18:2 *n*-6 (Linoleic)	46.8	25.5	23.0	26.4
C20:2 *n*-6 (Eicosadienoic)	0.17	1.39	0.77	1.40
C20:4 *n*-6 (Arachidonic)	0.17	1.39	0.77	1.40
C18:3 *n*-3 (α-Linolenic)	5.26	26.5	25.6	26.0
C22:6 *n*-3 (Docosahexaenoic)	0.19	0.28	0.18	0.25
ΣPUFA	52.5	54.7	50.2	55.2
ΣUFA/ΣSFA	4.65	5.60	6.30	5.81
Σ*n*-6	47.0	28.0	24.5	29.0
Σ*n*-3	5.45	26.8	25.7	26.2
Σ*n*-6/Σ*n*-3	8.63	1.05	0.95	1.11
Identified, %	98.0	98.1	98.5	98.1

FAME: Fatty acid methly esters; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated Fatty Acids.

Table 4. Amino acids content (g/100 g, as fed) of the experimental diets.

	Experimental diets			
	Control	Calena	Pearl	Alan
Essential amino acids				
Arginine	1.48	1.37	1.27	1.57
Cysteine	0.21	0.20	0.19	0.24
Histidine	0.82	0.79	0.75	0.94
Isoleucine	0.76	0.67	0.64	0.79
Leucine	1.78	1.55	1.47	1.82
Lysine	1.55	1.40	1.31	1.68
Methionine	0.31	0.21	0.19	0.25
Phenylalanine	1.17	1.01	0.96	1.18
Threonine	0.99	0.87	0.83	1.04
Tryptophan	0.29	0.31	0.40	0.41
Valine	0.80	0.70	0.70	0.87
Non-essential amino acids				
Alanine	1.13	0.99	0.96	1.19
Aspartic acid	2.64	2.34	2.24	2.77
Glycine	1.39	1.21	1.22	1.45
Glutamic acid	5.19	4.53	4.34	5.26
Proline	1.29	1.12	1.06	1.32
Serine	0.90	0.79	0.75	0.92
Tyrosine	0.56	0.48	0.41	0.54

camelina cakes inclusion, Calena, Pearl and Alan diets showed an average 2.25% erucic acid. Differently for the FA profile, the overall AA profile of the Control diet seemed slightly superior that that of camelina diets (Table 4): the Control diet had 23.3 g/100 g diet total AA compared to 21.5 g/100 g diet of camelina ones, the latter showing also a lower essential AA content (9.53 g/100 g diets) than the Control (10.2 g/100 g diet).

Meat fatty acids

The dietary inclusion of camelina cake greatly modified the FA proportions (Table 5) of quail breast meat, with most singles FA and main classes being affected by the treatments. The difference, however, was not solely linked to the presence of camelina cake, but also depending on the camelina line. Specifically, SFA proportion was reduced in the Alan line compared to the Control and Calena meat, while Pearl showed an intermediate value (35.9 *vs* 36.0 *vs* 35.1 *vs* 33.9% for Control, Calena, Pearl, Alan meat, respectively; $p < .05$). Such result was attributable to the observed changes in C16:0 ($p < .001$), C20:0 ($p < .001$), C22:0 ($p < .01$), and C24:0 ($p < .001$). Total MUFA were the highest in the Control meat and the lowest in Calena and Alan, while Pearl was intermediate (29.3 *vs* 26.0 *vs* 27.4 *vs* 25.8% for Control, Calena, Pearl, Alan meat, respectively; $p < .01$). For MUFA, changes were mainly due to C18:1 *n*-9 ($p < .05$), and C16:1 ($p < .001$). Erucic acid was present in the meat of camelina-fed quails and not in the Control. Furthermore, a higher percentage of erucic acid was observed in Calena and Alan meat compared to Pearl one (0.00, 0.24, 0.22, 0.09, and for Control, Calena, Alan and Pearl, respectively; $p < .001$). The *n*-6 PUFA fraction decreased in the meat of camelina-fed quails compared to the Control, while the *n*-3 PUFA fraction increased, which was mainly attributable to the C18:3 *n*-3 ($p < .001$), C20:5 *n*-3 ($p < .001$) and C22:6 *n*-3 ($p < .001$). Also, C20:3 *n*-3 was significantly higher ($p < .001$) in camelina-fed quails compared to Control. As a consequence, it was observed a notable reduction ($p < .001$) in the *n*-6/*n*-3 ratio of Calena (3.10), Pearl (3.03) and Alan (2.63) meat compared to that of the Control (20.4).

As a result of the consistent changes in the FA profile according to the dietary treatment, the health indexes of quail breast meat were also influenced: the AI and the TI decreased ($p < .001$), thus improved, with the dietary inclusion of camelina cakes into the broiler quail diets ($p < .001$). Diversely, the meat PI index increased ($p < .001$), thus worsened, in the Calena (63.5) and Alan (69.8) groups compared to Pearl (54.7) and Control (51.2) ones. The hH index was affected by the dietary treatments too with Alan meat exhibiting a higher value than Control, Calena and Pearl ones ($p < .01$).

The proportional changes in FA associated with the dietary treatments were notable also in quantitative terms (mg/100 g meat), as presented in Table 6. The SFA ($p < .01$) and MUFA ($p < .01$) decreased in the breast meat of camelina-fed quails compared to the Control group. Among MUFAs, erucic acid was present

Table 5. Effect of the dietary inclusion of *Camelina sativa* cake into broiler quail's diet on the fatty acids profile (% FAME) and health indexes of breast meat.

	Experimental groups					
	Control	Calena	Pearl	Alan	RSD[1]	*p*-values
N.	12	12	12	12		
C14:0 (Myristic)	0.36	0.34	0.31	0.30	0.12	.6098
C15:0 (Pentadecylic)	0.07^{B}	0.12^{A}	0.07^{B}	0.09^{AB}	0.03	.0028
C16:0 (Palmitic)	22.5^{A}	21.7^{B}	20.7^{AB}	19.9^{B}	1.07	<.0001
C17:0 (Margaric)	0.16	0.18	0.17	0.15	0.03	.1691
C18:0 (Stearic)	12.0	12.7	13.1	12.7	0.98	.0574
C20:0 (Arachidic)	0.23^{B}	0.38^{A}	0.33^{A}	0.37^{A}	0.05	<.0001
C22:0 (Behenic)	0.29^{AB}	0.34^{Aa}	0.22^{B}	0.25^{ABb}	0.08	.0032
C24:0 (Lignoceric)	0.34^{A}	0.18^{B}	0.15^{B}	0.15^{B}	0.07	<.0001
ΣSFA	35.9^{a}	36.0^{a}	35.1^{ab}	33.9^{b}	1.71	.0173
C14:1 (Myristoleic)	0.07	0.05	0.06	0.05	0.02	.1031
C16:1 (Palmitoleic)	4.55^{A}	3.13^{B}	2.87^{B}	2.99^{B}	0.65	<.0001
C18:1 *n*-9 (Oleic)	22.7^{a}	19.0^{ab}	19.2^{ab}	18.7^{b}	3.39	.0208
C18:1 *n*-7	1.89	1.45	3.26	1.49	2.64	.3077
C20:1 *n*-9 (Eicosenoic)	0.19^{B}	2.19^{A}	1.98^{Ab}	2.29^{Aa}	0.24	<.0001
C22:1 *n*-9 (Erucic)	0.00^{C}	0.24^{A}	0.09^{B}	0.22^{A}	0.05	<.0001
ΣMUFA	29.3^{Aa}	26.0^{ABb}	27.4^{AB}	25.8^{B}	2.45	.0029
C18:2 *n*-6 (Linoleic)	24.3^{A}	21.0^{B}	19.9^{B}	21.0^{B}	1.37	<.0001
C20:2 *n*-6 (Eicosadienoic)	0.17^{B}	0.54^{A}	0.40^{AB}	0.64^{A}	0.22	<.0001
C20:3 *n*-6 (Dihomo-γ-linolenic)	0.36^{ABb}	0.44^{ABab}	0.30^{Bc}	0.49^{Aa}	0.11	.0007
C20:4 *n*-6 (Arachidonic)	4.43^{a}	3.55^{b}	3.67^{ab}	3.77^{ab}	0.72	.0220
C18:3 *n*-3 (α-Linolenic)	1.00^{C}	6.04^{B}	6.22^{B}	7.19^{A}	0.57	<.0001
C20:3 *n*-3 (Eicosatrienoic)	0.03^{B}	0.38^{A}	0.39^{A}	0.40^{A}	0.08	<.0001
C20:5 *n*-3 (Eicosapentaenoic)	0.16^{B}	0.93^{Ab}	1.03^{A}	1.13^{Aa}	0.16	<.0001
C22:6 *n*-3 (Docosahexaenoic)	0.56^{Bb}	0.97^{ABa}	0.81^{AB}	1.19^{A}	0.360	<.0001
ΣPUFA	31.1^{B}	33.9^{AB}	32.4^{ABb}	35.8^{Aa}	2.61	.0004
ΣUFA/ΣSFA	1.69^{ab}	1.67^{b}	1.71^{ab}	1.82^{a}	0.14	.0354
Σ*n*-6	29.3^{A}	25.5^{B}	24.3^{B}	25.9^{B}	2.03	<.0001
Σ*n*-3	1.75^{C}	8.32^{B}	8.07^{B}	9.91^{A}	0.84	<.0001
Σ*n*-6/Σ*n*-3	20.4^{A}	3.1^{B}	3.03^{B}	2.63^{B}	5.97	<.0001
AI	0.40^{A}	0.39^{ABa}	0.37^{AB}	0.34^{Bb}	0.03	.0016
TI	1.02^{A}	0.68^{B}	0.68^{B}	0.59^{B}	0.09	<.0001
PI	51.2^{B}	63.5^{Aa}	54.7^{ABb}	69.8^{A}	7.06	<.0001
hH	2.34^{ABb}	2.34^{ABb}	2.27^{B}	2.63^{Aa}	0.24	.0025
Identified, %	96.6	95.9	94.9	95.5		

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids; [1]Residual standard deviation; [2]AI: Atherogenicity index = (C12:0 + 4 x C14:0 + C16:0)/[total MUFA + total (n-6) + total (n-3)]; [3]TI: Thrombogenicity index = (C14:0 + C16:0 + C18:0)/[(0.5 x total MUFA) + 0.5 x (n-6) + 3 x (n-3/n-6)]; [4]PI: Peroxidability index = (% monoenoic x 0.025) + (% dienoic x 1) + (% trienoic x 2) + (% tetraenoic x 4) + (% pentaenoic x 6) + (% hexaenoic x 8); [5]hH: Hypocholesterolemic / Hypercholesterolemic index = (C18:1 n-9 + C18:2 n-6 + C20:4 n-6 + C18:3 n-3 + C20:5 n-3 + C22:5 n-3 + C22:6 n-3)/(C14:0 + C16:0); [A,B]Means in the same row with different superscript letters differ for $p < 0.01$; [a,b]Means in the same row with different superscript letters differ for $p < 0.05$.

solely in the meat of camelina-fed quails with a greater amount in Calena and Alan meat compared to that of Pearl ($p < .001$). Even if overall meat PUFA content remained unaffected, the total meat *n*-6 fraction was significantly reduced by the dietary presence of 15% camelina cake compared to the Control ($p < .001$), whereas the total *n*-3 PUFA followed the inverse trend ($p < .001$). The latter was attributable to the notables increases of C18:3 *n*-3 ($p < .001$), C20:3 *n*-3, and C20:5 *n*-3 ($p < .001$) in the meat of camelina-fed quails compared to that of Control quails.

Meat amino acids

The dietary incorporation of different *Camelina sativa* cakes into the broiler quails' diet influenced the AA composition of quail's breast meat (Table 7): leucine and lysine among the essential AA, and alanine, aspartic acid, glutamic acid, and proline among the non-essential ones. Specifically, the Pearl-fed group provided meat with better AA contents, with improved leucine ($p < .05$), lysine ($p < .01$), alanine ($p < .01$), aspartic acid ($p < .01$), glutamic acid ($p < .01$), and proline ($p < .05$) compared to the Alan group whereas, Control and Calena groups displayed intermediate values. Additionally, in the case of lysine, the Calena-fed group displayed a lower value compared to the Pearl group ($p < .05$).

Meat sensory profile

The dietary incorporation of *Camelina sativa* cakes into the broiler quails' diet did not modify the overall sensory traits of breast meat, including odour, flavour, texture, off-odour and off-flavour attributes (Table 8). The only exceptions were one textural and

Table 6. Effect of the dietary inclusion of *Camelina sativa* cake into broiler quail's diet on the fatty acids content (mg/100 g meat) of breast meat.

	Experimental groups					
	Control	Calena	Pearl	Alan	RSD[1]	*p*-values
N.	12	12	12	12		
C14:0 (Myristic)	6.60	4.69	5.11	4.61	2.35	.1504
C15:0 (Pentadecylic)	1.28	1.60	1.15	11.3	0.60	.3070
C16:0 (Palmitic)	415^{Aa}	297^{B}	337^{ABb}	300^{B}	68.6	.0003
C17:0 (Margaric)	2.86	2.41	2.81	2.29	0.56	.0577
C18:0 (Stearic)	219^{a}	173^{b}	213^{ab}	190^{ab}	37.3	.0148
C20:0 (Arachidic)	4.21^{b}	5.13^{ab}	5.39^{ab}	5.46^{a}	1.05	.0204
C22:0 (Behenic)	5.34^{a}	4.77^{ab}	3.61^{b}	3.84^{ab}	1.47	.0200
C24:0 (Lignoceric)	6.20^{A}	2.44^{B}	2.37^{B}	2.31^{B}	1.37	<.0001
ΣSFA	660^{A}	491^{B}	570^{AB}	510^{B}	107	.0015
C14:1 (Myristoleic)	1.38^{a}	0.67^{b}	0.92^{ab}	0.83^{ab}	0.56	.0210
C16:1 (Palmitoleic)	86.4^{A}	43.9^{B}	47.0^{B}	45.9^{B}	21.1	<.0001
C18:1 *n*-9 (Oleic)	422^{A}	261^{B}	322^{AB}	285^{B}	100	.0015
C18:1 *n*-7	35.0	19.9	36.0	22.7	30.9	.1590
C20:1 *n*-9 (Eicosenoic)	3.4^{B}	29.5^{A}	32.0^{A}	34.1^{A}	5.29	<.0001
C22:1 *n*-9 (Erucic)	0.00^{C}	3.18^{A}	1.62^{B}	3.31^{A}	0.85	<.0001
ΣMUFA	548^{Aa}	358^{B}	450^{AB}	392^{ABb}	118	.0017
C18:2 *n*-6 (Linoleic)	447^{A}	288^{B}	324^{B}	316^{B}	66.8	<.0001
C20:2 *n*-6 (Eicosadienoic)	3.17^{Bb}	7.14^{Aa}	6.42^{A}	9.250^{A}	3.19	.0004
C20:3 *n*-6 (Dihomo-γ-linolenic)	6.68	6.06	4.84	7.42	2.35	.0656
C20:4 *n*-6 (Arachidonic)	81.1^{Aa}	49.1^{B}	59.6^{ABb}	56.5^{B}	17.3	.0003
C18:3 *n*-3 (α-Linolenic)	18.7^{B}	83.2^{Ab}	101^{A}	108^{Aa}	20.2	<.0001
C20:3 *n*-3 (Eicosatrienoic)	0.55^{B}	5.16^{A}	5.53^{A}	5.89^{A}	1.36	<.0001
C20:5 *n*-3 (Eicosapentaenoic)	2.89^{B}	13.0^{A}	16.8^{A}	17.0^{A}	4.19	<.0001
C22:6 *n*-3 (Docosahexaenoic)	10.2	13.7	13.3	17.8	6.85	.0711
ΣPUFA	570	465	526	538	108	.1338
Σ*n*-6	537^{A}	350^{B}	395^{B}	389^{B}	83.3	<.0001
Σ*n*-3	32.4^{B}	115^{Ab}	131^{A}	149^{Aa}	28.5	<.0001

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; [1]Residual standard deviation; [A,B]Means in the same row with different superscript letters differ for $p < 0.01$; [a,b]Means in the same row with different superscript letters differ for $p < 0.05$.

Table 7. Effect of the dietary inclusion of *Camelina sativa* cake into broiler quail's diet on the amino acid content (g/100 g meat) of breast meat.

	Experimental groups					
	Control	Calena	Pearl	Alan	RSD[1]	*p*-values
N.	6	6	6	6		
Essential amino acids						
Arginine	1.16	1.17	1.18	1.07	0.09	.1429
Cysteine	0.14	0.15	0.14	0.13	0.01	.0588
Histidine	0.87	0.90	0.87	0.84	0.07	.4974
Isoleucine	0.68	0.69	0.70	0.62	0.06	.1106
Leucine	1.40^{ab}	1.39^{ab}	1.46^{a}	1.26^{b}	0.12	.0396
Lysine	1.75^{AB}	1.70^{ABb}	2.01^{Aa}	1.50^{B}	0.18	.0011
Methionine	0.50	0.51	0.50	0.46	0.04	.2627
Phenylalanine	0.75	0.77	0.68	0.73	0.06	.1196
Threonine	0.92	0.93	0.96	0.83	0.08	.0776
Tryptophan	0.14	0.14	0.14	0.13	0.01	.1746
Valine	0.70	0.72	0.72	0.64	0.07	.1215
Non-essential amino acid						
Alanine	0.99^{AB}	0.98^{AB}	1.08^{A}	0.88^{B}	0.09	.0091
Aspartic acid	1.74^{AB}	1.71^{AB}	1.93^{A}	1.53^{B}	0.17	.0049
Glycine	1.09	1.09	1.11	0.99	0.09	.0965
Glutamic acid	3.35^{AB}	3.31^{AB}	3.66^{A}	2.98^{B}	0.30	.0087
Proline	0.63^{ab}	0.62^{ab}	0.65^{a}	0.56^{b}	0.05	.0365
Serine	0.56	0.56	0.58	0.51	0.04	.0569
Tyrosine	0.65	0.66	0.64	0.61	0.05	.4262

[1]Residual standard deviation; [A,B]Means in the same row with different superscript letters differ for $p < 0.01$; [a,b]Means in the same row with different superscript letters differ for $p < 0.05$.

one flavour attributes: the breast meat from the Control group was scored more tender compared to the meat of the Alan group ($p < .05$), whereas the Calena and Pearl groups were intermediate. In the case of animal fat flavour, a higher value was recorded for the Control group compared to the Calena ($p < .001$) and Alan ones ($p < .05$), while Pearl was intermediate.

Table 8. Effect of the dietary inclusion of *Camelina sativa* cake into broiler quail's diet on the sensory* traits of breast meat.

	Experimental groups				
	Control	Calena	Pearl	Alan	*p*-values
N.	14	14	14	14	
Normally distributed (mm)[1]					
Odour:					
General	93.6 ± 3.35	89.7 ± 3.35	92.3 ± 3.35	96.2 ± 3.35	.5941
Animal fat	41.3 ± 3.70	38.3 ± 3.70	34.3 ± 3.70	38.6 ± 3.70	.6076
Texture:					
Juiciness	66.2 ± 5.73	75.3 ± 5.73	64.7 ± 5.73	67.3 ± 5.73	.5622
Tenderness	126.6 ± 3.66^{a}	118.3 ± 3.66^{ab}	114.4 ± 3.66^{ab}	110.7 ± 3.66^{b}	.0273
Flavour:					
General	115.6 ± 3.29	109.9 ± 3.29	108.4 ± 3.29	113.7 ± 3.29	.3978
Liver	34.4 ± 5.65	35.2 ± 5.65	36.9 ± 5.65	51.7 ± 5.65	.1219
Animal fat	52.3 ± 3.89^{Aa}	33.2 ± 3.89^{B}	41.1 ± 3.89^{AB}	36.8 ± 3.89^{ABb}	.0094
Non-normally distributed (mm)[2]					
Off-odour:					
General	7.00 (0–76)	27.0 (0–60)	15.0 (0–75)	0.00 (0–90)	.0644
Liver	17.0 (0–115)	27.0 (0–60)	15.50 (0–45)	15.0 (0–60)	.7362
Off-flavour:					
General	0.00 (0–91)	7.50 (0–75)	0.00 (0–75)	0.00 (0–81)	.9577
Chi-square (%)[3]					
Off-odour:					
Mustard	0.00	0.00	0.00	7.00	.9990
Rancid	14.0	0.00	14.0	7.00	.7310
Off-flavour:					
Mustard	0.00	0.00	0.00	7.00	.9900
Cabbage	21.0	36.0	14.0	14.0	.6170
Rancid	14.0	7.00	14.0	0.00	.7360
Onion	7.00	21.0	7.00	7.00	.7030

*Sensory attributes were scored on numerical (10-points) and continuous scales from 0 (the lowest score for each attribute) to 150 mm (the highest score for each attribute); [1]Means ± Standard Error; [2]Median and data interval (min-max); [3]Frequency; [a,b]Means in the same row with different superscript letters differ for $p < 0.05$.

Discussion

As reported by Cullere et al. (2023), the average fat content of commercial camelina (Calena) and two improved camelina lines (Pearl and Alan) cakes was determined to be 25.4%, and with a FA profile characterised by a high PUFA content (average 57%), predominantly comprised of *n*-3 FA. This explains why the healthiness of breast meat substantially improved (absolute *n*-3 amount and *n*-6/*n*-3 ratio of about 1) in camelina-fed quails, independently from the camelina line. Specifically, camelina cakes in the diet of broiler quails increased meat *n*-3 PUFA and reduced the *n*-6/*n*-3 ratio by about 5 and 7 times, respectively.

Interestingly, despite the Pearl line was selected to have a lower content of C18:2 *n*-6 FA, the *n*-6 proportion and content of breast meat did not differ depending on the camelina treatment. From a nutritional point of view, reducing the *n*-6/*n*-3 ratio aligns with dietary recommendations for humans, aiming to mitigate cardiovascular diseases and other chronic diseases (Simopoulos 2011). Current literature on poultry demonstrated that *Camelina sativa* is an effective feedstuff to improve meat FA profile: the addition of varied levels of camelina cakes (3%–24%) or oil (2.5%–6.9%) significantly increased *n*-3 PUFA content and beneficially reduced the *n*-6/*n*-3 ratio in the meat of chickens (Ryhänen et al. 2007; Aziza et al. 2010a, 2010b; Thacker and Widyaratne 2012; Pietras and Orczewska-Dudek 2013; Nain et al. 2015; Ciurescu et al. 2016; Orczewska-Dudek and Pietras 2019; Untea et al. 2019), and duck (Juodka et al. 2018).

The C18:3 *n*-3, a precursor of long-chain FA, contributed to the increase the C20:5 *n*-3 and C22:6 *n*-3 contents in meat. This metabolic pathway is catalysed by the enzymatic activity of desaturase and elongase enzymes, leading to the biosynthesis of long-chain FA (Jing et al. 2013). Coherently, in this study the 15% inclusion of camelina cakes (Calena, Pearl, and Alan) in quail diets substantially increased the dietary C18:3 *n*-3. This led to a consistent improvement of the meat content of this FA, but also to enhanced C20:3 *n*-3 and C20:5 *n*-3 contents. Conversely C22:6 *n*-3 was similar in all treatments. Similar findings were also depicted in the sole other study testing the inclusion of camelina cake (10%) into broiler quail diets (Juodka et al. 2023).

In discussing present results, it must be emphasised that the breast meat cut is the leanest one in the quail carcase, as it is for the chicken. This is relevant since

the absolute fat amount is a key factor in affecting the magnitude effect of a dietary treatment on meat FA profile and content.

An increase in meat unsaturation degree tendentially makes it more susceptible to oxidative deterioration, potentially leading to the formation of undesirable compounds detrimental to the quality and safety of the food product and/or harmful for consumer's health (Cortinas et al. 2005; Narciso-Gaytán et al. 2010). The higher susceptibility to oxidative deterioration is indicated by the PI which was higher in the Calena and Alan groups, but this did not affect the oxidative status of fresh meat, as it was shown in the first part of the study (Cullere et al. 2023). In fact, camelina demonstrated to be rich in antioxidants, including phenolic compounds, α- and γ-tocopherols, flavonoids, xanthophylls, and phytosterols (Aziza et al. 2010a; Singh et al. 2023), which effectively contribute in protecting meat from oxidative phenomena.

In the context of nutritional indices, the AI points out the relationship between the main SFA and the main classes of unsaturated FA (MUFA and PUFA), considering the former as proatherogenic, promoting the activation of immunological cells, leading to their adhesion to vessel walls. Conversely, the latter are deemed antiatherogenic, inhibiting plaque aggregation and reducing levels of esterified fatty acids, cholesterol, and phospholipids. This, in turn, mitigates the risk of micro- and macro-coronary diseases. The TI reflects the tendency for clot formation in blood vessels and is defined as the ratio between pro-thrombogenic (saturated) and antithrombogenic fatty acids. Both AI and TI signify a potential for stimulating platelet aggregation (Ghaeni et al. 2013; Dal Bosco et al. 2022). Consequently, lower AI and TI values indicate a protective effect against atherosclerosis and support coronary artery health. Our results indicate that the AI values in quail breast meat align with desirable values, below 1.0 (0.40 *vs* 0.37 for Control and camelina-fed groups, respectively). Concerning TI, values were slightly higher than the desirable threshold, ideally below 0.5 (1.02 *vs* 0.65 for Control and camelina-fed groups, respectively) (Dal Bosco et al. 2022; Meira et al. 2023). The hH ratio suggests the effects of the consumed product on cholesterol metabolism: values above 2.0 suggest a beneficial balance of cholesterol-lowering fatty acids, therefore being considered beneficial for human health (Dal Bosco et al. 2022). In this study, higher values for camelina-fed groups (2.41) compared to the Control group (2.34) were observed.

The sole potential drawback in meat FAs of camelina-fed quails was the presence of erucic acid, a monounsaturated FA which is typically is present in the seeds and seed oils of the Brassicaceae family members. Once assimilated, erucic acid is distributed to the tissues for energy derivation *via* β-oxidation. However, in muscles (including the cardiac one) this process is limited: as a result, an excessive consumption of erucic acid can lead to an accumulation of fat in the heart muscle, which can lead to heart diseases and myocardial lesions. For this reason, the EFSA recommends a percentage of erucic acid in edible oils equal or lower than 2% of total FA (Wani et al. 2022). In the present study the average erucic acid percentage in the meat of camelina-fed quails was 0.18%, thus not posing any particular health concern. Results of the present research about erucic acid content in camelina cakes and in the meat of camelina-fed quails are in agreement with the study by Juodka et al. (2023), the sole other one considering the impact of a dietary inclusion of camelina cake on broiler quails' meat quality. In fact, also in the latter it was observed that camelina cake had a notable proportion of this antinutritional factor (2.52%), but the meat of camelina-fed quail had a negligible amount of this FA considering both breast and leg meat cuts.

Another key nutritional factor that needs to be investigated when dealing with meat quality is the AA profile. This because AA quantities and proportions directly influence the protein quality, and as they play pivotal functions in different metabolic and physiological pathways (Wu et al. 2014). Camelina is renowned for its substantial protein content and favourable AA profile: it is reported to be rich in methionine, a crucial limiting AA in poultry nutrition (Juodka et al. 2022). However, the protein and methionine contents of the camelina cake in the present study were found to be lower than the values reported in the literature (Thacker and Widyaratne 2012; Bulbul et al. 2015). This discrepancy can be attributed to various factors, including genetic variability, growth conditions, harvesting time, processing methods, and geographical variations (Zanetti et al. 2021; Singh et al. 2023). Notably, the dietary inclusion of camelina cakes did not significantly impact the protein content of quail breast meat (Cullere et al. 2023). However, the AA profile of quail breast meat was influenced by the dietary inclusion of camelina cakes in the present study. Pearl meat showed a higher content of leucine compared to Alan and a higher lysine compared to Alan and Calena. The *de novo* synthesis of essential AA is insufficient to meet the nutritional requirements and therefore diet plays the greatest role in this sense. In turn, the quantity of essential AA

ingested can also influence their quantity in meat. Of course, intrinsic dietary factors affecting the digestibility of nutrients can be key determinants in defining the absorption percentage. Alan cake was selected to have a low content of glucosinolates, as shown by Cullere et al. (2023), but all three camelina lines had similar contents of phytic acid, condensed tannins, trypsin inhibitor and sinapine. As a result, *in vivo* results highlighted that all three camelina cakes penalised the growth performance of broiler quails in the first phase of the cycle (15 – 25 d). Based on these findings, the above-mentioned results on the AA contents in meat were unexpected and require further investigations.

Similar to the essential AA, the non-essential AA alanine, aspartic acid, glutamic acid and proline displayed a similar trend with Pearl meat having a higher content than the Alan group. Synthesis rates of non-essential AA depend on several factors including amounts of available essential AA and glucose, but also on breed, age of the animal, and physiologic status (Hou and Wu 2017). Therefore, the observed increase of the above-cited AA in Pearl meat could be associated to active *de novo* synthesis processes occurring from essential AA (Wu 2009; Wu et al. 2014). Also, some non-essential AA can serve as precursors of other non-essential AA. This is the case, for example, of proline which is synthesised from glutamic acid through a series of enzymatic reactions, involving reduction and cyclisation processes (Wu 2009; He et al. 2021).

Assessing the sensory characteristics of a new food product is pivotal to outline the key sensory traits, if the case of it. This ultimately helps to outline the possible market strategies to meet consumers' acceptability, fundamental for the marketability of the new food product (Meilgaard et al. 2015). Within the existing literature, studies agree that the inclusion of camelina oil (3–6%) into chicken diets does not generate any negative impact on the sensory properties of cooked meat (Pietras and Orczewska-Dudek 2013), or it provides a slight improvement in the textural attributes, as shown in the study by Orczewska-Dudek and Pietras (2019) where the dietary inclusion of 4% camelina oil enhanced chicken breast juiciness. Consistently, in the sole study considering the sensory traits of meat obtained from chickens fed with camelina cake (Orczewska-Dudek and Pietras 2019), it was observed that a 5% or 10% inclusion did not influence the sensory descriptors of chicken leg meat.

Also, the results of the present study agreed with existing literature on this topic, because the overall sensory profile of quail breast meat was comparable in camelina-fed quails and the Control one. The higher tenderness of Control meat compared to the Alan, as well as the higher animal fat flavour of the Control meat than Calena and Alan meat, could possibly be explained by the results highlighted in the first part of the study (Cullere et al. 2023). In fact, the meat of the Calena and Alan group had a lower lipids content compared to that of the Control group, thus explaining why the sensory attribute 'animal fat' was perceived the least in these two treatments compared to the Control meat. The different fat content of quail meat as a result of the dietary treatment could explain also the observed results concerning 'tenderness'. In fact, as described in a comprehensive review on meat tenderness, Warner et al. (2021) indicates that meat fat can contribute to perceived meat tenderness by exerting a lubricating effect during mastication, thus indirectly enhancing the sensation of tenderness. Furthermore, fat depots within the endomysium and perimysium can loosen the connective tissue after cooking and, also, a higher intramuscular fat lowers protein density, thus reducing the required shear strength. Another factor that was reported to positively affect meat tenderness is the unsaturation degree of meat (Wood et al. 2008), which was however not supported by the results of the present research.

Interestingly, in the first part of the study it was depicted that the meat of control quails and that of quails fed with different camelina lines showed similar Warner-Bratzler Shear Force (WBSF) values. This seems to partly contrast with the results on meat sensory tenderness evaluated by the trained panellists in the present study. However, this apparent discrepancy can likely be attributed to different factors. The first possible explanation is the inherent limitation of the WBSF method, which quantifies a single aspect of meat toughness i.e. the force required to shear a specific meat sample. Conversely, sensory tenderness as perceived by trained panellists can vary in function of other sensory attributes, such as chewiness, juiciness, and overall mouthfeel (Warner et al. 2021). These additional sensory characteristics, which are not measured by WBSF, may result in divergence between mechanical and sensory assessments. In addition, since sensory human perception can benefit of a complex combination among senses, training and experience, the panellists could hypothetically have been more effective than the instrument in depicting the treatment-linked differences among quail meat samples.

Conclusions

The present study demonstrated that the inclusion of a 15% *Camelina sativa* cake obtained from different lines into growing quails' diet positively influenced the FA profile of breast meat. Indeed, the meat of all camelina-fed quails showed a remarkable improvement in the *n*-3 FA proportion and content, resulting in a *n*-6/*n*-3 ratio in line with current dietary recommendations for human health. Specifically, all tested camelina cakes increased quail meat *n*-3 PUFA and reduced the *n*-6/*n*-3 ratio by about 5 and 7 times, respectively. The FA improvement was also emphasised by the observed improvements of the health indexes AI and TI. Another important finding of the present research is linked to the AA profile, since meat of the Control and camelina-fed quails was substantially comparable thus emphasising that protein quality was ensured, which is another important dietary implication for human's health. Last but not least, the sensory traits of quail breast meat were in line with those of a standard product, thus technically making it already acceptable by consumers. Overall, the findings of the present research confirm the potential of camelina cake as an innovative feedstuff for broiler quails with a remarkable nutritional quality, thus offering a promising perspective for the poultry industry. In addition, among the tested camelina lines, Alan was the one maximising the positive impact of meat FA, while Pearl was the one ensuring the best meat AA contents.

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Ethical approval

The research was approved by the ethical committee of the university of padova (prot. n. 362845).

Authors contributions

Conceptualisation: Dalle Zotte; Methodology: Dalle Zotte; Validation: Dalle Zotte, Pellattiero, Singh, and Cullere; Formal analysis: Pellattiero, Singh, Palumbo, and Cullere; Investigation: Pellattiero, Singh, and Cullere; Resources: Dalle Zotte; Data curation: Singh, Cullere, Pellattiero, and Dalle Zotte; Writing-original draft preparation: Singh; Writing-review and editing: Cullere, Dalle Zotte, Singh; Supervision: Dalle Zotte; Funding acquisition: Dalle Zotte. All the authors read and approved the final version.

Disclosure statement

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Data availability statement

The data that support the findings of this study are available upon reasonable request.

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