Comparison of meat quality characteristics and oxidative stability between conventional and free-range chickens

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ABSTRACT The aim of this research was to evaluate quality traits and oxidative stability of meat products from free-range (FR) and conventionally (C) raised chickens as they actually reach consumers in the Italian retail market. Free-range female and male chickens (n = 1,500 + 1,500), medium growing ISA strain, were raised under commercial conditions for 56 (1.8 kg of live weight) and 70 d (3.1 kg of live weight), respectively; C female and male birds (n = 5,000 + 5,000) were a fast growing hybrid (Ross 708) and were separately raised for 39 (1.9 kg of live weight) and 50 d (3.1 kg of live weight), respectively. A total of 96 chickens (equally divided by production system and sex) were slaughtered in 2 separate sessions to obtain the main 2 commercial categories (rotisserie and cut-up, respectively). After slaughtering, 12 carcasses of each treatment group were randomly selected and used to assess quality properties, chemical composition, and oxidation stability of breast and leg meat. The C birds had dramatic higher carcass and breast meat yield, whereas FR had higher wing and leg yields. The FR birds exhibited higher water holding capacity in both breast and leg meat. Although shear force did not differ in breast meat, legs from FR birds were tougher. Fatty acid composition of FR breast and thigh meat of both categories were characterized by a higher polyunsaturated fatty acid n-6-/n-3 ratio. In general, a low lipid oxidation level (peroxide value < 1.3 mEq O_2/kg of lipid and TBA reactive substances < 0.2 mg malondialdehyde/kg of sample) was found in breast and legs, regardless of the commercial category. However, the C system significantly increased peroxide value in rotisserie thigh meat, whereas FR led to a significantly higher TBA reactive substances in breast meat. Our results demonstrated that free range can modify the properties of chicken meat and also highlighted the importance of the bird genetic background to select nutritional strategies to improve meat quality traits and oxidative stability in poultry.

Key words: chicken meat, production system, quality trait, lipid oxidation

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INTRODUCTION

Over the past few years, the concept of food has undergone a radical transformation, as its safety and impact on human health has become more and more important. Poultry farming systems have been influenced by consumers' priorities, as more attention is being paid to birds raised without using antibiotics or synthetic chemicals. Following the growing demand of consumers who are more sensitive to the ethical and cultural aspects of foods from animal origin, there is an increasing interest toward animal-friendly farming systems, which can improve animal welfare as well as guarantee high qualitative standards concerning food safety, nutritional, and sensory properties (Castellini et al., 2008; Cavani et al., 2009). The EC Regulation 1538/91 has defined processing and marketing standards for poultry meat produced using alternative farming systems (indoor/barn-reared, free range, traditional free range, and free range, total freedom), whereas organic poultry production has been ruled from 1999 onward (EC Regulation 1804/99; European Commission, 1999). Factors that have fostered this development include the incredible current impact of the media on public opinion on the relationship between diet and health, the growing life expectancy of the population, with major concern about disease prevention (Jimènez-Colmenero et al., 2001). Understanding consumer perception of risk and impact on purchase behavior is therefore a key issue for the mutual benefit of both consumers and food industry (Yeung and Morris, 2001). The prospected correlation between high meat intake and human health problems, such as obesity, cardiovascular, and cancer

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diseases, has led to a reduction of red meat consumption (Schönfeldt and Gibson, 2008). Throughout the years, the poultry industry has changed and adapted to meet the consumer demands of meat products. Regarding nutritional aspects and human health, poultry meat fits well the current consumer request for a low-fat meat (Barroeta, 2007), but there is a growing demand to improve its nutritional value and the animal well-being with suitable dietary strategies (Bou et al., 2009; Gibbs et al., 2010). In the poultry sector, the majority of meat products that reach the food market are produced with birds reared under intensive conditions. These birds belong to genotypes that have been selected for rapid growth and feed efficiency and are kept indoors in poultry houses equipped with strict environmental control (photoperiod, light intensity, temperature, RH, and so on; Cavani et al., 2009). Recent studies conducted under alternative housing systems showed that reduced stocking densities, increased possibility of movement in both indoor housing and outdoor areas, and different feed sources from vegetation in open-air runs may contribute to modify the product quality (Castellini et al., 2008). Among meat macronutrients, the lipid fraction has the highest susceptibility to modifications. Lipid peroxidation, commonly known as lipid oxidation, is considered one the most important factors affecting the quality of food (Esterbauer, 1993; Kanner, 2007). It is also a major cause of chicken meat quality deterioration, as it can affect shelf life of meat and meat products. In muscle foods, lipid peroxidation has been reported to initiate and propagate primarily in the phospholipid fraction of cell membranes, due to the high content of polyunsaturated fatty acids (**PUFA**; Wood et al., 2008). Rhee et al. (1996) observed that raw poultry meat is less prone to lipid oxidation than beef or pork meat because of its lower iron content. Because consumers are aware of the importance of animal welfare, there is nowadays an increasing demand for poultry meat produced from free-range birds. The relevance and effects of rearing systems and dietary supplementation on quality broiler meat has been emphasized in several studies. Chen et al. (2013) observed that outdoor access had no effect on growth performance and yield traits, but it could improve meat quality. In addition, Fanatico et al. (2005) demonstrated that meat quality differences exist among genotypes with very different growth rates and reared with or without outdoor access. In another study, Fanatico et al. (2008) evidenced differences among slow-growing and fast-growing genotypes and provided information about the efficiency and potential for alternative poultry systems. Sirri et al. (2011) showed that meat functional properties of fast-growing and medium-growing strains appeared much more attractive for both industry and consumer (lower drip and cook losses and higher tenderness), whereas from a nutritional point of view, slow-growing meat appeared healthier (less fat and higher content of n-3 PUFA) and thus might better fit with the consumer's expectations of organic products. In general, outdoor rearing leads to a higher content of PUFA, especially n-6, as demonstrated by Kralik et al. (2005) who detected that chickens reared outdoor had significantly higher portion of α-linolenic acid, linoleic, arachidonic acid, and total PUFA n-6 acids than chickens that were kept indoors.

However, previous studies have not compared product quality characteristics representative of retail broilers from alternative and conventional poultry production systems, as currently marketed in Italy. Free-range products have been the major market share among those produced under alternative farming systems, and they have been marketed mainly in form of whole carcass (rotisserie type) or cut-up (Magdelaine et al., 2008; Cavani et al., 2009). Therefore, the objective of this study was to assess quality traits and oxidative stability of meat products from free-range (**FR**) and conventionally (**C**) raised chickens as they actually reach consumers in the Italian retail market.

MATERIALS AND METHODS

Experimental Design

The experiment was carried out under commercial conditions, using 2 flocks of birds farmed by either C or FR production system with the aim to yield similar rotisserie-type (around 1.2 kg) and cut-up (around 2.1 kg) carcasses from female and male chickens, respectively. The C group was composed of a total of approximately 10,000 Ross 708 chickens birds (fast-growing genotype), equally divided between male and female, and kept separately in the same commercial poultry house under controlled environmental conditions and without outdoor access. Chicks were fed a wheat/soybean multiphase diet (Table 1), suited for the 2 different genotypes used in the C and FR production systems. Females were reared up to 1.9 kg of live weight (39 d old) to yield 1.2 to 1.3 kg rotisserie-type carcasses, whereas males were grown up to 3.1 kg (50 d) to produce 2.2 to 2.3 kg carcasses for cut-up products. The FR group was composed of a total of about 3,000 birds equally divided between male and female chickens belonging to ISA Brown genotype for meat production (ADG around 30–35 g/d) and farmed according to EC Regulation 1538/91 (European Commission, 1991). Birds were housed in the same environmentally controlled commercial poultry house till 28 d of age; afterward, birds had continuous daytime access to open-air area (mainly covered by vegetation, 1 square meter/bird), and indoor stocking density did not exceed 27.5 kg/square meter. At the end of the growing period, chicks were fed a corn-soybean multiphase (Table 1), to produce a yellow skin. Females were reared up to 1.8 kg of live weight (56 d old, the minimum slaughter age required by the regulation 1538/91) to yield 1.1 to 1.2 kg rotisserie-type carcasses, whereas males were grown up to 3.1 kg (70 d) to produce 1.9 to 2.0 kg carcasses for cut-up products. Prior to slaughter, broilers were sub-

Table 1. Ingredients and composition of experimental diets

Item	Conventional diet			Free-range diet			
	Period I (0–14 d)	Period II (15–35 d)	Period III (36–50 d)	Period I (0–14 d)	Period II (15–35 d)	Period III (36–54 d)	Period IV (54–70 d)
Main ingredient (%)							
Corn	20.0	5.0	5.0	20.0	5.0	5.0	60.2
Wheat	35.8	57.0	60.0	39.5	60.9	65.8	10.0
Soybean meal	29.8	24.1	21.8	22.6	20.3	16.6	19.0
Sunflower meal				2.2			
Wheat bran	3.0	3.0	3.0	10.0	3.0	3.0	2.5
Sunflower oil	5.0	7.1	7.0				
Soybean whole seed					3.0	3.0	2.5
Corn gluten	2.0						
Soybean oil				1.5	3.7	3.3	2.3
Calcium phosphate	1.3	0.9	0.7	1.4	1.2	0.7	0.8
Calcium carbonate	1.0	0.9	0.9	1.0	1.0	0.9	0.9
Salt	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Sodium bicarbonate	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vitamin-mineral premix[1] (g/kg)	1.8	1.7	1.3	1.4	1.5	1.3	1.2
Calculated composition							
Energy (MJ of ME/kg)	12.8	13.3	13.4	11.9	12.6	12.7	13.0
DM (%)	88.2	88.4	88.3	87.7	88.1	88.1	87.8
CP (%)	22.1	19.3	18.5	19.6	18.9	17.5	16.5
Lipid (%)	6.8	8.6	8.4	3.5	5.7	5.4	5.3
Crude fiber (%)	2.5	2.5	2.5	3.0	2.6	2.5	2.4
Ash (%)	5.5	4.8	4.4	5.6	5.1	4.4	4.5

[1]Provided the following per kilogram of diet: vitamin A (retinyl acetate), 13,000 IU; vitamin D_3 (cholecalciferol), 4,000 IU; vitamin E (DL-α-tocopheryl acetate), 80 IU; vitamin K (menadione sodium bisulfite), 3 mg; riboflavin, 6.0 mg; pantothenic acid, 6.0 mg; niacin, 20 mg; pyridoxine, 2 mg; folic acid, 0.5 mg; biotin, 0.10 mg; thiamine, 2.5 mg; vitamin B_{12}, 20 mg; Mn, 120 mg; Zn, 90 mg; Fe, 30 mg; Cu, 10 mg; I, 1.5 mg; Se, 0.2 mg; ethoxyquin, 100 mg of ME.

jected to a total feed withdrawal of 8 to 12 h, including a holding time at the processing plant of 2 to 3 h.

Female birds of both production systems were separately slaughtered from males, with 1 mo difference between processing. The birds were subsequently processed under commercial conditions using electrocution (120 V, 200 Hz, 90 mA/bird) as the stunning system. After being air-chilled (precooling at 5°C for 60 min, followed by chilling at 0°C for 90 min), 20 carcasses per each market class and flock were randomly collected and carcass yields were determined according to the method described by WPSA (1984) to obtain the main commercial parts [breast, thigh, drumstick, wing, and frame (carcass without breast, wings, and legs)]. Moreover, 12 carcasses of each group (total number of 96 carcasses, equally divided by production system and sex) were randomly selected and used to assess quality properties and oxidation stability of breast and thigh meat. All carcasses were kept at 1 to 2°C before sampling. For each carcass, right pectoralis major and ilio tibialis muscles were used at 48 h postmortem to assess color (both skin and meat), ultimate pH, drip and cooking losses, and Allo-Kramer shear force. Moreover, left pectoralis major (skinless) and deboned thigh muscles (skin-on) were removed from each carcass at 48 h postmortem, immediately minced, packed in plastic bags under vacuum, covered with aluminum foil, and kept at –18°C; these samples were used to determine moisture, protein, lipid, ash, and collagen contents, as well as fatty acid (**FA**) composition, peroxide value (**PV**), and TBA reactive substances (**TBARS**). Lipid extraction and both lipid oxidation parameters were determined the week after sample processing; the same timing and modus operandi were followed in all cases.

Analytical Methods

Color Measurement. The International Commission on Illumination (CIE, 1976) system color profile of lightness (L*), redness (a*), and yellowness (b*) was performed by a reflectance colorimeter (Minolta Chroma Meter CR-400, Minolta Italia S.p.A., Milano, Italy) using illuminant source C. The color measurements were carried out averaging 3 measurements on both breast and thigh pterylae (skin color), as well as pectoralis major and ilio tibialis muscles (meat color). The selected areas for color measurements were free of obvious color defects (bruises, discolorations, hemorrhages, full blood vessels, or any other condition that may have affected uniform color reading).

pH Measurement. Breast and thigh meat pH was measured using a modified version of the iodoacetate method described by Jeacocke (1977). Approximately 2.5 g of meat were removed from the cranial end of each pectoralis major muscle, minced by hand, and homogenized for 30 s in 25 mL of a 5 m*M* iodoacetate solution with 150 m*M* of potassium chloride. The pH of the homogenate was determined using a pH meter (Crison Basic 201, Crison Strumenti S.p.A, Carpi, Italy) calibrated at pH 4.0 and 7.0.

Drip and Cook Loss Determination. A sample (7 × 3 × 2 cm) weighing about 50 g was obtained from the cranial part of each pectoralis major muscle, whereas a second sample (6 × 3 × 1.5 cm) weighing about

30 g was excised from each ilio tibialis muscle. Both samples were used to assess drip loss, cook loss, and Allo-Kramer shear force. Drip loss was measured by keeping samples suspended in covered plastic boxes on sieved plastic racks for 48 h at 2 to 4°C and calculated as percentage of weight loss during storage. Cook loss was also measured by cooking samples after drip loss determination on aluminum trays in a convection oven at 180°C until 80°C at core sample. The samples were then allowed to equilibrate to room temperature, reweighed, and cook loss was determined as percentage of weight loss (Petracci and Baéza, 2011).

Shear Value Determination. Shear values were determined using a TA.HDi Heavy Duty texture analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with an Allo-Kramer shear cell. After cooking and covered storage in a refrigerator for 2 h, a strip from each pectoralis major (approximately 4 × 2 × 1 cm) and ilio tibialis muscle (approximately 3 × 2 × 0.7 cm) was excised parallel to the fiber direction and sheared with the blades at a right angle to the fibers using a 250 kg load cell and cross head speed of 500 mm/min, as described by Sams et al. (1990). Shear values are reported as kilograms of shear per gram of sample.

Proximate Analysis. Proximate analysis (moisture, protein, and ash contents) was carried out on both breast and thigh meat. Moisture and ash were determined in duplicate according to the Association of Official Analytical Chemists procedure (AOAC, 1990). Proteins were determined using the standard Kjeldahl copper catalyst method (AOAC, 1990). Finally, collagen was determined on breast meat following the modified colorimetric method of Kolar (1990) and total collagen content was calculated by multiplying the amount of hydroxyproline by 7.5.

Lipid Extraction. Lipids were extracted according to a modified version (Boselli et al., 2001) of the method described by Folch et al. (1957). The frozen samples were minced and were homogenized (21,500 rpm, for 3 min) with 200 mL of a chloroform:methanol solution (1:1, vol/vol) in a glass bottle with screw cap. The bottle was kept in an oven at 60°C for 20 min before adding 100 mL chloroform. After 2 min of homogenization (21,500 rpm), the content of the bottle was filtered through filter paper to eliminate the solid residue, which mostly consisted of proteins. The filtrate was thoroughly mixed with 100 mL of a 1 *M* KCl solution and left overnight at 4°C to obtain phase separation. The lower phase containing the lipids was collected and dried with a rotary evaporator. The fat content was determined gravimetrically. Two lipid extractions were performed for each sample.

Determination of FA Composition. About 20 mg of lipid extract were methylated with 200 μL of diazomethane (Fieser and Fieser, 1967); 1.01 mg of tridecanoic acid methyl ester was added (as internal standard), and the mixture was transmethylated with 40 μL of 2 *N* KOH in methanol (European Commission, 2002), vortexed for 1 min, left standing for 5 min, and centrifuged at 1,620 × *g* for 5 min. Supernatant was transferred to a vial before being injected into a gas chromatograph coupled to a flame ionization detector (GC-FID). The GC-FID instrument was a GC8000 series (Fisons Instruments, Milan, Italy) interfaced with an autosampler and a computerized system for data acquisition (Chromcard Data System, ver. 2.3.1, Fisons Instruments). A RTX 2330 fused-silica column (105 m × 0.25 mm × 0.2 μm film thickness; Restek, Bellefonte, PA) coated with 90% biscyanopropyl- and 10% cyanopropylphenyl-polysiloxane was used. Oven temperature was programmed from 60°C to 240°C at a rate of 10°C/min; the final temperature was kept for 30 min. The injector and detector temperatures were both set at 250°C. Helium was used as carrier gas at a constant pressure of 260 kPa. The split ratio was 1:50. Two replicates were run per sample. Tridecanoic acid methyl ester was used as internal standard for FA quantification, and peak identification was carried out by comparing the peak retention times with those of the GLC 463 fatty acid methyl ester (**FAME**) standard mixture. The GC response factor of each FA was calculated by using the GLC 463 FAME standard mixture and the internal standard (C13:0). The limit of detection of FAME was 0.0035 mg, whereas the limit of quantification was 0.011 mg. The limit of detection and limit of quantification were calculated as a signal-to-noise ratios equal to 3:1 and 10:1, respectively.

Determination of PV. Peroxide value was determined using a modified version of the method of Shantha and Decker (1994). Briefly, 20 mg of extracted lipids were mixed with 9.8 mL of choloform:methanol (2:1, vol/vol) and 50 μL of thiocyanate/Fe^{2+} solution and then vortexed. After 5 min, the absorbance was measured at 500 nm using a double beam UV-VIS spectrophotometer (Jasco model V-550, Jasco International, Tokyo, Japan). The PV was calculated using a Fe (III) standard calibration curve with a concentration range of 0.1 to 5 μg/mL ($y = 0.0311x - 0.0375$; $r^2 = 0.998$). Peroxide value was expressed as mEq of O_2/kg of fat. Two replicates were run per sample.

Determination of TBARS. Thiobarbituric acid reactive substances were used to evaluate secondary lipid oxidation products by using the method of Tarladgis et al. (1960). Briefly, 8 mL of phosphate buffer aqueous solution at pH 7 were added to 2 g of meat in a 25-mL Sovirel tube and the resulting mixture was homogenized using an Ultra-Turrax T 25 BASIC (Ika-Werke, Staufen, Germany). Two milliliters of a 30% (vol/vol) trichloroacetic acid aqueous solution was then added to the sample mixture, homogenized, and filtered. Five milliliters of 0.02 *M* aqueous solution of TBA was added to 5 mL of the resulting sample solution in capped tubes, which were stored at 90°C for 20 min and then kept at 4°C for 30 min. After centrifugation, the absorbance of the supernatant was measured at 530 nm with a UV spectrophotometer (Jasco model V-550, Jasco International, Tokyo, Japan). For the quantitative determination of TBARS, a 1,1,3,3-tetramethoxypro-

pane standard calibration curve was used with a concentration range of 0.03 to 2.26 μg/mL ($y = 0.0015x - 0.0078$; $r^2 = 0.999$). The TBARS value was expressed as milligrams of malondialdehyde (**MDA**) per kilogram of sample. Two replicates were run per sample.

Statistical Analysis. Data were analyzed by means of one-way-ANOVA (GLM/PASW procedure) to test the effect of production system (C vs. FR) on carcass and meat quality traits within each carcass type (rotisserie and cut-up). Each bird was considerate as a replicate unit. Overall differences between rearing means were tested according to Tukey's test, performed at a 95% confidence level, and considered to be significant when $P < 0.05$ (PASW Statistics, 17).

RESULTS AND DISCUSSION

Carcass Part Yield

Carcass part yields mainly reflected genetic differences in breeds used for C (Ross 708) and FR (ISA) systems (Table 2). Free-range rotisserie carcasses exhibited a dramatic lower breast yield (31.3 vs. 37.4%; $P < 0.01$) in favor of higher proportion of legs (31.6 vs. 28.3%; $P < 0.01$) and their parts (thighs and drumstick), wings (12.0 vs. 10.5%; $P < 0.01$) and frame (25.1 vs. 23.8%; $P < 0.01$). These remarkable differences were essentially confirmed in cut-up carcasses, even though the drumstick proportion was higher with respect to thigh in both production systems. Overall, these results agree with previous studies when different genotypes were used (Fanatico et al., 2005, 2008; Wang et al., 2009; Sirri et al., 2011). Fanatico et al. (2008) evidenced that also production system (outdoor vs. indoor) contributed to increase leg yield in both fast- and slow-growing birds as a consequence of their increased activity when provided outdoor access.

Meat Quality

Skin and meat color traits are reported in Tables 3 and 4. Color is an appearance property that is important to consumers when they buy meat products (Fletcher, 2002). Skin color is most critical for the marketing of fresh carcasses or skin-on parts (e.g., legs). The most relevant differences were found in yellowness coordinate (b*), which is dramatically higher in FR skin rotisserie and cut-up carcasses in both breast and thigh. This marked diversity reflects differences in carotenoid levels of the diets. Free-range birds received a corn-based diet, which allowed them to obtain a deeply yellow pigmented skin that is desired to get very distinct FR products with a traditional appearance. On the contrary, the C birds were fed a wheat-based diet, which resulted in a white skin color that is the prevalent appearance for conventional production, even though there are special regional consumer preferences within Italian regions. As evidenced by other studies, the consumption of vegetation present in outdoor spaces can also contribute to increased skin yellowness (Fanatico et al., 2007). It is important to note that yellowness was also remarkably higher in both FR breast and thigh meat. This result is in agreement with Bianchi et al. (2007), who found a strong relationship between the yellowness of the skin and breast meat. It can be argued that dietary carotenoid pigments are deposited not only in the epidermis and fat depots, but also in muscle intramuscular and intracellular lipids. Because the color of raw poultry meat is critical for consumer selection, this noteworthy difference can highly contribute to differentiate FR products when marketed fresh as whole carcass and skin-on parts, but also in the form of skinless meat. It means that the nutritional profile of diet is the major environmental (nongenetic) factor in commercial production (Zhao et al., 2012). Differences in lightness (L*) and redness (a*) are of little practical importance. Overall, meat lightness was lower in FR birds with the exception of cut-up breast where it did not differ between groups. Difference in meat redness was significant only in breast meat, being higher in C products. Meat quality traits are shown in Tables 3 and 4. Within rotisserie carcasses, FR birds exhibited significantly higher ultimate pH values in both breast and thigh. In a previous study, it was observed that slow-growing birds showed a more intense and rapid struggling activity between hanging and stunning in

Table 2. Carcass parts yield of rotisserie and cut-up carcasses obtained from chickens farmed under conventional (C) and free-range (FR) production systems (mean ± SEM)

Item	Carcass (n)	Carcass weight (CW; g)	Breast[1] (% CW)	Breast meat[2] (% CW)	Legs[1] (% CW)	Thighs[1] (% CW)	Drumsticks[1] (% CW)	Wings[1] (% CW)	Frame[1] (% CW)
Rotisserie									
C	20	1.215 ± 8	37.4 ± 0.3^{A}	29.6 ± 0.3^{A}	28.3 ± 0.3^{B}	14.2 ± 0.3^{B}	14.1 ± 0.2^{B}	10.5 ± 0.1^{B}	23.8 ± 0.3^{A}
FR	20	1.213 ± 16	31.3 ± 0.4^{B}	22.2 ± 0.3^{B}	31.6 ± 0.4^{A}	16.4 ± 0.3^{A}	15.2 ± 0.2^{A}	12.0 ± 0.2^{A}	25.1 ± 0.5^{B}
Probability		NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cut-up									
C	20	2.299 ± 46^{A}	37.5 ± 0.4^{A}	30.3 ± 0.4^{A}	27.7 ± 0.3^{B}	12.8 ± 0.3^{B}	14.8 ± 0.1^{B}	9.7 ± 0.1^{B}	25.2 ± 0.5^{A}
FR	20	1.913 ± 14^{B}	30.1 ± 0.3^{B}	21.1 ± 0.3^{B}	31.0 ± 0.3^{A}	14.7 ± 0.2^{A}	16.3 ± 0.1^{A}	12.0 ± 0.1^{A}	26.9 ± 0.4^{B}
Probability		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

^{A,B}Means within a column followed by different superscript letters differ significantly ($P < 0.01$).

[1]With bone and skin.

[2]Without bone and skin.

the slaughtering line with respect to heavy or fast-growing lines, thus causing a reduction of glycogen content at death and a decrease of ultimate pH (Debut et al., 2005). These results could also be linked to the thermogenesis for the energy cost (ATP metabolism), which is upregulated to increase heat production (Silva, 2006). Animals exposed to cool temperatures, such as FR birds, had a lower available postmortem adenosine triphosphate, which can result in higher pH value and reduced drip loss (Schneider et al., 2012). Le Bihan-Duval et al. (2008) had suggested that ultimate pH is a relevant selection criterion to improve meat characteristics, besides genetic selection, because the ultimate pH parameter can be strongly correlated to meat color, water-holding capacity, and texture. In contrast, breast meat pH obtained from cut-up carcass was higher in C group and no modifications were observed in thigh meat pH. This dissimilar behavior could be due to the different bird sex and age at slaughter. Bianchi et al. (2007) found that conventional rotisserie carcasses (1.2 kg) had lower breast meat pH than medium (1.6 kg) and heavy (2.4 kg) broilers. Moreover, Berri et al. (2007) showed that male birds slaughtered at advanced slaughter age selected for rapid growth and high breast meat yield tended to produce meat with a higher ultimate pH. Nevertheless, it is well known that differences in ultimate pH are strictly associated with different water-holding capacity behaviors (Petracci et al., 2004). In spite of these conflicting pH results, overall FR meats exhibited significant lower drip and cooking losses. As a consequence, different water holding abilities cannot be fully explained by pH differences, but may be due to difference in muscle characteristics. Conventional products of both commercial types were obtained from a fast-growing genotype, which is characterized by muscle hypertrophy and large fiber diameter. When studying the consequence of muscle hypertrophy on characteristics of pectoralis major muscle and breast meat quality of broiler chickens, Berri et al. (2007) found a significant effect of sex on most traits under study. Therefore, comparing male and female chickens could be helpful to assess the impact of increased muscle fiber diameter on muscle and meat properties between muscles with similar weights. The greater muscle fiber diameter in females was associated with an increased plasma creatine kinase activity. Consequently, it can be suggested that plasma creatine kinase activity may also reflect the protein turnover, which is closely related to muscle growth rate. Moreover, conventional birds were slaughtered at lower age and this may be associated with a lower collagen thickness and crosslinking (McCormick, 1999; An et al., 2010). Both these elements may be the cause of lower water-holding capacity observed in C breast and thigh meat. Although no differences were found in Allo-Kramer shear values measured in breast meat, FR thigh in both rotisserie (2.54 vs. 1.89 kg/g; $P < 0.01$) and cut-up carcasses (3.08 vs. 2.18 kg/g; $P < 0.01$) had higher shear force. These results were associated with a higher collagen content of both commercial categories (Table 6), which could be due to older slaughtering age that led to thicker collagen layers, mainly at the perimysium level (An et al., 2010).

Chemical Composition

Tables 5 and 6 show the effects of rearing systems on the chemical composition (moisture, protein, lipid, and ash) of the breast (skinless) and thigh (with skin) meat. In both rotisserie and cut-up categories, C breast meat had significantly higher lipid and moisture contents. Moreover, C cut-up carcasses exhibited a lower protein content. In thigh meat, on the contrary, the production system did not significantly affect the chemical composition, except for the protein content, which is higher in FR cut-up carcasses. Wang et al. (2009) found that nutrient composition (water, protein, and fat) of the chicken muscle were not influenced ($P > 0.05$) by the FR system, but the latter had a significant impact on reduction of abdominal fat. Moreover, Fanatico et al. (2005) demonstrated that pectoralis major muscle DM (%), fat (%), and ash (%) were not affected ($P > 0.05$) by genotype or outdoor access, demonstrating that FR production system had a limited effect on fat content of breast meat. Castellini et al. (2002), in agreement with Wang et al. (2009), showed that FR rearing could favor a higher energy consumption, improving lipogenesis and increasing motor activity that leads to less abdominal fat on carcass traits. The latter can be explained considering that neutral lipids (triacylglycerol), mainly rich in saturated and monounsaturated fatty acids, are found in the intramuscular adipocytes (adipose tissue) located in the perimysium (Sanosaka et al., 2008). Breast meat contains more phospholipids than thigh meat, where the predominant lipid class are triacylglycerols (Gonzalez-Esquerra and Leeson, 2001). However, a large data variation on intramuscular fat content of breast muscles has been observed in the literature, which might be attributed to both sampling and analytical procedures used (Cortinas et al., 2004). Lipid content of breast meat found in the present study is in agreement with those of previous works (Du and Ahn, 2002; Barroeta, 2007). Moreover, our results are consistent with recent studies that show how free-range system can reduce muscle fat content (Fanatico et al., 2007; Bogosavljevic-Boskovic et al., 2010; Chen et al., 2013).

FA Composition

Tables 7 and 8 report the effects of rearing systems on the FA composition (expressed as %) of breast and thigh meat chicken. In breast meat, the most abundant FA was oleic acid, followed by linoleic, palmitic, and stearic acids; thigh meat showed a similar FA abundance order, but with different percentage distribution. Among PUFA, arachidonic acid was the most abundant FA in breast meat, followed by linolenic and docosahexaenoic acids; in thigh meat, the main PUFA was lin-

Table 3. Skin and meat color (L*a*b*) and quality characteristics of breast meat (pectoralis major muscle) of rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems (mean ± SEM)[1,2]

	Skin			Meat						
Item	L*	a*	b*	L*	a*	b*	pH_u	Drip loss (%)	Cooking loss (%)	Shear force (kg/g)
Rotisserie										
C	77.2 ± 0.3^{A}	5.0 ± 0.4^{A}	12.8 ± 0.4^{B}	58.9 ± 0.5^{A}	2.0 ± 0.2^{A}	3.8 ± 0.2^{B}	5.77 ± 0.03^{b}	1.53 ± 0.10^{A}	19.6 ± 0.5^{A}	2.36 ± 0.15
FR	75.1 ± 0.5^{B}	1.5 ± 0.4^{B}	29.1 ± 1.7^{A}	54.6 ± 0.5^{B}	0.8 ± 0.3^{B}	9.9 ± 0.9^{A}	5.85 ± 0.02^{a}	1.12 ± 0.04^{B}	16.6 ± 0.4^{B}	2.35 ± 0.11
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	NS
Cut-up										
C	75.9 ± 0.6^{A}	5.9 ± 0.6^{A}	12.0 ± 0.3^{B}	55.4 ± 0.9	2.0 ± 0.2^{A}	3.0 ± 0.2^{B}	5.84 ± 0.04^{a}	1.46 ± 0.14^{a}	21.8 ± 0.6^{A}	2.14 ± 0.07
FR	72.1 ± 0.6^{B}	1.2 ± 0.4^{B}	32.3 ± 0.7^{A}	54.1 ± 0.7	0.9 ± 0.2^{B}	12.8 ± 0.4^{A}	5.72 ± 0.02^{b}	1.14 ± 0.04^{b}	17.2 ± 0.2^{B}	2.29 ± 0.08
P-value	<0.01	<0.01	<0.01	NS	<0.01	<0.01	<0.05	<0.05	<0.01	NS

$^{A,B}P < 0.01$; $^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates.

[2]L* = lightness; a* = redness; b* = yellowness; pH_u = ultimate pH.

Table 4. Skin, meat color, and quality characteristics of thigh meat of rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems (mean ± SEM)[1,2]

	Skin			Meat						
Item	L*	a*	b*	L*	a*	b*	pH_u	Drip loss (%)	Cooking loss (%)	Shear force (kg/g)
Rotisserie										
C	75.0 ± 0.5^{a}	2.0 ± 0.2^{A}	8.9 ± 0.4^{B}	56.7 ± 0.7^{a}	2.2 ± 0.2	3.1 ± 0.3^{B}	6.16 ± 0.04^{b}	1.35 ± 0.09^{A}	15.1 ± 0.6^{A}	1.89 ± 0.07^{B}
FR	73.0 ± 0.5^{b}	-0.1 ± 0.3^{B}	23.4 ± 1.4^{A}	54.1 ± 0.6^{b}	1.4 ± 0.3	9.7 ± 0.9^{A}	6.26 ± 0.03^{a}	1.05 ± 0.05^{B}	12.4 ± 0.3^{B}	2.54 ± 0.10^{A}
P-value	<0.05	<0.01	<0.01	<0.05	NS	<0.01	<0.05	<0.01	<0.01	<0.01
Cut-up										
C	77.9 ± 0.4^{A}	2.7 ± 0.3^{A}	10.0 ± 0.4^{B}	57.7 ± 0.6^{A}	2.2 ± 0.2	1.7 ± 0.2^{B}	6.17 ± 0.02	1.18 ± 0.05	18.3 ± 0.6^{A}	2.18 ± 0.13^{B}
FR	72.1 ± 0.5^{B}	0.2 ± 0.6^{B}	32.1 ± 1.0^{A}	54.0 ± 0.3^{B}	1.6 ± 0.2	9.5 ± 0.4^{A}	6.13 ± 0.02	1.14 ± 0.04	13.2 ± 0.2^{B}	3.08 ± 0.11^{A}
P-value	<0.01	<0.01	<0.01	<0.01	NS	<0.01	NS	NS	<0.01	<0.01

$^{A,B}P < 0.01$; $^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates.

[2]L* = lightness; a* = redness; b* = yellowness; pH_u = ultimate pH..

Table 5. Chemical composition and oxidative stability of breast meat (pectoralis major muscle) of rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems (mean ± SEM)[1]

Item	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)	Collagen (%)	PV (mEq of O_2/kg of lipids)	TBARS (mg of MDA/kg of meat)
Rotisserie							
C	73.35 ± 0.16^{A}	23.27 ± 0.20	1.04 ± 0.03^{a}	1.18 ± 0.01	1.13 ± 0.01^{b}	1.06 ± 0.10	0.15 ± 0.01^{b}
FR	72.52 ± 0.21^{B}	23.53 ± 0.35	0.89 ± 0.03^{b}	1.17 ± 0.01	1.26 ± 0.03^{a}	1.02 ± 0.09	0.19 ± 0.01^{a}
P-value	<0.01	NS	<0.05	NS	<0.05	NS	<0.05
Cut-up							
C	73.36 ± 0.10^{A}	22.79 ± 0.27^{b}	1.71 ± 0.04^{a}	1.13 ± 0.03^{b}	1.26 ± 0.03	0.79 ± 0.09	0.06 ± 0.00^{b}
FR	72.34 ± 0.10^{B}	23.65 ± 0.14^{a}	1.07 ± 0.03^{b}	1.22 ± 0.03^{a}	1.33 ± 0.03	0.97 ± 0.09	0.15 ± 0.03^{a}
P-value	<0.01	<0.05	<0.05	NS	NS	NS	<0.05

$^{A,B}P < 0.01$; $^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates. PV = peroxide value; TBARS = TBA reactive substances; MDA = malondialdehyde.

Table 6. Chemical composition and oxidative stability of thigh meat (skin-on) rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems (mean ± SEM)[1]

Item	Moisture (%)	Protein (%)	Lipid (%)	Ash (%)	Collagen (%)	PV (mEq of O_2/kg of lipids)	TBARS (mg of MDA/kg of meat)
Rotisserie							
C	68.27 ± 0.37	17.84 ± 0.43	11.56 ± 0.35	1.03 ± 0.03	2.11 ± 0.05^{b}	0.46 ± 0.05^{a}	0.12 ± 0.01
FR	67.94 ± 0.34	18.63 ± 0.34	10.80 ± 0.32	1.01 ± 0.03	2.73 ± 0.11^{a}	0.30 ± 0.03^{b}	0.12 ± 0.01
P-value	NS	NS	NS	NS	<0.05	<0.05	NS
Cut-up							
C	68.68 ± 0.28	17.91 ± 0.21^{b}	10.40 ± 0.42	1.01 ± 0.02	2.47 ± 0.07^{b}	1.29 ± 0.43	0.10 ± 0.00
FR	68.36 ± 0.23	18.61 ± 0.17^{a}	10.73 ± 0.35	0.99 ± 0.03	3.02 ± 0.09^{a}	0.66 ± 0.15	0.13 ± 0.02
P-value	NS	<0.05	NS	NS	<0.05	NS	NS

$^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates. PV = peroxide value; TBARS = TBA reactive substances; MDA = malondialdehyde.

Table 7. Fatty acid composition (as % of total fatty acids) of breast meat (pectoralis major muscle) of rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems[1]

Item	C14:0	C16:0	C16:1 (n-7)	C18:0	C18:1 (n-9)	C18:2 (n-6)	C20:0	C18:3 (n-3)	C20:4 (n-6)	C22:6 (n-3)	ΣSFA	ΣMUFA	Σ PUFA	Σ n-3	Σ n-6	Σ n-6/ Σ n-3	Σ UFA/ Σ SFA	Σ SFA/ Σ PUFA	Δ desaturase
Rotisserie																			
C	0.36	20.69^{b}	2.58	9.21	27.38	25.40^{a}	0.08^{a}	1.90^{a}	4.63^{b}	0.40^{b}	30.57^{b}	32.50^{a}	36.89	3.67	32.87	9.06^{b}	2.29^{a}	0.83^{b}	22.51^{b}
FR	0.35	23.07^{a}	2.38	9.66	26.43	23.20^{b}	0.06^{b}	1.09^{b}	6.72^{a}	0.70^{a}	33.34^{a}	29.45^{b}	37.17	3.32	33.61	10.24^{a}	2.00^{b}	0.90^{a}	28.88^{a}
P-value	NS	<0.05	NS	NS	NS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NS	NS	NS	<0.05	<0.05	<0.05	<0.05
Cut-up																			
C	0.38	19.84^{b}	3.72^{a}	6.58^{b}	31.69^{a}	28.47^{a}	0.07	2.68^{a}	2.33^{b}	0.25^{b}	27.06^{b}	36.24^{a}	36.51	3.75	32.62	8.70^{b}	2.71^{a}	0.74^{b}	11.35^{b}
FR	0.40	23.50^{a}	2.97^{b}	8.96^{a}	26.91^{b}	25.81^{b}	0.07	1.55^{b}	5.51^{a}	0.64^{a}	33.16^{a}	30.49^{b}	37.88	3.54	34.14	9.67^{a}	2.07^{b}	0.88^{a}	23.00^{a}
P-value	NS	<0.05	<0.05	<0.05	<0.05	<0.05	NS	<0.05	<0.05	<0.05	<0.05	<0.05	NS	NS	NS	<0.05	<0.05	<0.05	<0.05

$^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates. SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids.

Table 8. Fatty acid composition (as % of total fatty acids) of thigh meat (skin-on) of rotisserie and cut-up carcasses yielded from chickens farmed under conventional (C) and free-range (FR) production systems[1]

Item	C14:0	C16:0	C16:1 (n-7)	C18:0	C18:1 (n-9)	C18:2 (n-6)	C20:0	C18:3 (n-3)	C20:4 (n-6)	C22:6 (n-3)	Σ SFA	Σ MUFA	Σ PUFA	Σ n-3	Σ n-6	Σ n-6/ Σ n-3	Σ UFA/ Σ SFA	Σ SFA/ Σ PUFA	Δ desaturase
Rotisserie																			
C	0.41	18.71^{b}	3.91^{b}	5.71^{b}	35.55^{b}	29.60^{a}	0.08	2.87^{a}	0.70^{b}	0.06	25.07^{b}	40.45^{b}	34.28	3.11	31.11	10.01^{b}	3.07^{a}	0.75^{b}	3.59^{b}
FR	0.46	21.02^{a}	4.45^{a}	6.00^{a}	36.75^{a}	26.24^{b}	0.08	1.99^{b}	0.85^{a}	0.06	30.20^{a}	41.98^{a}	30.16	2.21	27.89	12.64^{a}	2.52^{b}	1.00^{a}	4.47^{a}
P-value	NS	<0.05	<0.05	<0.05	<0.05	<0.05	NS	<0.05	<0.05	NS	<0.05	<0.05	NS	NS	NS	<0.05	<0.05	<0.05	<0.05
Cut-up																			
C	0.40^{b}	19.64	4.27	5.50	34.65	29.77	0.08	2.98^{a}	0.75^{b}	0.05^{b}	25.86	39.47	34.56	3.22^{a}	31.29	9.73^{b}	2.90	0.75^{b}	3.65^{b}
FR	0.48^{a}	20.99	4.52	5.83	34.50	28.15	0.08	2.30^{b}	0.99^{a}	0.08^{a}	27.65	39.62	32.63	2.56^{b}	30.02	11.71^{a}	2.63	0.85^{a}	4.72^{a}
P-value	<0.05	NS	NS	NS	NS	NS	NS	<0.05	<0.05	<0.05	NS	NS	NS	<0.05	NS	<0.05	NS	<0.05	<0.05

$^{a,b}P < 0.05$. Means within a column followed by different superscript letters differ significantly.

[1]Each value is the average of 12 replicates. SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids.

olenic acid. These results are in agreement with those reported by Ponte et al. (2008) and Betti et al. (2009a).

Regarding the FA classes, PUFA was the most abundant FA class in breast (~37–38%), whereas monounsaturated FA (**MUFA**) and saturated FA (**SFA**) accounted for ~30 to 36% and ~27 to 33% of total FA, respectively. On the contrary, the most relevant FA class in thigh meat was MUFA (~39–42% of total FA), followed by PUFA (~30–34%) and SFA (~25–30%). Cortinas et al. (2004) also observed a higher incorporation of PUFA in breast than in thigh meat. These differences could be ascribed to the role of FA in these tissues or to the phospholipid contents (Hulan et al., 1988; Ratnayake et al., 1989).

As shown in Tables 7 and 8, the C and FR systems differently affected breast and thigh FA composition in rotisserie and cut-up categories, despite the data variability due to the nature of samples. In general, the FR system resulted in a significantly ($P < 0.05$) higher level of SFA with respect to the conventional one (except for cut-up thigh meat), which could be mainly ascribed to the palmitic acid content. Conventional rearing, instead, led to a significantly ($P < 0.05$) higher MUFA level in breast, being mostly related to the amount of oleic acid; the opposite trend was noted in rotisserie thigh meat. No significant effects of the rearing system were observed in the total PUFA levels of both commercial categories of breast and thigh. However, it must be pointed out that the C system significantly ($P < 0.05$) increased the level of linoleic and linolenic acids in both breast and thigh meat (except for cut-up thigh). The PUFA n-3 content was only significantly higher in thigh meat from birds reared by C system. Givens et al. (2011) found that FR breast and leg meat contained significantly less total PUFA (n-6 and n-3) than those from intensive rearing.

The differences observed in the FA composition of poultry meat obtained with the 2 rearing systems in the present study can be attributed to a great extent to the different types and amounts of oils (sunflower and soybean oils) used in the FR and C diets, respectively (Table 1). In fact, sunflower oil has a higher linoleic acid content than soybean oil, whereas the latter is characterized by a higher level of palmitic and linolenic acids (Gunstone et al., 1986). In addition, chicken grown with the FR rearing had access to grassland areas, so they could have eaten grass, insects, and worms.

The FR rearing led to a significantly higher n-6/n-3 and SFA/PUFA in both breast and thigh meat, but UFA/SFA ratio was significantly lower. Givens et al. (2011) reported that FR breast and leg meat had a higher PUFA n-6/n-3 ratio (7.9) than those from intensive rearing (6.0). It must be noted that, in the present study, the PUFA n-6/n-3 ratio (8.7–10.2 and 9.7–12.7 in breast and thigh, respectively) was always higher than the one suggested (<4) for a healthy human diet (Simopoulos, 1999).

The Δ-desaturase index [(C20:2n-6 + C20:4n-6 + C20:5n-3 + C22:5n-3 + C22:6n-3/C18:2n-6 + C18:3n-3 + C20:2n-6 + C20:4n-6 + C20:5n-3 + C22:5n-3 + C22:6n-3) × 100] is useful to evaluate the activity of both Δ^5- and Δ^6-desaturases, which are enzymes that catalyze the formation of PUFA n-6 and n-3. Free-range rearing led to a significantly higher Δ-desaturase index in both breast and thigh meat, but the Δ-desaturase activity levels in thigh meat were about 3 to 6 times lower than in breast meat. The reduced Δ^5-desaturase activity indicates that linolenic acid suppress bioconversion of arachidonic acid from linoleic acid (Garg et al., 1988). The FA composition of feeding will affect therefore Δ^5-desaturase activity as confirmed by Betti et al. (2009a), who noted a strong decrease in the enzyme activity in poultry meat supplemented by flaxseed. The low Δ-desaturase index found in poultry meat from C system can be partly ascribed to the dietary oil, as soybean oil is characterized by a higher content of linolenic acid (Gunstone et al., 1986). Another aspect that might have contributed is that free-reared chicken could have also eaten grass, insects, and worms. This aspect might partly explain some differences between the higher level of PUFA (such as arachidonic acid) and more Δ-desaturase activity in meat obtained with FR system, especially in breast. In addition, essential FA (linoleic and linolenic acids) are precursors of the long-chain PUFA n-6 and n-3 series so, besides being absorbed, essential FA are elongated and desaturated to give rise to long-chain PUFA n-6 and n-3 (such as arachidonic and docosahexaenoic acid).

Lipid Oxidation

Tables 5 and 6 show the effects of rearing on the PV and TBARS of breast and thigh meat. In general, a low lipid oxidation level was observed in all samples, which was confirmed by both primary and secondary oxidation products parameters; these data are in agreement with those reported in literature (Barroeta, 2007; Betti et al., 2009b). In fact, low PV (0.79–1.06 and 0.30–1.29 mEq O_2/kg of lipid in breast and thigh, respectively) and TBARS (0.06–0.19 and 0.10–0.13 mg of MDA/kg of sample in breast and thigh, respectively) were found, regardless of the commercial category. Both oxidation parameters are far below the PV level (20 mEq of O_2/kg of lipids) associated with oil rancidity, and below TBARS level (1 mg of MDA/kg of sample) associated with lamb meat rancidity (Ripoll et al., 2011). However, in the rotisserie and cut-up categories, only the FR system led to a significantly higher TBARS content in breast meat. On the contrary, the C system significantly increased PV only in rotisserie thigh meat. In the cut-up category, the factorial analysis shows no significant differences due to rearing on the oxidative stability of thigh meat. Although it is usually expected that the C system causes more stress than FR one, a good and similar oxidative stability was observed in samples from both types of breeding systems. Several studies report that dietary polyunsaturation level significantly affect TBARS values (Cortinas et al., 2005);

in the present study, no significant differences were observed in the total PUFA levels of both commercial categories of breast and thigh, even though the C system significantly increased the level of linoleic and linolenic acids mainly due to the use of soybean as dietary oil. However, different studies (Castellini et al., 2002, 2008) have reported a higher TBARS in meat from free-reared poultry, which could be due to the higher content of metallic ions (total and heme Fe) that catalyze peroxidation, and to the greater degree of unsaturation of intramuscular lipids. In addition, more natural rearing conditions also increase motor activity, which in turn favors muscle oxidative metabolism and free radical production, thus favoring lipid peroxidation (Castellini et al., 2002).

In conclusion, if compared with C carcass and meat, FR products were characterized by a very distinct appearance due to the different conformation (higher proportion of leg and wing meat to the detriment of breast) and yellower (>b*) skin and meat color, as well as to their remarkable higher ability to retain water during both refrigerated storage and cooking. Moreover, thigh meat had higher shear values and this can be likely attributed to the greater content and higher degrees of cross-linking of collagen, which may have increased due to the greater slaughter age of birds farmed outdoors (Touraille et al., 1981). It was shown that currently marketed FR products have some extrinsic characteristics (such as longer and leaner thighs, yellower skin), which are very distinct compared with C ones. These characteristics can be recognizable by both retailers and consumers and can allow the products to reach different market segments (large-scale retailers, small butcheries, food store, catering, and so on). Our results demonstrated that FR conditions (in particular dietary oils) can modify the properties and FA composition (higher PUFA n-6-/n-3 ratio) of chicken meat; also of importance is the animal genetic background to select nutritional strategies to improve meat quality traits in poultry. Moreover, FR products displayed a low lipid oxidation level, even after 1 wk of frozen storage (packed under vacuum and protected from light). However, it would be important to verify their oxidative stability during storage under commercial retail conditions (using different storage times and packaging atmospheres) to further ensure the safety and quality characteristics requested by consumers.

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