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Effects of dietary processed former foodstuffs on slaughter performance and meat quality in broilers

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ABSTRACT

This study assessed the effects of incorporating commercially processed former foodstuffs (cFF) as substitutes for corn, soybean meal and soybean oil in broilers' diet on slaughter performance, physicochemical properties and meat sensory attributes. Two hundred and one-day-old male chicks (ROSS-308) were divided into four dietary groups with increasing levels of cFF (0, 6.25%, 12.5% and 25%) named cFF0, cFF6.25, cFF12.5 and cFF25, respectively. On d 33, 25 chickens per dietary group were slaughtered for analyses. Carcase traits were similar across groups, except for a decrease in gizzard yield in cFF25 group ($p = .008$). Shear force, cooking loss and drip loss were unaffected by the diet. Meat pH decreased linearly in both breast and thigh muscles, and the thigh muscle yellowness index increased ($p < .05$). Breast crude protein (CP) decreased, while thigh CP and breast ether extract increased as the cFF inclusion level rose ($p < .05$). The fatty acid (FA) content of breast and thigh meat showed a linear increase in monounsaturated FA, with thigh meat also exhibiting a linear increase in saturated FA (SFA). Conversely, polyunsaturated FA (PUFA) and the PUFA to SFA ratio decreased with increasing cFF levels ($p < .05$). Lipid oxidation levels remained unchanged across groups. Sensory analysis revealed no differences in overall acceptability or liking among groups, although two sensory attributes (sour and hard) resulted as discriminating factors ($p < .05$). Overall, cFF inclusion did not affect meat quality, oxidative stability or consumer perception but altered the FA composition, suggesting the need of further investigation to assess the optimal inclusion level.

HIGHLIGHTS

- Commercially processed former foodstuffs (cFF) in broiler diets did not impact carcase traits or meat quality.
- Inclusion of cFF in broiler diets reduced gizzard yield, especially at 25% inclusion.
- Inclusion of cFF reduced polyunsaturated fatty acids to saturated fatty acids ratio in chicken meat, while increasing the *n*-6 to *n*-3 ratio.
- Inclusion of cFF did not affect the sensory attributes or overall liking of the final product.

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Former foodstuff; fatty acid composition; meat quality; carcass yield; sensory analysis

Introduction

Poultry meat will account for 41% of global meat protein by 2030 (OECD-FAO 2021). Statista's report (Statista 2023) predicts that worldwide consumption of poultry meat will reach 156.24 metric kilotons by 2032. The widespread popularity of chicken meat can be attributed to its affordability, nutritional and sensory attributes, simple preparation, and lack of religious restrictions (Baldi et al. 2020).

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Poultry meat contains compounds such as linoleic acid, vitamins and antioxidants, contributing to its perception as a healthy food (Grashorn 2007; Cavani et al. 2009). However, its omega-6 to omega-3 ratio (*n*-6/*n*-3) is generally not well-balanced according to nutritional guidelines for healthy meat (Nur Mahendra et al. 2023). This ratio is primarily influenced by the fatty acids (FAs) and dietary lipids consumed by the birds (Mandal et al. 2014; Dal Bosco et al. 2022). Modifications to the chicken's diet can improve this ratio, thereby enhancing the meat's health benefits (Nieto et al. 2012).

Meat production is crucial for protein supply but poses economic, environmental and resource challenges (FAO 2023). The livestock sector, especially for monogastric animals such as pigs and poultry, faces a significant feed-food competition challenge. Although human-edible grains make up only 13% of livestock feed, they represent about one-third of global cereal production (FAO 2022). Addressing this challenge involves incorporating more non-human-edible food into feed, which is crucial for sustainably feeding nearly 10 billion people by 2050 (FAO 2018).

To ensure sustainable meat production, seeking alternative feed ingredients aligned with circular economy principles is essential (FAO 2017; Fiorilla et al. 2024). Among these, commercially processed former foodstuffs (cFF) offer a viable option. cFF mainly includes bakery by-products and former foodstuffs (dry pasta, puffed cereals and chocolate) as reported by Srikanthithasan, Gariglio, Diaz Vicuna, et al. (2024) which are unsuitable for human consumption due to logistical reasons and is legislated by the European catalogue of feed materials, EU regulation 2022/1104. This aligns with EU circular economy principles aimed at reducing food waste (Reg. EU 2018/851). Despite this, while alternative feed ingredients such as cFF can improve meat production sustainability, their impact on meat quality must be considered. The meat industry needs to understand consumer perceptions of quality and how these influence their choices (de Araújo et al. 2022). Moreover, consumer preferences have evolved, placing increasing importance on attributes like 'welfare-friendly', 'sustainable' and 'healthily produced meat' (Sander et al. 2021; Mirade and Font-I-Furnols 2023).

Over the past decade, cFF has been proven suitable for animal feed, including for ruminants and monogastric animals, as highlighted by Srikanthithasan, Giorgino, Fiorilla, et al. (2024). In particular, several *in vivo* studies in poultry nutrition have investigated the use of cFF, referred to by various names such as bakery by-products (Boros et al. 2004), dried bakery waste (Al-Tulaihan et al. 2004), bakery product (Catalá-Gregori et al. 2009), bakery meal (Stefanello et al. 2016) and biscuit dough (Shittu et al. 2016), as substitutes for traditional feed ingredients like wheat, corn and soybean meal. These studies generally reported no negative effects on growth performance, nutrient digestibility, carcase characteristics or organ weights in broilers (Al-Tulaihan et al. 2004; Boros et al. 2004; Catalá-Gregori et al. 2009; Adedokun et al. 2015), although some variations in amino acid digestibility, energy or nitrogen utilisation were observed (Adedokun et al. 2015; Stefanello et al. 2016). Nevertheless, these variations do not modify the overall conclusion that cFF are a viable alternative to traditional ingredients like corn–soybean meal, and wheat providing a sustainable option for broiler feed formulations (Shittu et al. 2016; Epao et al. 2017).

Despite technological advancements and European standardisation, the use of commercially available cFF with consistent chemical composition has not been thoroughly explored in poultry nutrition. To address these gaps, this study aims to assess the impact of different cFF levels in broiler diets, substituting corn, soybean meal and soybean oil. The focus will be on evaluating slaughter performance, physicochemical qualities and sensory attributes of broiler chicken meat.

Materials and methods

Birds' management and experimental diets

The study was conducted at the University of Turin's poultry facility (Turin, Italy) and approved by its Bioethical Committee (Protocol no. 245, 1 January 2022).

Two hundred and one-day-old male broiler chicks (ROSS-308) were housed in 20 pens based on their initial body weight (BW, 38.00 ± 0.11 g) and divided into four dietary groups (five replicates per group, 10 birds per replicate). The cFF used, provided by Dalma Mangimi SpA (Cuneo, Italy), had the following composition detailed in Supplementary Table 1 and in Srikanthithasan, Gariglio, Diaz Vicuna, et al. (2024). Diets were isonitrogenous and isoenergetic to meet the nutritional needs of broilers with nitrogen-corrected apparent metabolisable energy (AMEn – calculated, Table 1) levels set at 3000 kcal/kg for starter (d 1–12) and 3100 kcal/kg for grower phases (d 12–33) according to NRC (1994). Four diets were formulated increasing levels of cFF (0% (0 g/kg), 6.25% (62.5 g/kg), 12.5% (125 g/kg) and 25% (250 g/kg)) named: cFF0,

Table 1. Ingredients (g/kg as fed) and chemical composition of the experimental diets[a].

	Starter (d 1–12)				Grower (d 12–33)			
Ingredients	cFF0	cFF6.25	cFF12.5	cFF25	cFF0	cFF6.25	cFF12.5	cFF25
Corn meal	498.5	452	409	314.5	526.5	482	434.5	342.5
Soybean meal	397	390.5	381	369	359	350.5	345	331
cFF	–	62.5	125	250	–	62.5	125	250
Soybean oil	58.5	49	39	20.5	69.5	60	50.5	31.5
Dicalcium phosphate	5	5	5	5	5	5	5	5
Calcium carbonate	17.7	17.7	17.7	17.7	15.8	15.8	15.8	15.8
Sodium chloride	1.5	1.5	1.5	1.5	2.9	2.9	2.9	2.9
Sodium bicarbonate	3.2	3.2	3.2	3.2	3.5	3.5	3.5	3.5
DL-Methionine	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
L-Lysine	2.3	2.3	2.3	2.3	1.5	1.5	1.5	1.5
Vitamin–mineral premix[b]	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Choline chloride	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Optifos 250 bro	1	1	1	1	1	1	1	1
Avizyme 1500 x	1	1	1	1	1	1	1	1
Titanium dioxide	5	5	5	5	5	5	5	5
Total	1000	1000	1000	1000	1000	1000	1000	1000
AMEn[c], kcal/kg	3000	3000	3000	3001	3100	3101	3100	3100
DM[d], %	91.27	91.60	91.18	92.01	90.93	90.88	90.43	91.63
CP[d], %	23.51	23.90	23.09	23.62	21.01	20.78	20.88	20.60
EE[d], %	7.41	6.92	6.89	6.12	9.27	8.83	8.01	7.37
CF[d], %	1.78	1.50	1.65	1.21	1.87	1.58	1.69	1.57
Ash[d], %	6.31	6.66	6.42	6.66	6.28	6.12	5.82	6.35

AMEn: nitrogen-corrected apparent metabolisable energy. *Chemical composition*. DM: dry matter; CF: crude fibre; CP: crude protein; EE: ether extract; FA: fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Σ*n*-6: total omega-6; Σ*n*-3: total omega-3; cFF: commercially processed former foodstuffs.
Chemical composition expressed in % as fresh matter basis.
[a]*Four dietary groups*. cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF.
[b]*Mineral–vitamin premix*: Vitamin A (retinyl acetate): 12,500 IU; vitamin D3 (cholecalciferol): 3500 IU; vitamin E (DL-a-tocopheryl acetate): 40 mg; vitamin K (menadione sodium bisulfite): 2.0 mg biotin, 0.20 mg; thiamine: 2.0 mg; riboflavin: 6.0 mg; pantothenate: 15.21 mg; niacin: 40.0 mg; choline: 750.0 mg pyridoxine: 4.0 mg; folic acid: 0.75 mg; vitamin B12: 0.03 mg; Mn: 70 mg; Zn: 62.15 mg; Fe: 50.0 mg; Cu: 7.0 mg; I: 0.25 mg; Se: 0.25 mg.
[c]Calculated according to INRA (2004). AMEn of cFF as communicated by Dalma Mangimi spa, Cuneo, Italy.
[d]The chemical analyses were carried out on three replicates of each feed sample.

cFF6.25, cFF12.5 and cFF25, respectively, as a substitution for corn, soybean meal and soybean oil. Chickens had *ad libitum* access to feed and water. Diets were analysed using AOAC (2003) methods for dry matter (DM), crude protein (CP), ether extract (EE) and AOAC (2000) methods for ash and crude fibre. Fatty acid composition was determined by the Sukhija and Palmquist (1988) method, with nonadecanoic acid (C19:0; Sigma Aldrich Chemical Co., St. Louis, MO) as the internal standard. The lipid extract was injected into a gas chromatograph (HP6890, Agilent Technologies, Santa Clara, CA) under conditions described by Cortinas et al. (2004). FAs were identified based on retention times of commercial standards (Supelco 37 component FAME Mix), and quantification was performed by internal normalisation.

The details of the *in vivo* study, including BW (g), average daily gain (ADG, g/d), average daily feed intake (ADFI, g/d) and feed conversion ratio (FCR, g/g) across feeding phases (d 1, 12 and 33), have been previously reported in Srikanthithasan, Gariglio, Diaz Vicuna, et al. (2024).

Slaughter performance and carcase traits

On d 33, 100 birds (25 birds per dietary group, five birds per replicate) were selected based on the pen's average BW and labelled with shank rings. After a 12 h feed withdrawal, their slaughter weight (SW) was recorded. The birds were slaughtered according to EU regulation (1099/2009), and the plucked and eviscerated carcases were weighed. The hot carcase weight (HCW; with head, neck and feet) was recorded and the hot carcase yield (HCY) was calculated as a percentage of SW. After removal of the head, neck and feet, the weight of the ready-to-cook carcase (RTCCW) was registered. Weights of the spleen, liver, bursa of fabricius, heart, gizzard and proventriculus ($n = 15$ per dietary group) were recorded and expressed as a percentage of SW. After 24 h of refrigeration (4 ± 1 °C), the chilled carcase weight (CCW) was registered, and the chilled carcase yield (CCY) calculated as a percentage of SW. The breast yield (% CCW) and thigh yield (% CCW) were also calculated. The breasts and thighs of 100 birds ($n = 25$ per dietary group) were deboned, divided by side, vacuum sealed and stored at −20 °C.

Left-side breast and thigh meat samples ($n = 15$ per dietary group) were ground, freeze-dried at −80 °C, reground, and used for FA composition and meat proximate analyses.

Meat quality and physicochemical properties of meat

pH and colour. The pH_{24} and colour were evaluated after 24 h of storage at +4 °C on the left side of the breast (*Pectoralis major*) and thigh (*Biceps femoris*) muscles ($n = 15$ per dietary group). Measurements were taken on the muscle under the skin on the dorsal side and were recorded in triplicate using a pH metre (Crison Instruments, SA, Alella, Spain). The lightness (L*), redness (a*) and yellowness (b*) colour indexes were measured in the same samples (taken at three locations and averaged) using a portable Chroma Meter CR-400 colorimeter (Minolta Sensing Inc., Osaka, Japan).

Drip loss (DL). The breast meat samples ($n = 5$ per dietary group) were weighed, placed within a container on a supporting mesh and sealed. Excess surface fluids were removed and the samples were reweighed. Drip losses were determined as the percentage of weight lost by the samples during the refrigerated storage period (24 h, 4 ± 1 °C) (Honikel 1998).

Cooking loss (CL). The breast meat samples ($n = 5$ per dietary group) were placed in plastic bags and cooked in a water bath at 80 °C for 30 min, then cooled under running tap water for 15 min, following the method described by Branciari et al. (2017). Samples were weighed before and after cooking, and losses were calculated.

Meat proximate composition analysis. The freeze-dried thigh and breast samples ($n = 5$ per dietary group) were analysed for DM, ash, CP and EE content according to AOAC (2016).

Meat fatty acid composition analysis. Fresh meat samples from chicken thigh and breast were weighed (g) and subsequently freeze-dried to remove moisture. The freeze-dried samples were reweighed to determine their final dry weight (g). These freeze-dried thigh and breast samples ($n = 10$ per dietary group) were used to analyse the FA composition according to methodology described by Carrapiso et al. (2000). This process involved homogenising fresh freeze-dried meat and subjecting it to gas chromatography in duplicate. The percentage of each FA was obtained by peak area normalisation according to Cortinas et al. (2004). To provide a nutritionally relevant presentation of FA data, the FA concentrations were converted from freeze-dried (mg/100 g) to fresh meat (as-is) basis (mg/100 g). This conversion was performed using the following formula to adjust for moisture content:

$$\begin{aligned}\text{FA content (as-is basis)} &= \text{FA content of freeze-dried meat} \\ &\times \frac{\text{freeze-dried weight}}{\text{fresh weight}}\end{aligned}$$

The FA composition results are presented as both FA content (mg/100 g) for freeze-dried meat and fresh meat (as-is basis) and as the FA profile (% of total FA) for freeze-dried meat. Additionally, the atherogenicity (AI) and thrombogenicity (TI) indexes were calculated according to Ulbricht and Southgate (1991) as follows:

$$AI = \frac{[C12:0 + (4 \times C14:0) + C16:0]}{(\sum MUFA + \sum n\text{-}6 + \sum n\text{-}3)}$$

$$TI = \frac{[C14:0 + C16:0 + C18:0]}{[(0.5 \times \sum MUFA) + (0.5 \times \sum n\text{-}6) + (3 \times \sum n\text{-}3)] + \left(\frac{\sum n\text{-}3}{\sum n\text{-}6}\right)}$$

Shear force. The Warner-Bratzler shear force (SF) was evaluated in three cylindrical cores (1.25 cm Ø; 2 cm length; INSTRON Instrument, Norwood, MA; 50 kg loading range, shearing velocity 100 mm/min) equipped with a Warner-Bratzler meat shear apparatus, obtained from the midportions of the breast samples ($n = 10$ per dietary group) by following the CL method in accordance with Honikel (1998). The peak force was expressed in N/cm^2.

Determination of thiobarbituric acid reactive substances (TBARS). Lipid oxidation in breast meat ($n = 5$ per dietary group) was assessed using the 2-thiobarbituric acid (TBA) distillation method, following Tarladgis et al. (1960), at five storage time points: d 0 (*T1*), d 3 (*T2*), d 5 (*T3*), d 7 (*T4*) and d 9 (*T5*), under refrigerated storage (4 °C ± 1) in an oxygen-permeable package consisting of a polystyrene foam tray covered with a PVC film.

$$\text{TBA number} = 7.8 \times \text{optical density (MDA mg/kg muscle)}$$

Sensory analysis

To assess the impact of different levels of cFF on the sensory profile and liking of chicken breasts, sensory analyses were conducted on breast meat samples from the four dietary groups (n = 5 per dietary group). Thawed meat samples were portioned into individual pieces (14 g ± 1) and vacuum sealed. Before sensory test, these portions were cooked at 90 °C using a thermostatic bath (Techne, TE-10D, Temp unit) for 15 min, ensuring a core temperature of 72 °C prevent *Salmonella* spp. contamination. After cooking, samples were dried with paper tissues and stored at 50 °C to maintain a tasting temperature of at least 40 °C.

Two sensory sessions were held one week apart in the 'Sensory Laboratory of Edmund Mach Foundation', equipped with 22 individual booths under white lights. Sensory responses were collected using an iPad with Eye Question® software. Panellists were recruited from Center Agriculture Food Environment of the University of Trento and Fondazione Mach, with informed consent and privacy information provided.

In the first session, a discriminant method compared the experimental meat samples to assess overall differences (ISO 4120:2021 Sensory analysis – Methodology-Triangle test; Meilgaard et al. 1999). Three consecutive triangle tests were conducted, each comparing one cFF0 sample to two treated samples: cFF6.25, cFF12.5 and cFF25. Twenty-four judges with basic experience in sensory analysis participated. In the second session, 42 consumers (mean age = 35.7; SD = 11.4; 50% female) evaluated the acceptability and descriptiveness of the samples using Check-All-That-Apply (CATA) (Varela and Ares 2012). Samples, coded with three-digit numbers, were presented in a balanced order. Participants rated their liking on a nine-point hedonic scale and described the samples using the CATA questionnaire (1 = Dislike extremely; 2 = Dislike very much; 3 = Dislike moderately; 4 = Dislike slightly; 5 = Neither like nor dislike; 6 = Like slightly; 7 = Like moderately; 8 = Like very much; 9 = Like extremely).

Subsequently, participants were asked to observe, smell and taste the samples, providing descriptions using the CATA questionnaire. They were asked to choose all the attributes (Supplementary Table 2) that were relevant for each sample (Baston and Barna 2010; Tasoniero et al. 2016).

At the end, participants provided their gender, birth year and chicken meat consumption frequency on a scale from 1 to 4 (1 = I've never tasted it; 2 = I've tasted it but don't consume it; 3 = I consume it occasionally; 4 = I consume it regularly).

Statistical analysis

The meat physicochemical properties' data were analysed by means of IBM SPSS Statistics software (Version 20.0, Armonk, NY). Homogeneity of variance was tested with Levene's test, and normality of residuals was assessed using the Shapiro–Wilk test. The individual bird was used as the experimental unit for the slaughter performance and meat quality traits. Moreover, for the TBARS analysis, a general linear mixed model (GLMM) with a gamma probability distribution and log-link function was used to compare TBARS levels as a function of two fixed factors (diet and storage time) and their interaction. The interactions between the levels of the fixed factors were evaluated using pairwise comparisons. Results were expressed as mean and pooled standard error of the mean (SEM).

For sensory analysis, the statistical analysis for the discriminant test involved calculating the mean number of correct judgments and their probability of occurrence based on a binomial distribution (Schlich 1993). Liking data underwent one-way ANOVA (fixed factor: samples/dietary groups) and further exploration with a two-way ANOVA model (fixed factors: samples, chicken consumption frequency; samples, gender). For the CATA results, the occurrence matrix was calculated, and Cochran's Q test assessed the significance of discrimination among the four dietary groups. A correspondence analysis created a perceptual map illustrating the sensory description of the samples. Data analysis was conducted using Jamovi software (Version 2.3.21, Sydney, Australia) and R software (Version 4.1.1, R Foundation for Statistical Computing, Vienna, Austria). All statistical analyses were performed with a $p < .05$.

Results

Chemical composition and fatty acid composition of experimental diets

The raw materials, chemical composition and the FA composition – including both FA content (mg/100 g) and FA profile (% of total FAs) of the experimental diets are summarised in Table 1 and Supplementary Tables 1 and 3.

The analysis of the FA content and profile of the cFF ingredient and the four experimental diets revealed that cFF is high content of monounsaturated FA (MUFA), primarily oleic acid (C18:1n9). It also contains substantial levels of saturated fatty acids (SFAs), with palmitic acid (C16:0) being the most abundant, followed by stearic (C18:0), lauric (C12:0) and myristic acid (C14:0). Conversely, cFF has relatively low polyunsaturated fatty acids (PUFAs), mainly consisting of linoleic acid (C18:2n6) and α-linolenic acid (C18:3n3). Overall, both the FA content and profile of cFF collectively reflected in the experimental diets with the different inclusions level of cFF. Particularly, the *n*-6 and *n*-3 PUFA contents increased in the experimental diets with the increasing levels of cFF.

Carcase and organ traits

No differences observed in SW (Table 2), nor in *in vivo* performance for BW and ADG recorded during the experimental period (d 1–33: cFF0; 1977 g, 60.6 g/d and cFF25; 2041 g, 62.6 g/d, respectively, $p > .05$). However, the inclusion of cFF linearly decreased the ADFI (1–33 d: cFF0; 93.85 g/d and cFF25; 86.35 g/d, $p = .026$) and FCR (1–33 d: cFF0; 1.55 and cFF25; 1.38, $p = .002$) (Srikanthithasan, Gariglio, Diaz Vicuna, et al. 2024).

No differences were observed among dietary groups for HCW, CCY (% RTCW), RTCY (% HCW), yield of breast and thigh (% RTCW). However, RTCW linearly increased with cFF inclusions, with the highest value corresponded in cFF25 group (cFF25; 1517 g and cFF0; 1448 g, $p = .046$, Table 2).

The yield (% SW) of the spleen, liver, heart, bursa of fabricius, and abdominal fat was similar among all dietary groups. Nonetheless, a difference was observed in the yield of the gizzard (% SW), with the lowest yield observed in the cFF25-fed group ($p = .008$; Table 2).

Physicochemical properties of meat

The pH_{24} of thigh and breast muscles exhibited a linear decrease ($p < .05$) with increasing levels of cFF. Regarding the colour of the thigh and breast muscles, lightness (L*) was linearly increased ($p < .05$) with dietary cFF inclusions. However, redness (a*) and yellowness (b*) and were not affected by the dietary groups (Table 3).

There were no differences in SF, DL and CL values among dietary groups (Table 3). However, a quadratic response ($p = .043$) was observed in DL among the dietary groups.

The nutrient composition of the freeze-dried thigh and breast meat samples is presented in Table 3. No differences were observed in thigh and breast DM and ash contents, or in thigh EE. However, a linear decrease in breast CP was noted with the increasing levels of cFF, whereas thigh CP exhibited an increase ($p < .05$). Additionally, there was a linear increase ($p = .043$) in breast EE with increasing levels of cFF.

Fatty acid composition of meat. The differences in the FA composition of the feed were reflected in the FA composition of the meat, as shown in Table 4. FA content (mg/100 g) was presented for both freeze-dried and fresh meat (as-is basis), while the FA profile

Table 2. Effects of different levels of cFF in broiler diets on the slaughter performance.

	Dietary treatments					*p* Value	
Parameters	cFF0	cFF6.25	cFF12.5	cFF25	SEM	Linear	Quadratic
Carcase traits (n = 15/dietary group)							
Slaughter weight (SW), g	2124	2174	2124	2200	13.52	.134	.629
Hot carcase weight (HCW), g	1642	1664	1637	1712	11.74	.074	.253
Hot carcase yield, % of SW	77.3	76.5	77.1	77.8	0.184	.175	.027
Ready to cook carcase weight (RTCW), g	1448	1465	1453	1517	11.03	.046	.284
Ready to cook carcase yield, % of HCW	88.2	88.0	88.8	88.6	0.121	.071	.963
Chilled carcase yield, % of RTCW	97.4	97.4	96.9	97.3	0.105	.401	.276
Breast yield, % of RTCW	23.5	23.8	23.0	23.7	0.167	.953	.454
Thigh yield, % of RTCW	30.8	31.2	31.5	31.0	0.153	.526	.201
Organ traits (n = 15/dietary group)							
Spleen, % of SW	0.103	0.105	0.093	0.093	0.003	.077	.802
Liver, % of SW	2.69	2.69	2.74	2.66	0.036	.959	.546
Bursa of fabricius, % of SW	0.297	0.285	0.292	0.270	0.008	.319	.767
Heart, % of SW	0.563	0.550	0.552	0.561	0.006	.947	.403
Gizzard, % of SW	2.57^{ab}	2.70b	2.42^{ab}	2.30^{a}	0.048	.008	.153
Proventriculus, % of SW	0.472	0.483	0.477	0.465	0.009	.740	.527
Abdominal fat, % of SW	0.828	0.891	0.875	0.813	0.037	.858	.403

SEM: standard error of the mean; cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF.
Values within a row not sharing the same superscript (a, b) are significantly different ($p < .05$).

Table 3. Effects of different levels of cFF in broiler diets on the physicochemical qualities of meat.

	Dietary treatments					*p* Value	
Parameters	cFF0	cFF6.25	cFF12.5	cFF25	SEM	Linear	Quadratic
pH_{24} and colour (n = 15/dietary group)							
Breast pH_{24}	5.85b	5.84b	5.81^{ab}	5.70^{a}	0.017	.002	.091
Thigh pH_{24}	6.05	6.06	6.03	5.95	0.015	.014	.201
Breast L*	57.1	57.6	58.3	59.3	0.345	.020	.732
Breast a*	1.60	2.40	1.43	1.97	0.229	.948	.773
Breast b*	9.99	11.7	9.18	9.35	0.450	.273	.402
Thigh L*	57.6^{a}	60.5^{ab}	61.3b	59.9^{ab}	0.439	.042	.013
Thigh a*	5.28	7.18	4.75	5.32	0.627	.685	.602
Thigh b*	14.2	13.7	14.0	13.8	0.328	.779	.860
Cooking loss and drip loss (n = 5/dietary group), shear force (n = 10/dietary group)							
Breast cooking loss, %	22.6	25.2	22.8	25.3	0.820	.463	.978
Breast drip loss, %	4.86	2.85	1.91	3.56	0.454	.212	.043
Breast shear force, N/cm^2	17.1	18.6	17.2	19.3	0.476	.238	.767
Chemical composition of thigh and breast meat freeze-dried samples (n = 5/dietary group) (g/100 g, fresh matter basis)							
Thigh DM	88.5	88.9	89.2	88.1	0.205	.606	.085
Thigh CP	68.0^{a}	70.0^{ab}	70.3^{ab}	71.5b	0.460	.007	.656
Thigh EE	23.4	23.2	23.9	23.4	0.269	.819	.746
Thigh ash	3.90	4.13	4.27	4.33	0.102	.140	.676
Breast DM	86.1	86.6	86.7	86.0	0.176	.848	.074
Breast CP	93.2b	90.6^{ab}	88.6^{a}	87.9^{a}	0.593	.000	.222
Breast EE	3.05	3.54	3.90	4.20	0.203	.043	.813
Breast ash	4.89	5.03	4.89	4.77	0.050	.292	.214

L*: lightness; a*: redness; b*: yellowness; DM: dry matter; CP: crude protein; EE: ether extract; cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF.
Values within a row not sharing the same superscript (a, b) are significantly different ($p < .05$).

(% of total FA) was shown for freeze-dried samples only. Across dietary groups, the FA content for freeze-dried and fresh meat demonstrated consistent significance levels, although absolute values varied between the two formats. An analysis of both the FA content in breast and thigh meat (freeze-dried and fresh basis) and the FA profile (freeze-dried meat) revealed a linear increase in total MUFA and the *n*-6 to *n*-3 ratio ($p < .05$). Conversely, total SFA content increased linearly only in the thigh meat of both freeze-dried and fresh samples ($p < .05$), with no differences observed in the breast meat. In contrast, the FA profile of both breast and thigh freeze-dried meat exhibited a linear increase in total SFA. Meanwhile, total PUFA and the PUFA-to-SFA ratio decreased linearly with increasing levels of cFF (linear and quadratic response, $p < .05$) in both FA content and profiles for freeze-dried and fresh basis samples.

In detail, an analysis of the FA content of thigh meat (both freeze-dried and fresh basis) and the FA profile of thigh and breast (in freeze-dried meat) in broilers fed cFF dietary groups revealed a significantly higher proportion of SFA compared with the cFF0 group. This increase was primarily attributed to the abundance of palmitic acid (C16:0) and stearic acid (C18:0) in the cFF ingredient. Consequently, total MUFA content (both freeze-dried and fresh basis) showed a linear and quadratic increase ($p < .05$) with increasing levels of cFF, driven primarily by the abundance of oleic acid (C18:1n9). Simultaneously, a decrease in PUFA was observed with the increasing levels of cFF, mainly due to reductions in linoleic acid (C18:2n6) and α-linolenic acid (C18:3n3). As a result, AI and TI of both thigh and breast meat were increased (linear, quadratic response, $p < .05$) with increasing levels of cFF.

Lipid oxidation of meat. The analysis of TBARS values across the four dietary groups and five storage times (*T*1 to *T*5) showed no differences among the dietary groups. However, TBARS values progressively increased over the storage period ($p = .000$, Supplementary Table 4a). Additionally, an interaction between the diets and the storage times ('diet × time', $p = .033$, Figure 1, Supplementary Table 4b) was observed. In this interaction, cFF0 showed a gradual increase over time, with a substantial rise from *T*3 to *T*4 and the highest increase at *T*5. cFF6.25 had a steady increase over time, peaking at *T*5. cFF12.5 also showed a gradual increase, with the highest value at *T*5 but with a slightly different pattern compared to cFF0 and cFF6.25. cFF25 started with lower values but exhibited an increase from *T*4, reaching a high at *T*5.

Sensory attributes

Discriminant analysis showed no significant differences among dietary groups (Supplementary Table 5). For the consumer panel, different inclusion levels of cFF in the broiler diet did not affect the perception of the

Table 4. Fatty acids composition of thigh and breast meat on freeze-dried and fresh (as-is) basis ($n = 5$ per dietary group).

		Dietary treatments					*p* Value	
Fatty acids	Meat sample	cFF0	cFF6.25	cFF12.5	cFF25	SEM	Linear	Quadratic
Effects of different levels of cFF in broiler diets on the fatty acids' composition of freeze-dried thigh and breast meat (% of total fatty acids)								
C12:0	TM	0.014[a]	0.156[b]	0.326[c]	0.588[d]	0.050	<.001	.006
	BM	0.000[a]	0.000[a]	0.302[b]	0.554[c]	0.054	<.001	<.001
C14:0	TM	0.340[a]	0.466[b]	0.642[c]	0.872[d]	0.046	<.001	.004
	BM	0.318[a]	0.424[b]	0.566[c]	0.764[d]	0.039	<.001	.012
C15:0	TM	0.080[a]	0.090b	0.092[b]	0.096	0.002	<.001	.198
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C16:0	TM	16.4[a]	16.9[a]	17.9[c]	19.0[d]	0.240	<.001	.037
	BM	17.8[a]	18.0[a]	18.9[b]	19.7[c]	0.178	<.001	.037
C17:0	TM	0.164[b]	0.166[b]	0.154[ab]	0.148[a]	0.002	.002	.284
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:0	TM	6.88	6.95	7.01	7.11	0.054	.153	.929
	BM	9.46	9.31	9.42	9.38	0.090	.888	.793
C20:0	TM	0.128	0.124	0.128	0.126	0.002	.889	.756
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C22:0	TM	0.000	0.000	0.000	0.014	0.004	.198	.332
	BM	0.000	0.000	0.000	0.000	0.000	–	–
ΣSFA	TM	24.0[a]	24.8[b]	26.2[c]	28.0[d]	0.356	<.001	.028
	BM	27.6[a]	27.8[a]	29.2[b]	30.4[c]	0.278	<.001	.039
C14:1	TM	0.000[a]	0.038[b]	0.082[c]	0.118[d]	0.011	<.001	.908
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C16:1	TM	2.03[a]	2.11[a]	2.50[ab]	2.99[b]	0.104	<.001	.110
	BM	1.45[a]	1.56[a]	1.74[ab]	2.17[b]	0.080	.000	.160
C20:1*n*9	TM	0.244[a]	0.248[a]	0.272[b]	0.302[c]	0.006	<.001	.010
	BM	0.100[a]	0.150[ab]	0.290[bc]	0.346[c]	0.030	.000	.946
C18:1*n*9t	TM	0.000[a]	0.000[a]	0.000[a]	0.050[b]	0.006	<.001	.001
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:1*n*9c	TM	26.3[a]	27.5[b]	31.0[c]	35.0[d]	0.784	<.001	<.001
	BM	23.1[a]	24.4[a]	26.9[b]	30.5[c]	0.678	<.001	.013
C18:1*n*7	TM	1.48[ab]	1.45[a]	1.48[ab]	1.57[b]	0.015	.015	.020
	BM	1.81[ab]	1.73[a]	1.80[ab]	1.94[b]	0.027	.031	.026
ΣMUFA	TM	30.1[a]	31.4[a]	35.4[b]	40.0[c]	0.902	<.001	<.001
	BM	26.5[a]	27.8[a]	30.8[b]	35.0[c]	0.782	<.001	.009
C20:2	TM	0.396[b]	0.400[b]	0.354[ab]	0.322[a]	0.009	<.001	.146
	BM	0.784	0.778	0.738	0.738	0.016	.236	.927
C18:2*n*6	TM	39.3[d]	37.3[c]	32.8[b]	27.2[a]	1.079	<.001	<.001
	BM	36.0[d]	34.7[c]	31.0[b]	26.3[a]	0.874	<.001	<.001
C20:5*n*3	TM	0.072	0.070	0.072	0.040	0.005	.029	.107
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:3*n*6	TM	0.194[b]	0.198[b]	0.180[ab]	0.154[a]	0.005	.001	.053
	BM	0.140	0.154	0.102	0.142	0.009	.535	.435
C18:3*n*3	TM	3.63[d]	3.41[c]	2.79[b]	2.09[a]	0.139	<.001	<.001
	BM	2.93[c]	2.81[c]	2.28[b]	1.71[a]	0.112	<.001	<.001
C20:3*n*6	TM	0.364	0.368	0.354	0.334	0.006	.046	.281
	BM	0.740	0.736	0.772	0.774	0.015	.353	.927
C20:4*n*6	TM	1.75	1.80	1.72	1.70	0.026	.383	.529
	BM	4.70	4.59	4.65	4.54	0.101	.658	.989
C22:6*n*3	TM	0.232[b]	0.234[b]	0.192[ab]	0.174[a]	0.009	.003	.473
	BM	0.670[b]	0.624[b]	0.520[ab]	0.448[a]	0.027	.001	.756
ΣPUFA	TM	45.9[d]	43.8[c]	38.4[b]	32.0[a]	1.249	<.001	<.001
	BM	45.9[c]	44.4[c]	40.1[b]	34.6[a]	1.023	<.001	<.001
Σ*n*3	TM	3.94[c]	3.71[c]	3.05[b]	2.31[a]	0.148	<.001	<.001
	BM	3.60[c]	3.43[c]	2.80[b]	2.17[a]	0.131	<.001	<.001
Σ*n*6	TM	41.6[d]	39.7[c]	35.0[b]	29.4[a]	1.093	<.001	<.001
	BM	41.6[c]	40.2[c]	36.5[b]	31.7[a]	0.888	<.001	<.001
Σ*n*-6/Σ*n*-3	TM	10.6[a]	10.7[a]	11.5[b]	12.8[c]	0.212	<.001	.001
	BM	11.5[a]	11.7[a]	13.1[b]	14.6[c]	0.296	<.001	.001
ΣPUFA/ΣSFA	TM	1.91[d]	1.77[c]	1.47[b]	1.14[a]	0.069	<.001	.004
	BM	1.66[d]	1.60[c]	1.37[b]	1.14[a]	0.048	<.001	<.001
AI	TM	0.236[a]	0.252[b]	0.284[c]	0.322[d]	0.008	<.001	.007
	BM	0.266[a]	0.276[a]	0.308[b]	0.340[c]	0.007	<.001	.002
TI	TM	0.494[a]	0.520[a]	0.578[b]	0.646[c]	0.014	<.001	.006
	BM	0.612[a]	0.628[a]	0.684[b]	0.748[c]	0.013	<.001	.004
Effects of different levels of cFF in broiler diets on the fatty acids' composition of freeze-dried thigh and breast meat (mg/100 g)								
C12:0	TM	2.78[a]	30.8[b]	64.2[c]	114[d]	9.663	<.001	.025
	BM	0.000[a]	0.000[a]	14.1[b]	26.3[c]	2.630	<.001	.002
C14:0	TM	69.1[a]	92.1b	126[c]	168[d]	8.769	<.001	.059
	BM	14.8[a]	21.6[ab]	26.4b[c]	36.4[c]	2.126	<.001	.526
C15:0	TM	16.3[a]	17.6[ab]	18.0[ab]	18.8[b]	0.342	.008	.629
	BM	0.000	0.000	0.000	0.000	0.000	–	–

(*continued*)

Table 4. Continued.

		Dietary treatments					*p* Value	
Fatty acids	Meat sample	cFF0	cFF6.25	cFF12.5	cFF25	SEM	Linear	Quadratic
C16:0	TM	3327	3336	3525	3655	50.092	.007	.487
	BM	833	915	882	927	28.319	.355	.759
C17:0	TM	33.3^{b}	32.4^{b}	30.3^{ab}	28.3^{a}	0.594	<.001	.565
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:0	TM	1394	1371	1383	1366	15.866	.641	.927
	BM	442	470	437	439	9.830	.674	.536
C20:0	TM	25.5	24.4	25.0	24.2	0.360	.332	.791
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C22:0	TM	0.000	0.000	0.000	2.68	0.670	.198	.332
	BM	0.000	0.000	0.000	0.000	0.000	–	–
ΣSFA	TM	4868^{a}	4904^{ab}	5172^{ab}	5376^{b}	72.615	.004	.493
	BM	1289	1406	1360	1429	39.716	.325	.778
C14:1	TM	0.000^{a}	7.72^{b}	16.5^{c}	22.6^{c}	2.108	<.001	.624
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C16:1	TM	411^{a}	418^{a}	493^{ab}	573^{b}	18.720	<.001	.148
	BM	67.8	79.7	81.8	103	5.207	.021	.636
C18:1*n*7	TM	300.5	285.5	292.2	301.0	3.133	.766	.067
	BM	84.5	87.3	83.8	90.7	2.109	.452	.653
C18:1*n*9t	TM	0.000^{a}	0.000^{a}	0.000^{a}	9.54^{b}	1.095	<.001	.001
	BM	0.00	0.00	0.00	0.00	0.000	–	–
C18:1*n*9c	TM	5333^{a}	5440^{a}	6116^{b}	6724^{b}	147.201	<.001	.127
	BM	1082	1241	1258	1451	57.294	.031	.876
C20:1*n*9	TM	49.4^{ab}	48.5^{a}	53.6^{bc}	58.1^{c}	1.037	<.001	.046
	BM	4.80^{a}	8.38^{ab}	13.5^{ab}	16.2^{b}	1.487	.002	.848
ΣMUFA	TM	6093^{a}	6199^{a}	6971^{b}	7688^{c}	167.665	<.001	.095
	BM	1239	1416	1437	1661	65.099	.030	.851
C18:2*n*6	TM	7961^{c}	7369^{c}	6458^{b}	5230^{a}	248.550	<.001	.077
	BM	1681^{b}	1761^{b}	1445^{ab}	1240^{a}	64.492	.002	.160
C18:3*n*3	TM	737^{c}	673^{c}	550^{b}	402^{a}	30.446	<.001	.030
	BM	137b^{c}	143^{c}	107^{ab}	81.4^{a}	6.933	<.001	.094
C18:3*n*6	TM	39.2^{b}	39.0^{b}	35.4^{a}	29.7^{a}	1.243	.002	.163
	BM	6.54	7.62	4.76	6.88	0.516	.684	.608
C20:2	TM	80.5^{c}	78.7^{c}	69.8^{b}	61.9^{a}	1.837	<.001	.059
	BM	36.7^{ab}	39.1^{b}	34.2^{a}	34.2^{a}	0.727	.035	.328
C20:3*n*6	TM	73.5^{b}	72.9^{b}	69.7^{ab}	63.9^{a}	1.117	<.001	.105
	BM	34.6	37.1	35.7	35.9	0.633	.679	.392
C20:4*n*6	TM	354^{b}	352^{ab}	339^{ab}	327^{a}	3.913	.004	.455
	BM	220^{ab}	230^{b}	215^{ab}	209^{a}	2.724	.032	.088
C20:5*n*3	TM	14.4	13.8	13.8	7.76	0.994	.017	.131
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C22:6*n*3	TM	47.1^{b}	45.8^{b}	37.8^{a}	33.3^{a}	1.576	<.001	.415
	BM	31.2^{b}	30.9^{b}	24.0^{a}	20.8^{a}	1.157	<.001	.227
ΣPUFA	TM	9306^{c}	8644^{c}	7572^{b}	6155^{a}	286.435	<.001	.059
	BM	2146^{b}	2248^{b}	1865^{ab}	1628^{a}	75.402	.001	.146
Σ*n*-3	TM	798^{a}	733^{a}	601^{b}	443^{c}	32.199	<.001	.017
	BM	168^{b}	174^{b}	131^{a}	102^{a}	7.749	<.001	.065
Σ*n*-6	TM	8428^{c}	7833^{c}	6901^{b}	5650^{a}	252.803	<.001	.071
	BM	1942^{b}	2036^{b}	1700^{ab}	1492^{a}	67.309	.002	.155
Σ*n*-6/Σ*n*-3	TM	10.6^{a}	10.7^{a}	11.5^{b}	12.8^{c}	0.212	<.001	.001
	BM	11.5^{a}	11.7^{a}	13.1^{b}	14.6^{c}	0.296	<.001	.001
ΣPUFA/ΣSFA	TM	1.91^{d}	1.77^{c}	1.47^{b}	1.14^{a}	0.069	<.001	.004
	BM	1.66^{d}	1.60^{c}	1.37^{b}	1.14^{a}	0.048	<.001	<.001
AI	TM	0.236^{a}	0.252^{b}	0.284^{c}	0.322^{d}	0.008	<.001	.007
	BM	0.266^{a}	0.276^{a}	0.308^{b}	0.340^{c}	0.007	<.001	.002
TI	TM	0.494^{a}	0.522^{b}	0.578^{c}	0.648^{d}	0.014	<.001	.006
	BM	0.612^{a}	0.628^{a}	0.688^{b}	0.748^{c}	0.013	<.001	.011
Effects of different levels of cFF in broiler diets on the fatty acids' composition of thigh and breast meat (as-is basis, mg/100 g)								
C12:0	TM	0.906^{a}	10.0^{b}	21.1^{c}	37.2^{d}	3.171	<.001	.031
	BM	0.000^{a}	0.000^{a}	4.37^{b}	8.11^{c}	0.813	<.001	.002
C14:0	TM	22.9^{a}	30.1^{b}	41.6^{c}	54.9^{d}	2.870	<.001	.072
	BM	4.60^{a}	6.69^{ab}	8.17^{bc}	11.21^{c}	0.659	<.001	.556
C15:0	TM	5.40^{a}	5.75^{ab}	5.94^{ab}	6.15^{b}	0.115	.018	.743
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C16:0	TM	1103	1088	1161	1196	18.435	.033	.477
	BM	258	283	273	286	9.016	.402	.748
C17:0	TM	11.0^{c}	10.5^{ab}	9.99^{ab}	9.28^{a}	0.209	.001	.744
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:0	TM	462	447	456	447	6.234	.541	.805
	BM	137	145	136	135	3.155	.628	.533

(*continued*)

Table 4. Continued.

		Dietary treatments					p Value	
Fatty acids	Meat sample	cFF0	cFF6.25	cFF12.5	cFF25	SEM	Linear	Quadratic
C20:0	TM	8.46	7.94	8.22	7.93	0.135	.297	.685
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C22:0	TM	0.000	0.000	0.000	0.886	0.222	.198	.332
	BM	0.000	0.000	0.000	0.000	0.000	–	–
ΣSFA	TM	1614^{ab}	1600^{a}	1704^{ab}	1759^{b}	26.593	.022	.478
	BM	400	435	421	441	12.650	.373	.766
C14:1	TM	0.000^{a}	2.55^{b}	5.43^{c}	7.37^{c}	0.690	<.001	.583
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C16:1	TM	136^{a}	136^{a}	162^{ab}	187^{b}	6.145	<.001	.152
	BM	21.0	24.7	25.4	31.7	1.624	.025	.660
C18:1*n*7	TM	99.6	93.1	96.3	98.4	1.255	.973	.093
	BM	26.2	27.0	26.0	27.9	0.666	.511	.685
C18:1*n*9t	TM	0.000^{a}	0.000^{a}	0.000^{a}	3.11^{b}	0.356	<.001	.001
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C18:1*n*9c	TM	1768^{a}	1775^{a}	2015^{ab}	2200^{b}	50.095	<.001	.165
	BM	336^{a}	384^{ab}	390^{ab}	447^{b}	17.968	.038	.899
C20:1*n*9	TM	16.4^{a}	15.8^{a}	17.7^{ab}	19.0^{b}	0.363	.001	.077
	BM	1.49^{a}	2.60^{ab}	4.19^{ab}	4.99^{b}	0.461	.002	.832
ΣMUFA	TM	2020^{a}	2023a	2297^{ab}	2515^{b}	56.950	<.001	.132
	BM	384^{a}	439^{ab}	445^{ab}	512^{b}	20.413	.037	.876
C18:2*n*6	TM	2639^{c}	2402^{c}	2128^{b}	1711^{a}	84.158	<.001	.170
	BM	521^{b}	545^{b}	448^{ab}	382^{a}	20.324	.002	.167
C18:3*n*3	TM	244^{c}	219^{c}	181^{b}	131^{a}	10.184	<.001	.066
	BM	42.5^{b}	44.2^{b}	33.0^{ab}	25.1^{a}	2.173	<.001	.101
C18:3*n*6	TM	13.0^{b}	12.7^{b}	11.7^{ab}	9.73^{a}	0.424	.002	.222
	BM	2.03	2.35	1.47	2.12	0.160	.670	.607
C20:2	TM	26.7^{c}	25.6^{b}	23.0^{a}	20.3^{a}	0.613	<.001	.104
	BM	11.4^{ab}	12.1^{b}	10.6^{a}	10.5^{a}	0.232	.034	.335
C20:3*n*6	TM	24.4^{b}	23.8^{b}	23.0^{ab}	20.9^{a}	0.380	<.001	.175
	BM	10.7	11.5	11.1	11.1	0.206	.770	.403
C20:4*n*6	TM	117^{b}	115^{ab}	111^{ab}	107^{a}	1.261	.001	.635
	BM	68.1^{ab}	71.1^{b}	66.5^{ab}	64.4^{a}	0.869	.026	.089
C20:5*n*3	TM	4.79^{b}	4.50^{ab}	4.53^{ab}	2.51^{a}	0.327	.014	.134
	BM	0.000	0.000	0.000	0.000	0.000	–	–
C22:6*n*3	TM	15.6^{b}	14.9b	12.5^{a}	10.9^{a}	0.508	<.001	.483
	BM	9.69^{b}	9.54^{b}	7.43^{a}	6.39^{a}	0.355	<.001	.197
ΣPUFA	TM	3085^{c}	2817^{c}	2495^{b}	2014^{a}	96.915	<.001	.143
	BM	666^{b}	695^{b}	578^{ab}	502^{a}	23.787	.001	.153
Σ*n*-3	TM	265^{d}	239^{c}	198^{b}	145^{a}	10.759	<.001	.041
	BM	52.2^{b}	53.7^{b}	40.4^{a}	31.5^{a}	2.424	<.001	.070
Σ*n*-6	TM	2794^{c}	2553^{c}	2274^{b}	1849^{a}	85.686	<.001	.165
	BM	602^{b}	630^{b}	527^{ab}	460^{a}	21.249	.002	.163
Σ*n*-6/Σ*n*-3	TM	10.6^{a}	10.7^{a}	11.5^{b}	12.8^{c}	0.212	<.001	.001
	BM	11.5^{a}	11.7^{a}	13.1^{b}	14.6^{c}	0.296	<.001	.001
ΣPUFA/ΣSFA	TM	1.91^{d}	1.77^{c}	1.47^{b}	1.14^{a}	0.069	<.001	.004
	BM	1.66^{d}	1.60^{c}	1.37^{b}	1.14^{a}	0.048	<.001	<.001
AI	TM	0.236^{a}	0.252^{b}	0.284^{c}	0.322^{d}	0.008	<.001	.007
	BM	0.266^{a}	0.276^{a}	0.308^{b}	0.340^{c}	0.007	<.001	.002
TI	TM	0.494^{a}	0.522^{b}	0.578^{c}	0.648^{d}	0.014	<.001	.006
	BM	0.612^{a}	0.628^{a}	0.688^{b}	0.748^{c}	0.013	<.001	.011

FA: fatty acids; ΣSFA: total saturated fatty acids; ΣMUFA: total monounsaturated fatty acids; ΣPUFA: total polyunsaturated fatty acids; ΣPUFA/ΣSFA: total polyunsaturated fatty acid/total saturated fatty acid ratio; SEM: standard error of the mean; Σ*n*-6/Σ*n*-3: total PUFA *n*-6/total PUFA *n*-3 ratio; AI: atherogenicity index; TI: thrombogenicity index; TM: thigh meat; BM: breast meat; cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF.
Values within a row not sharing the same superscript (a, b, c, d) are significantly different ($p < .05$).

final product, and no perceived difference was noted among the meat samples.

In the acceptability test, no differences were observed in the liking scores among the dietary groups (Supplementary Table 6). This result was consistent across consumer groups categorised by gender and frequency of chicken meat consumption (Supplementary Tables 7 and 8).

Results from Cochran's *Q* test on CATA attributes indicated that only two attributes ('sour' and 'hard'; cFF0: 1 and 7 vs. cFF25: 6 and 19, respectively; $p < .05$; Table 5) could discriminate among the dietary groups. The multivariate exploratory analysis revealed tendential differences in sensory attributes among dietary groups (Figure 2). The cFF6.25 and cFF12.5 groups were associated with 'sulphurous', 'salty',

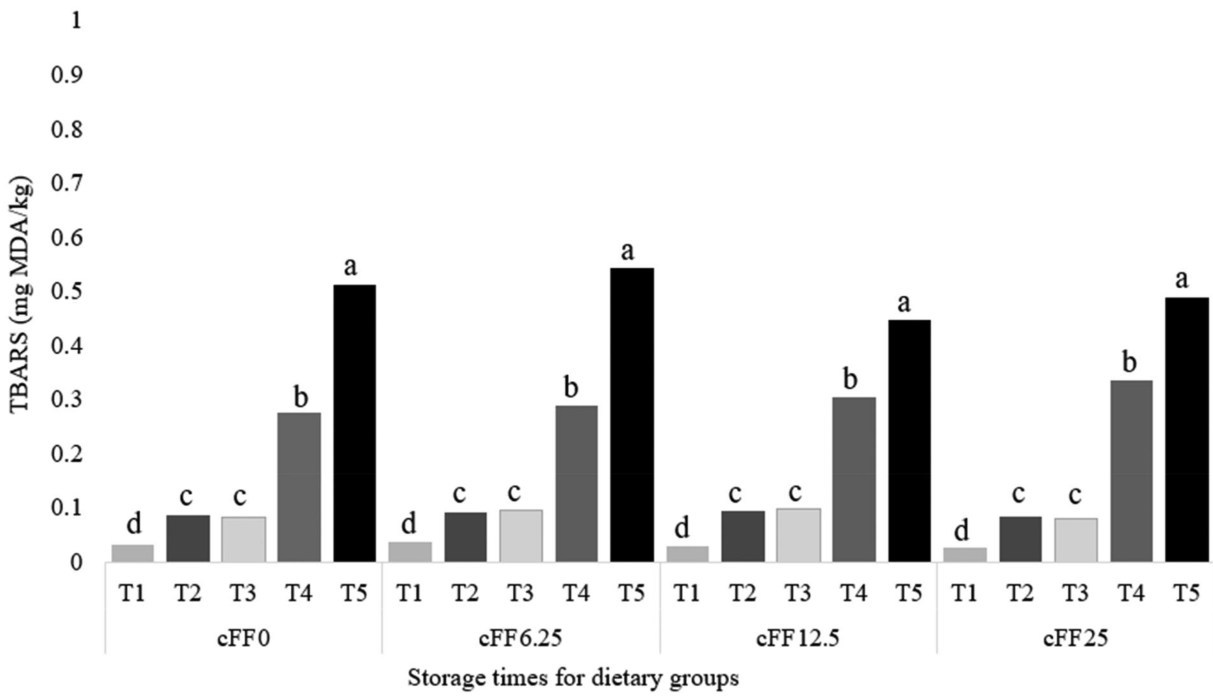

Figure 1. Effects of different levels of cFF in broiler diets on lipid oxidation of breast meat over storage time. cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF; five storage time points: day 0 (*T*1), day 3 (*T*2), day 5 (*T*3), day 7 (*T*4) and day 9 (*T*5); TBARS: thiobarbituric acid reactive substances; MDA: malondialdehyde; means with different letters (a, b, c, d) indicate significant differences for 'diet × time' interaction at $p = .033$.

Table 5. Effects of different levels of cFF in broiler diets on Cochran's *Q*-test for CATA attributes of breast meat ($n = 3$/dietary group).

Sensory modality	CATA attributes	cFF0	cFF6.25	cFF12.5	cFF25	*Q*	*p* Value
Odour/flavour	Ammoniacal	0	0	2	1	3.67	.300
	Beef broth	21	22	22	22	0.11	.991
	Cooked meat	3	0	1	2	2.55	.466
	Hay	6	7	8	4	0.30	.960
	Metallics	6	9	11	13	4.40	.222
	Rancid	26	24	22	20	3.33	.343
	Raw egg	4	2	4	2	1.85	.605
	Raw meat	5	2	0	5	6.75	.080
	Stale	2	3	3	7	5.06	.168
	Sulphureous	3	4	4	3	2.14	.543
	Toasted	4	3	0	3	3.86	.277
	Wet feathers	6	4	4	5	0.77	.857
Taste	Sour	1	10	7	6	9.33	.025
	Bitter	5	4	7	5	1.21	.750
	Salty	11	11	16	8	7.33	.062
	Sweet	12	10	5	9	5.57	.134
	Umami	15	16	17	14	1.07	.784
Texture	Dry	16	16	20	17	1.33	.722
	Fatty	1	4	2	0	5.53	.137
	Fibrous	13	13	12	18	2.75	.432
	Grainy	1	3	3	4	2.11	.550
	Gummy	12	12	14	12	0.46	.927
	Hard	7	9	7	19	14.49	.002
	Juicy	5	11	8	3	7.00	.072
	Tender	16	10	10	8	5.68	.128

cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF; CATA: Check-All-That-Apply.

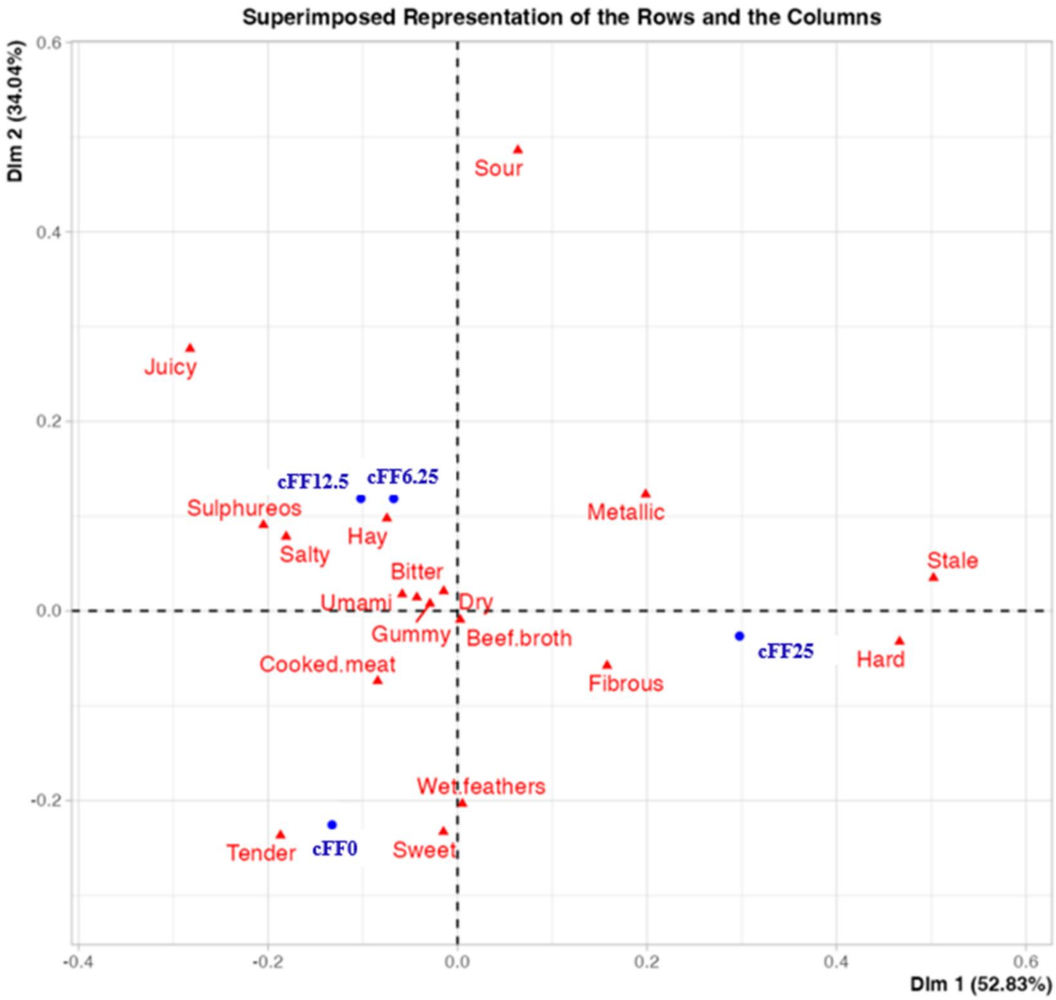

Figure 2. Perceptual map resulted from correspondence analysis ($p < .05$). cFF: commercially processed former foodstuffs; cFF0: control diet (based on corn, soybean meal and soybean oil); cFF6.25: 6.25% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF12.5: 12.5% w/w substitution of corn, soybean meal and soybean oil with cFF; cFF25: 25% w/w substitution of corn, soybean meal and soybean oil with cFF.

'umami' and 'dry' descriptors, while the cFF0 group was linked to 'tender' and 'sweet' descriptors.

Discussion

The cFF ingredient has proven to be an effective, and nutritious alternative resource for animal nutrition (Srikanthithasan, Giorgino, Fiorilla, et al. 2024). However, while existing studies have examined its effects on growth traits, digestibility, carcase and organ traits (Catalá-Gregori et al. 2009; Srikanthithasan, Gariglio, Diaz Vicuna, et al. 2024), the impact of cFF on meat quality and sensory attributes, crucial for practical use in poultry nutrition and consumer acceptance, have not been addressed in previous studies. The findings of this study are promising, showing comparable meat composition and quality, as well as positive consumer perception when broilers are fed a cFF diet. Regarding the nutritional properties of cFF, there is a growing interest in FAs due to their significance in poultry diet. Essential FAs enhance the health and productivity of birds and appeal to health-conscious consumers who prioritise well-balanced diets to mitigate potential health issues (Alagawany et al. 2019).

In this study, substituting corn, soybean meal and soybean oil with different levels of cFF resulted in variations in the FA composition of the experimental diets. These variations were primarily influenced by the fat components from the raw materials used in bakery production and the reduction of soybean oil in the diets. The difference in values between freeze-dried meat and as-is basis meat is due to the higher concentration of FA in freeze-dried samples, where the removal of moisture increases the relative proportion of lipids and other dry components. When these values are converted to the fresh meat (as-is) basis, the concentrations decrease to account for the water content, providing a more nutritionally realistic estimate of FA content per 100 g of fresh meat. The FA composition of the cFF ingredient indicates that MUFA were more abundant than SFA. Since cFF includes various items, particularly bakery by-products, its FA composition can vary significantly. For instance, bakery products made with olive oil, canola oil or certain nut oils will have a higher MUFA content (Caponio et al. 2013; Raghavendra et al. 2022). In overall, the predominant FAs identified in this study, such as palmitic acid, oleic acid and linoleic acid, align with findings of Yolci Omeroglu and Ozdal (2020), who reported similar contents in bakery products.

Additionally, since the cFF ingredient is predominantly composed of bakery by-products, fat sources such as butter, margarine, shortening and vegetable oils are commonly used in bakery production (Yolci Omeroglu and Ozdal 2020). Parcerisa et al. (1999) highlighted that bakery products rich in MUFA and SFA but low in PUFA are typically linked to animal- or vegetal-derived fats. The FA composition of experimental diets in this present study align with this observation, suggesting that the fat sources in cFF primarily originated from animal-derived (butter) and vegetable-derived (margarine) fat used in bakery production.

Importantly, the FA composition of the experimental diets corresponded with those of thigh and breast meat. Specifically, total MUFA in breast meat increased linearly with higher cFF levels, showing a 34.06% increase in cFF25 compared to cFF0. In contrast, PUFA in breast meat decreased linearly, resulting in a 24.13% reduction in cFF25. These results are consistent with Luciano et al. (2022), who found that replacing standard ingredients with cFF led to higher MUFA and lower PUFA in post-weaning pigs, attributed to the absence of PUFA in both salty and sugary cFF. Moreover, while only thigh meat shows an increase in the actual amount (mg/100 g) of SFA, both thigh and breast meat reflect changes in the proportion (% in total FAs) of SFA within the overall FA composition, which can differ due to variations in other types of FAs.

Concerns about PUFA/SFA and *n*-6/*n*-3 ratios, as well as AI and TI, which assess nutritional value and health implications (Wołoszyn et al. 2020). While not all SFAs and PUFAs affect cholesterol and cardiovascular disease (CVD) equally, a PUFA/SFA ratio above 0.45 is recommended to prevent CVD (Dal Bosco et al. 2022). Dal Bosco et al. (2022) stated that low AI and TI values suggest a protective potential for coronary artery health, with recommended dietary AI and TI values below 1.0 and 0.5, respectively. While our AI results fall within these limits, the TI values were slightly higher than 0.5 (ranging from 0.52 to 0.75). Maintaining an appropriate *n*-6/*n*-3 ratio is essential for health, oxidative balance and meat quality (Mancinelli et al. 2022), yet our *n*-6/*n*-3 ratio of 10 to 14:1. Alagawany et al. (2019) noted that the current human diet ratio of *n*-6 to *n*-3 is approximately 10 to 20:1, rather than the recommended 1 to 4:1. These findings suggest a growing interest in incorporating sources rich in EPA DHA and linolenic acid into poultry diets, including cFF, to enhance *n*-3 FA intake through sustainable meat consumption.

Diets high in MUFAs increase fat deposition in poultry, leading to higher EE values in meat (Dal Bosco et al. 2022). Consequently, the changes in meat composition are influenced by the nutritional factors of the diet (Summers and Leeson 1979), particularly FA composition (Choi et al. 2023). Despite differences in PUFA to SFA ratios, lipid oxidation in breast meat did not vary among dietary groups, indicating similar oxidative potential due to comparable SFA levels. However, lipid oxidation increased progressively with storage time, suggesting time-dependent oxidative degradation (Domínguez et al. 2019). This 'diet × time' interaction implies that dietary composition may impact lipid oxidation more during extended storage (Domínguez et al. 2019), potentially due to lower PUFA content in cFF-fed groups, which correlates with reduced lipid peroxidation and better meat stability. Since TBARS values rise with increased fat unsaturation (Janero 1990) and long-chain PUFAs are prone to oxidation, causing off-flavours and odours in poultry meat, negatively impacting meat quality and consumer acceptability (Alagawany et al. 2019). The study suggests that cFF inclusion did not affect initial oxidative stability compared to the cFF0. Additionally, natural antioxidants in bakery products may reduce oxidative stress and lipid oxidation (Nanditha and Prabhasankar 2009).

Salih et al. (1987) suggested a correlation between high TBARS values and altered texture attributes, such as increased toughness or dryness. However, no significant impact on instrumental textural analysis was observed with the experimental diets. Interestingly, the consumer test revealed hardness in the cFF25 group, typically considered negative as it may be associated with chewiness and fibrousness (Barbut 2015), potentially due to hydrogenated shortenings used in bakery products to achieve specific sensory attributes, texture and rheology (Yolci Omeroglu and Ozdal 2020).

Considering the study limits, Brewer (2014) stated that meat juiciness and tenderness depend on its moisture content and water-holding capacity, which were not analysed in this study. Additionally, Zelenka et al. (2008) found that meat tenderness was linked to chickens fed low levels of C18:3*n*3, which aligns with the current study's observation of low PUFA *n*-3 in the cFF diets compared to cFF0. Pinotti et al. (2023) observed that salty cFF improved pork meat's sweetness and tenderness, likely due to changes in the amino acid profile, but this was not assessed in our study.

Despite all experimental diets being pelletised, corn particle size affects gizzard weight (Downs et al. 2023). Ground coarse corn in poultry diets increases gizzard size because it requires more mechanical breakdown, stimulating the gizzard to work harder and leading to increased muscular activity and gizzard wall development. Over time, this results in gizzard enlargement as the muscle tissue adapts (Amerah et al. 2007). The reduced gizzard yield in the cFF25 group may be due to lower corn content. The optimal grain particle size remains debated (Abd El-Wahab et al. 2020).

Meat pH, which affects water-holding capacity, texture and shelf-life, is influenced by the diet. Post-mortem glycolysis converts glycogen to lactic acid, lowering pH (Baldi et al. 2020). Our pH and colour results align with Zhang et al. (2012), who reported that heat stress lowers pH and increases lightness in broiler breast meat, resulting in paler meat. Wideman et al. (2016) found that poultry fed a wheat-based diet produced significantly lighter coloured fillets compared to those fed a corn-based diet. Meat colour is closely tied to changes in the dietary fat profile, possibly due to the bakery by-products, which could influence the meat's visual characteristics. However, Pinotti et al. (2023) reported no major changes in meat quality traits when growing-finishing pigs were fed salty and sugary cFF. Further investigation is needed to confirm these findings.

Conclusions

The inclusion of cFF in broiler diets demonstrated no adverse effects on carcase traits or meat physical properties. Incorporating cFF in broiler diets up to 25% can modify the FA composition of the meat without affecting oxidation, making it a viable option. Additionally, the inclusion of cFF did not affect the sensory attributes or overall liking, suggesting its suitability in broiler diets without impacting consumer perception. These findings highlight the need to balance FA composition in cFF or broiler diets to meet consumer preferences for sustainable meat. Further research is needed to validate these results regarding human health aspect.

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Author contributions

Conceptualisation: KS, AS, CF. Data curation: KS, CF. Formal analysis: KS, MG, SD, RR. Investigation: KS, MG, EDV, MP, AG, EF, MC, DM, SD, FG, ACBL, IA, RR. Methodology: KS, MG, MC, DM, SD, ACBL, IA, AS, CF. Writing – original draft: KS. Writing – review and editing: KS, AS, CF.

Ethical approval

The experimental protocol was approved by the Bioethical Committee of the Department of Veterinary Sciences, University of Turin (Protocol no. 245, 1 January 2022).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data will be available on reasonable request from the corresponding author.

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