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The influence of sexual maturity on the meat quality of free-range chickens

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Abstract

This research study aimed to evaluate the influence of sexual maturity on meat quality parameters in chickens raised in a free-range system. The fully randomized design (FRD) used a (2x2) factorial scheme, with two sexes (male and female) and two categories of sexual maturity (immature and mature). Ninety birds (45 females and 45 males) belonging to the Label Rouge (Pescoço Pelado) strain were slaughtered at five different ages (70, 90, 120, 150, and 180 days). The physicochemical parameters, centesimal composition and shelf life of the meat were assessed. In both breast and leg cuts, sexual maturity promoted an increase in shear force and affected the meat color by increasing its redness (a*). Moisture was higher in leg meat after sexual maturity. In both breast and leg cuts, ether extract was higher in sexually mature females. Sexual maturity also caused a decrease in tenderness and shorter shelf life of the meat.

Keywords: sexual maturity; texture; sex.

Practical Application: Chicken meat from free-range system are considered the best meat quality. In Brazil, these chickens are slaughtered at an age below sexual maturity and had meat characteristics similar to conventional system. However, after puberty in the adulthood sex hormones and physiology changes the meat parameters and improving quality parameters considered to expectation by consumers of this product.

1 Introduction

In recent years, there has been an increasing demand for free-range chickens, which have thus become a promising market in the poultry industry. This fact has happened because in chicken produced by conventional industrial system, there are problems related to animal welfare and the number of consumers willing to pay more for products from welfare-friendly systems has been increasing (Martínez-Pérez et al., 2017; Sans et al., 2021). Brazil is the main producer and exporter of chicken meat, and despite having produced 6.2 billion birds and 14.6 million tons of poultry meat in 2021 (Instituto Brasileiro de Geografia e Estatística, 2022), there is not official data about the quantity of birds produced in free-range farms. However, it is expected that the number is lower than other markets from in European countries where the consumption of these products reaches around 35% of source animal protein (Sans et al., 2021).

In Brazil, a "free-range chicken production system" denotes a meat production system that allows birds slow growth and access to pasture, in addition to restricting the use of any growth promoters; the animals are slaughtered between 70 and 120 days of age (Brasil, 2020). Therefore, free-range birds are slaughtered before they reach sexual maturity.

In the literature, studies assessing meat quality parameters for chickens raised in alternative systems and slaughtered between 81 and 85 days of age did not find any difference when comparing them with those of chickens raised in a conventional system (Aguiar et al., 2008; Souza et al., 2011). However, research studies in which birds were slaughtered at 85-110 days of age reported differences, especially in the color (decreasing lightness in the breast (Faria et al., 2009) and leg cuts (Souza et al., 2012); increasing of yellowness in the leg (Faria et al., 2009)), firm texture in the breast and leg meat an older birds (Souza et al., 2012), slight increasing of fat content and decreasing of pH in the breast in free-range chicken meat (Faria et al., 2009; Souza et al., 2012). Nevertheless, the literature lacks studies evaluating the effect of sexual maturity in free-range chicken meat quality.

Sexual maturity may interfere with the final quality parameters of free-range chicken meat (Rose et al., 2016) due to the increase in animal age and the expression of sex hormones (Chen et al., 2006; Faria et al., 2009; Souza et al., 2012). We hypothesized, in the free-range chickens the meat quality change after reaching sexual maturity becomes firm texture and darker color and consequently improve the characteristics this product to the consumer preference. This is main reason that consumers raising expectation and looks for buying this type of product as compared to chicken than conventional system production (Cruz et al., 2018).

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Therefore, this study aimed to evaluate the effect of sexual maturity on the main meat quality parameters of broiler chickens raised in an alternative system.

2 Material and methods

2.1 Animals, experimental delineation, diet and sample collection

For this study, a total of 90 birds were used: 45 males and 45 females belonging to the Label Rouge (Pescoço Pelado) strain. The completely randomized design (CRD) used a (2x2) factorial scheme, with two sexes (male and female) and two categories of sexual maturity (immature and mature). The birds were slaughtered at 70, 90, 120, 150, or 180 days of age and each experimental parcel/repetition was represented by three birds. This project was approved by the Animal Ethics Committee (AEC) of the Federal Institute of Education, Science and Technology of Minas Gerais – Bambuí Campus under number 04/2019.

Feed was provided according to the growth phase of the birds (Table 1). They were kept in a warehouse for 28 days and then relocated to an area adequate for raising free-range chickens. Since of 29 days the birds were reared in an experimental area of free-range poultry production, where there was coverage area of the mobile hut with access to the grazing area with Tifton 85 (Cynodon spp), both feed and water being supplied ad libitum, and the animals overnight stayed there. Males and females were kept at a stocking rate of 3 m^2 per animal of free grazing area.

The birds were slaughtered in a humanitarian method. After evisceration, the carcasses were wrapped, labeled, and cooled in a cool chamber at 5 °C, where they remained for at least three hours. The cuts (breast and legs) were deboned 24 hours *postmortem*, wrapped, labeled, and preserved at -18 °C.

The group of sexually immature animals consisted of birds that did not have fully developed gonads. The sexual maturity of males was determined in accordance with Santos et al. (2012) by measuring the diameter of the seminiferous tubules in their testicles, and birds with a testicular diameter of 119.73 μm were considered sexually mature. For females, sexual maturity was visually determined; those with fully developed follicles were considered mature.

Of the immature males, 18 were slaughtered at 70 days (n = 9) and at 90 days (n = 9), and had an average weight of 2.908 ± 0.318 kg. Of the mature males, 27 were slaughtered at 120 (n = 9), 150 (n = 9), and 180 (n = 9) days of age, and had an average weight of 4.146 ± 0.482 kg. Twenty-one immature females were slaughtered at 70 (n = 9), 90 (n = 9) and 120 days (n = 3) of age, and had an average weight of 2.637 ± 0.255 kg. Of the mature females, 24 were slaughtered at 120 (n = 6), 150 (n = 9) and 180 (n = 9) days of age, and had an average weight of 3.301 ± 0.303 kg.

2.2 Laboratory analysis

A digital pH meter (Hanna Instruments, Model HI 99163) was used to measure last pH meat (24 h) after slaughter. Color

Table 1. Components and composition of Initial, Growth I and II, and Final Feed provided to free-range chickens.

Ingredients (kg)	Initial Feed (1-28 days)	Growth I Feed (29-49 days)	Growth II Feed (50-70 days)	Final Feed (71-180 days)
Corn	64.70	69.10	72.75	73.45
Soybean meal	31.70	27.70	23.85	22.80
Soybean oil	0	0	0.2	0.9
Kaolinite	0	0	0.2	0.2
Limestone	0.1	0.2	0	0.15
Premix for free-range chicken[1]	3.5	3.0	3.0	2.5
Calculated values	**Initial Feed (kg)**	**Growth I Feed (kg)**	**Growth II Feed (kg)**	**Final Feed (kg)**
ME[2] (kcal/kg)	2949.20	2996.13	3047.97	3098.19
CP[3] (%)	20.07	18.50	17.01	16.50
Calcium (%)	1.05	0.9051	0.8663	0.7911
Phosphorus Available (%)	0.4092	0.3609	0.3567	0.3102
Methionine + Cystine (%)	0.6911	0.6370	0.6430	0.5725
Lysine (%)	0.9609	0.8673	0.7789	0.7510
Threonine (%)	0.6778	0.6273	0.5721	0.5522
Tryptophan (%)	0.2292	0.2081	0.1877	0.1816
Choline (mg/kg)	1153.96	1059.73	994.67	945.74
Sodium (mg/kg)	1848.39	1613.59	1611.59	1375.69
Chloride (mg/kg)	3103.34	2744.98	2746.98	2381.02

[1]Guaranteed levels of the premix for free-range chicken: folic acid (min.) 23.33 mg/kg, pantothenic acid (min.) 333.33 mg/kg, B.H.T. (min.) 500 mg/kg, biotin (min.) 0.5 mg/kg, calcium (min.) 240 g/kg, calcium (max.) 270 g/kg, copper (min.) 333 mg/kg, choline (min.) 6.000 mg/kg, iron (min.) 1.667 mg/kg, fluoride (max.) 497.8 mg/kg, phosphorus (min.) 51 g/kg, iodine (min.) 28.33 g/kg, lysine (min.) 10 g/kg, manganese (min.) 2.333 mg/kg, methionine (min.) 40 g/kg, niacin (min.) 1.000 mg/kg, selenium (min.) 10 mg/kg, sodium (min.) 47.28 g/kg, Vitamin A (min.) 159 UI/kg, vitamin B1 (min.) 33.33 mg/kg, vitamin B12 (min.) 333.33 mcg/kg, vitamin B2 (min.) 133.33 mg/kg, vitamin B6 (min.) 66.67 mg/kg, vitamin D3 (min.) 50.000 UI/kg, vitamin E (min.) 266.667 UI/kg, vitamin K3 (min.) 53.33 mg/kg, and zinc (min.) 2.000 mg/kg. [2]Met. Energy. [3]Crude protein.

analysis was performed by a colorimeter (Konica Minolta® CM-700, Singapore) operating under with a CIE L*a*b* system, and A illuminant, at an observer angle of 10º, and Specular Component Excluded (SCE) to obtain the indexes L* represents lightness, a* represents redness and b* represents yellowness. These values were used to calculate the chroma or saturation index (C*) [C* = a*² + b*²) ½] and the hue angle (h*) [h* = tan-1 (b*/a*)] (Ramos & Gomide, 2017).

Meat samples for weight loss in cooking (WLC) were weighed on a scale and wrapped in aluminum foil; afterward, they were cooked on an electric grill (Mega Grill; Britânia, Curitiba, PR, Brazil) heated to 150 °C until they reached 72 °C (Faria et al. 2009). By calculating the weight before and after cooking, the percentage of WLC was obtained.

To evaluate tenderness, the WLC samples were cut into pieces measuring 2.0 cm x 1.0 cm x 1.0 cm, with the longest measurement following the muscle fibers longitudinally, following Froning & Uijttenboogaart (1988). Afterward, the samples were cross cut in relation to the fibers using a texture meter r (Extralab, model TA.XT Plus, Jarinu, SP, Brazil).

The moisture, protein, minerals, and ether extract were determined according to Association of Official Analytical Chemists (2005).

To carry out collagen analysis, the breast and leg samples were weighed, ground in an extraction solution, incubated at 77 °C for 70 minutes, agitated every 10 minutes, and then cooled and centrifuged. After separating the fractions and adding HCl, the fractions were maintained in a hothouse at 105 °C for 12-18 hours. After being cooled, activated charcoal was added to the fractions; subsequently, they were filtered and tilted, and the collagen content was measured by determining the content of hydroxyproline (Bergman & Loxley, 1963), as described by Ramos & Gomide (2017).

Shelf-life was evaluated according to the rate of lipid oxidation in the breast and leg samples at 0, 30, and 60 days after slaughter. Lipid oxidation was determined according to Kang et al. (2001), with a few modifications.

2.3 Statistical analysis

To run the statistical analyses the data were analyzed by SAS® software. The analysis of variance on the treatments evaluated main effects and/or interactions via F tests at 5% significance.

3 Results

In terms of the physical and chemical parameters analyzed in the breast cuts, an interaction was observed between sexual maturity, sex, for the color parameter (hue angle - h*), percentage of soluble collagen and total collagen content ($P < 0.05$) (Table 2).

In the interaction between sex and sexual maturity the sexually female mature showed greater means of h*; having effect

Table 2. Physicochemical parameters of breast meat of Label Rouge strain broilers as a function of sex, sexual maturity, and interaction effects.

Variables	Sexual Maturity (SM)		Sex (S)		SEM*	P value		
	Immature	Mature	Female	Male		SM	S	SM*S
L*	57.13	57.76	58.66	56.23	0.941	0.465	0.009	0.251
a*	4.61	7.27	5.47	6.41	0.983	0.027	0.210	0.990
b*	12.63	12.33	13.63	11.33	0.581	0.581	0.0002	0.778
C*	13.32	14.37	14.91	12.79	0.593	0.062	0.001	0.200
h*	74.25	59.51	68.35	65.41	2.946	<0.0001	0.062	0.014
WLC (%)	19.54	20.96	19.12	21.38	1.644	0.352	0.140	0.412
pH	5.77	5.79	5.81	5.76	0.050	0.673	0.307	0.662
SF (kgf)	1.25	2.03	1.52	1.77	0.195	<0.0001	0.078	0.417
Col Sol mg/g	0.98	1.04	0.71	1.32	0.291	0.922	0.004	0.024
Col Ins mg/g	1.58	3.17	2.17	2.58	0.494	0.015	0.406	0.085
Col Total mg/g	2.56	4.21	2.88	3.90	0.675	0.0547	0.174	0.036
Col Sol %	38.11	21.60	24.91	34.80	4.601	0.0005	0.025	0.483
Col Ins %	61.89	78.40	75.09	65.20	4.601	0.0005	0.025	0.483

Interactions (SM*S)

Variables	Sexual Maturity	Sex	
		Female	Male
h*	Immature	73.67^{aA}	74.84^{aA}
	Mature	63.04^{aB}	55.99^{bB}
Col Total mg/g	Immature	2.72^{aA}	2.40^{aB}
	Mature	3.03^{bA}	5.39^{aA}
Col Sol mg/g	Immature	0.92^{aA}	1.05^{aA}
	Mature	0.50^{bA}	1.59^{aA}

F tests at 5% probability. Lowercase letters in the rows and uppercase letters in the columns indicate significance with $P < 0.05$. L* - lightness; a* - red rate; b*- yellow rate; C* - saturation rate; h* - hue angle; WLC – weight loss in cooking; SF – shear force; Col. Sol mg/g – content of soluble collagen (mg/g) in the sample; Col. Ins mg/g – content of insoluble collagen (mg/g) in the sample; Col. Total mg/g – total collagen content (mg/g) in the sample; Col. Sol % - percentage of soluble collagen; Col. Ins. % - percentage of insoluble collagen; SEM –Standard Error of the Mean.

of sexual maturity between sexes where immature sexual birds presented greater means of h*. Additionally, an interaction was observed between sex and sexual maturity for soluble collagen content in breast, with the highest mean values observed in sexually mature males and immature birds are not different by sex was found. And, in the interaction between sex and sexual maturity for total collagen content in breast, with the highest mean values observed in sexually mature males ($P < 0.05$), however different between males related a sexual maturity were not found to sexual mature birds (Tables 2).

Considering the sexual maturity effect in breast, sexually mature birds had higher mean values of redness (a*), shear force (SF), content and percentage of insoluble collagen and lowest mean for h* and percentage of soluble collagen ($P < 0.05$). The breast cut of females had higher mean values for lightness (L*), yellowness (b*), saturation rate (C*) and percentage of insoluble collagen than males ($P < 0.05$). However, male have greater means of percentage of soluble collagen (Table 2).

In the leg cuts, no interaction was observed among the factors sexual maturity, sex, for color parameter, WLC, pH, SF, total collagen content and insoluble collagen content (Table 3).

In the interaction between sex and sexual maturity for soluble collagen content in the legs, with the highest mean values observed in sexually mature males; for female sexually mature birds had a higher content of soluble collagen content in leg cuts than immature birds. The percentage of soluble collagen was different by sexual maturity and lowest mean values in sexually mature birds in both sex was observed; to mature birds greater means was found at sexually male mature. On the other hand, in the percentage of insoluble collagen a reverse result has been observed for sex and sexual maturity (Table 3).

The leg cut of sexually mature birds had a reduction in L* and h* and an increase in C* and a* ($P < 0.05$). Additionally, sexually mature birds had a higher content of total collagen, content of insoluble collagen and SF than immature birds in leg cuts ($P < 0.05$) (Table 3).

Males had higher mean values contents of insoluble collagen and total collagen content in leg cuts than females ($P < 0.05$) (Table 3).

This study in the leg cut found no effect of sex or sexual maturity on b* and weight loss in cooking (WLC) and pH in breast and leg cuts ($P>0.05$). No effect of sex on content of insoluble collagen in the breast and L*, C* and h* in the leg and SF and a* was observed in both cuts (Tables 2 and 3).

In terms of centesimal composition, an interaction ($P < 0.05$) was observed between sex and sexual maturity for ether extract content and oxidation at Day 60 after slaughter in breast cut; sexually mature females had the highest mean than immature females and mature males (Table 4).

The breast cuts of sexually mature birds had the highest mean value of oxidation at Day 0 ($P < 0.05$) and male birds had the

Table 3. Physicochemical parameters of leg meat of Label Rouge strain broilers as a function of sex, sexual maturity, and interaction effects.

Variables	Sexual Maturity (SM)		Sex (S)		SEM*	P value		
	Immature	Mature	Female	Male		SM	S	SM*S
L*	51.26	47.93	50.33	48.86	0.893	0.0003	0.081	0.069
a*	11.89	17.01	13.99	14.91	1.281	0.0002	0.324	0.583
b*	13.77	13.24	13.45	13.56	0.406	0.157	0.777	0.164
C*	18.48	21.59	19.61	20.45	0.897	0.0007	0.312	0.851
h*	50.32	38.11	44.94	43.49	3.106	<0.0001	0.134	0.186
WLC %	31.01	32.09	30.34	32.76	1.566	0.453	0.100	0.100
pH	5.81	5.83	5.86	5.77	0.072	0.738	0.191	0.620
SF (kgf)	1.79	2.64	2.34	2.09	0.248	0.005	0.135	0.501
Col Sol mg/g	1.43	1.35	0.99	1.79	0.293	0.120	0.0002	0.003
Col Ins mg/g	2.56	5.70	3.56	4.71	0.633	<0.0001	0.030	0.277
Col Total mg/g	3.99	7.05	4.55	6.50	0.810	<0.0001	0.020	0.149
Col Sol %	35.45	17.45	23.01	29.90	2.323	<0.0001	0.002	0.038
Col Ins %	64.55	82.55	76.99	70.10	2.323	<0.0001	0.002	0.038

Interactions (SM*S)

Variables	Sexual Maturity	Sex	
		Female	Male
Col Sol mg/g	Immature	1.40^{aA}	1.47^{aA}
	Mature	0.58^{bB}	2.12^{aA}
Col Sol %	Immature	34.71^{aA}	36.19^{aA}
	Mature	11.31^{bB}	23.60^{aB}
Col Ins %	Immature	65.29^{aB}	63.81^{aB}
	Mature	88.69^{aA}	76.40^{bA}

F tests at 5% probability. Lowercase letters in the rows and uppercase letters in the columns indicate significance with $P < 0.05$. L* - lightness; a* - red rate; b*- yellow rate; C* - saturation rate; h* - hue angle; WLC – weight loss in cooking; SF – shear force; Col. Sol mg/g – content of soluble collagen (mg/g) in the sample; Col. Ins mg/g – content of insoluble collagen (mg/g) in the sample; Col. Total mg/g – total collagen content (mg/g) in the sample; Col. Sol % - percentage of soluble collagen; Col. Ins. % - percentage of insoluble collagen; SEM –Standard Error of the Mean.

lowest mean value for oxidation at 0 and 30 days after slaughter and higher moisture content (P < 0.05), Table 4.

There was no an interaction of sexual maturity and sex or effect this factors on protein and mineral content in breast cut (Table 4); and no effect of sexual maturity for moisture and oxidation at Day 30 after slaughter.

There was an interaction between sex and sexual maturity on ether extract content and oxidation at Day 0 in the leg cut (Table 5).

On oxidation at Day 0 in leg cuts sexually mature females had the highest mean values than mature males and sexually mature birds had higher means than immatures. And, an interaction

Table 4. Centesimal and shelf-life parameters of breast meat of Label Rouge strain broilers as a function of sex, sexual maturity, and their interaction effects.

Variables	Sexual Maturity (SM)		Sex (S)		SEM*	P value		
	Immature	Mature	Female	Male		SM	S	SM*S
Protein (%)	24.05	24.54	24.52	24.08	0.544	0.238	0.422	0.683
Minerals (%)	1.19	1.35	1.34	1.20	0.085	0.050	0.063	0.928
Moisture (%)	75.16	74.64	74.45	75.34	0.347	0.109	0.009	0.756
Ether Extract (%)	0.79	0.99	0.95	0.83	0.121	0.108	0.859	0.013
Oxid 0 (MDA/g)	0.06	0.29	0.27	0.09	0.058	<0.0001	<0.0001	0.507
Oxid 30 (MDA/g)	0.31	0.47	0.52	0.26	0.111	0.215	0.008	0.593
Oxid 60 (MDA/g)	0.31	0.34	0.36	0.28	0.057	0.552	0.145	0.010

Interactions (SM*S)

Variables	Sexual Maturity	Sex	
		Female	Male
Ether Extract (%)	Immature	0.69[aB]	0.89[aA]
	Mature	1.21[aA]	0.78[bA]
Oxid 60 (MDA/g)	Immature	0.27[aB]	0.34[aA]
	Mature	0.45[aA]	0.23[bA]

F tests with P < 0.05. Lowercase letters in the rows and uppercase letters in the columns indicate significance. Oxid. 0 – oxidation Day 0; Oxid. 30 – oxidation Day 30; Oxid. 60 – oxidation Day 60; SEM – Standard Error of the Mean.

Table 5. Centesimal and shelf-life parameters of leg meat of Label Rouge strain broilers as a function of sex, sexual maturity, and their interaction effects.

Variables	Sexual Maturity (SM)		Sex (S)		SEM*	P Value		
	Immature	Mature	Female	Male		SM	S	SM*S
Protein (%)	23.56	23.78	23.89	23.44	0.491	0.626	0.316	0.280
Minerals (%)	0.99	1.05	1.03	1.02	0.037	0.010	0.913	0.363
Moisture (%)	76.76	76.12	76.09	76.79	0.305	0.028	0.017	0.281
Ether Extract (%)	2.28	2.27	2.48	2.07	0.269	0.961	0.098	0.035
Oxid 0 (MDA/g)	0.13	0.69	0.64	0.18	0.199	<0.0001	0.017	0.023
Oxid 30 (MDA/g)	0.46	0.66	0.64	0.48	0.119	0.109	0.144	0.531
Oxid 60 (MDA/g)	0.37	0.98	0.84	0.50	0.225	0.0001	0.284	0.571

Interactions (SM*S)

Variables	Sexual Maturity	Sex	
		Female	Male
Ether Extract (%)	Immature	2.22[aA]	2.34[aA]
	Mature	2.75[aA]	1.79[bA]
Oxid 0 (MDA/g)	Immature	0.17[aB]	0.10[aB]
	Mature	1.12[aA]	0.26[bA]

F tests with P < 0.05. Lowercase letters in the rows and uppercase letters in the columns indicate significance. Oxid. 0 – oxidation Day 0; Oxid. 30 – oxidation Day 30; Oxid. 60 – oxidation Day 60. *SEM – Standard Error of the Mean.

between sex and sexual maturity for ether extract content highest mean value for mature females was observed and there was no difference by sexual mature (P < 0.05) (Table 5).

However, sexually mature birds had higher mean values for moisture content and oxidation at Day 60 and lower mean values for moisture content in leg cuts (P < 0.05) (Table 5).

There was no an interaction of sexual maturity and sex or effect this factors on protein and oxidation at Day 30 (P > 0.05) in leg cut; and no effect of sex at mineral and oxidation at Day 60 after slaughter (P > 0.05) was observed (Table 5).

4 Discussion

The breast cuts of sexually immature birds were predominantly yellow, according to the color scale of the CIEL*a*b* system (70 to 100°) (Ramos & Gomide, 2017). Upon sexual maturity, there was a reduction in hue, which was greater in males; however, despite the differences between sexes, the predominant color in the meat of males and females was orange (25 to 70°) (Ramos & Gomide, 2017). This may be a result of the increase in myoglobin with age (Tougan et al., 2013), a theory which is supported by the fact that both cuts of sexually mature birds had more reddish meat.

There was no effect of sexual maturity on the lightness, color intensity or yellowness of breast cuts, which corroborates the findings of Souza et al. (2012). This effect on color parameters were according to results was found to pH in the breast cut. pH changes can affect on water holding capacity and color of meat due to decreasing of pH value decreases solubility of meat proteins and result a reduction of space within the myofibril and in the amount of water that can be attracted and held by that protein. Thus, the amount of free water in the meat increases the light reflected from the surface and it becoming brightness (Huff-Lonergan & Lonergan, 2005). In the present study, this effect on color parameters in the breast cut there was no effect of the studied factors on the pH.

Sexually mature birds had a reduction in leg cut hue; however, the predominant color did not change between immature and mature birds, remaining orange (25 to 70°) (Ramos & Gomide, 2017). However, sexually mature birds had an increased saturation of orange color in leg cuts, which may be associated with the same effect observed for the breast cuts: as a function of age at slaughter (Tougan et al., 2013).

The leg cuts of sexually mature birds decreased in lightness, thus becoming darker. However, this modification was not related to pH (Huff-Lonergan & Lonergan, 2005; Souza et al., 2012) because, in this cut, pH values were similar in immature and mature birds. However, according to Faria et al. (2009), this reduction in lightness may be related to a decrease in moisture content and an increase redness in sexually mature birds. Moisture content may influence the amount of liquid in the surface of meat and, consequently, its brightness (Souza et al., 2012).

Females had more yellowish breast meat than males, which corroborates the results of Souza et al. (2011) and Nualhnuplong & Wattanachant (2020). This result may be due to the higher accumulation of fat in females because carotenoids are stored in animal fat after absorption (Prache et al., 2003). Additionally, the breast meat of female birds had higher values of lightness and saturation, similar to the results obtained by Cruz et al. (2021). This increase in color saturation for females may be related to the higher rates of yellow coloration due to the accumulation of carotenoid pigments (Faria et al., 2009).

Water retention is an important characteristic of meat quality and can be measured by weight loss in cooking (WLC). In both cuts, neither sexual maturity nor sex influenced WLC, a result that was also observed by Nualhnuplong & Wattanachant (2020) in the meat of old and young birds. The sex differences also confirmed the findings of Souza et al. (2011), Jung et al. (2015) and Cruz et al. (2018), who obtained similar sex differences in WLC. This effects on the WLC are associate of pH result was found in the breast and leg cuts and pH relation to water holding capacity (Huff-Lonergan & Lonergan, 2005).

In both leg and breast meat, there were no sex or sexual maturity differences in the final pH values, which remained at levels adequate for meat preservation. Faria et al. (2009) and Souza et al. (2012) observed a reduction in pH values in breast meat and an increase in final pH in leg meat as an effect of age, but the evaluated birds had not reached sexual maturity. Our findings corroborate the sex differences found by Souza et al. (2011), Jung et al. (2015) and Cruz et al. (2018). Chickens after reaching puberty when sexual organs are complete and mature and hormonal level is highest for reproductive life could increase struggle due to sexual behavior mainly in male; and consequently have effect on meat quality (Grandin, 1980). Thus, the level of stress of adulthood in both sex for chickens raising in free-range system looks like is the same than expected by other early phase how reported by Ericsson et al. (2016) and it is contributed to there was no difference in pH values according to sex and sexual maturity.

Sexually mature females had a reduced soluble collagen content and an increased percentage of insoluble collagen in both cuts, though the amount of total collagen was not affected. On the other hand, in both cuts, sexually mature males had a higher amounts of total collagen and soluble collagen, but a decreased proportion of soluble collagen. These results may be due to the conversion of collagen fibers into heat-resistant intermolecular bonds as animals get older and promote increasing meat toughness (Tornberg, 2005).

Sexually mature birds had higher shear force (SF), as verified by Rocha et al. (2019), who also observed a reduction in tenderness in older animals. In general, meat texture is influenced by collagen content and solubility (Li et al., 2019). Chumngoen & Tan (2015) also noticed this correlation in chicken meat, which showed higher collagen content as SF increased.

Males had higher insoluble collagen and total collagen content in leg meat than females. However, the percentage of insoluble collagen was lower in males. The increase in total collagen may be due to testosterone because, according to Sun et al. (2017) and Abou-Kassem et al. (2019), testosterone increases the intramuscular collagen content due to increased synthesis and reduced degradation of this substance. Despite the significant sex differences in the content and percentage of collagen, the shear force of the meat remained the same, consistent with Cruz et al. (2018).

Thus, despite the lack of interaction between sex and maturity effects in meat softness in both cuts and the effect of maturity level on its own, our results showed that the mechanism related to the increase of toughness in free-range chicken meat happened in different ways. The reduction of meat softness in the breast happened in male mature birds throughout the increase of the total collagen content, while in female mature birds, the content of soluble collagen decreased and in the thigh the pattern was similar with the decrease of content and percentage of soluble collagen and consequent increase of percentage of insoluble collagen in female mature birds in comparison to male mature birds.

In both cuts, in terms of centesimal composition, sexually mature females had the highest ether extract contents. Chen et al. (2006) examined the effect of sex on the liver enzymes that participate in the lipogenesis process; females had a higher number of enzymes that break down adenosine triphosphate (ATP), nicotinamide adenine dinucleotide phosphate (NADP) and glucose-6-phosphate dehydrogenase. Thus, these authors observed that the activity of these enzymes was influenced by sex hormones, such as estrogen, which had a promoted a larger production of fat in female birds after sexual maturity and showing increase level of total lipids in blood circulation than sexually female immature mainly they entering the laying production (Hawkins & Heald, 1966).

The protein and moisture content in breast cuts were not influenced by sexual maturity. Such behavior was also verified by Souza et al. (2011), who did not observe an effect of age on protein and moisture content in birds raised in an alternative system. Sexual maturity influenced the mineral content in both cuts. The highest mean values observed may be due to a reduction in mineral deposition on bone tissues, since mineral deposition is more intense during growth (Borges et al., 2010).

In leg meat, sexual maturity did not interfere with protein content, corroborating the findings of Faria et al. (2009); Cruz et al. (2017); and Cruz et al. (2018). However, moisture content decreased. As age increases, the rate of muscular anabolism decreases, but lipid deposition increases and causes a lower amount of water in animal muscles (Souza et al., 2011).

In both cuts, moisture content was higher in males. This finding may be related to the production of testosterone in males, which decreases lipogenic activity in favor of myogenic activity (Pérez-Linares et al., 2017), causing a reduction in the fat content, which is inversely proportional to moisture content (Faria et al. 2009). In this study, sexual maturity did not interfere with fat content in leg cuts; however, sexually mature males had a lower amount of fat in both cuts, which may have resulted in the higher moisture content in these birds. Regarding protein and mineral content, in both cuts, there was no effect of sex, which was also observed by Cruz et al. (2017).

Lipid oxidation is one of the main causes of meat deterioration and may be used to determine its shelf life (Gatellier et al., 2007). In this study, sexually mature females had higher oxidation values on the first day after slaughter and 60 days after slaughter in leg and breast meat, respectively. In the oxidation analyses, sexually mature birds had a higher content of malondialdehyde (MDA) in breast meat on the first day after slaughter, whereas in the leg cut, the MDA content was higher 60 days after slaughter. The breast meat of females had higher levels of MDA on the first and 30 days after slaughter. The increase in fat content in mature females may be due to the influence of sex hormones on the enzymes that participate in lipogenesis (Chen et al., 2006), which may have contributed to the higher oxidation of their meat (Gatellier et al., 2007).

In general, according to our findings, the characteristics of meat from mature birds is different from immature animals in both cuts analyzed, and the differences between sexes were only observed in the breast, while in the thigh there is not a difference for physicochemical parameters. Considering these characteristics in female birds, there will be higher brightness and intensity of color mainly yellowish in the breast regardless of maturity level. Regarding centesimal composition, the increase of mineral content is a parameter to be considered on meat for differences between mature to immature birds in both cuts, as well the increase of oxidation index. Therefore, in meat from mature birds raised in free-range system consequently there will be different shelf life, and it is expected that mature male birds keep their characteristics for a longer time.

Another parameter which can be used to set the difference regarding the influence of sex and maturity effect is the content of ether extract. Taking this parameter into account, it increases for female birds in the breast and decreases for male birds in the thigh. And, in the hue index for both sexes when birds were considered mature, there was change of these parameters and in spite of male presenting lesser value, the change of color probably will not be noticed by consumers in terms of maturity change. This phenomenon happens because the results are in the same color range of orange in the breast, despite the mature male birds had lesser value than mature female birds.

5 Conclusion

The meat of chickens raised in an free range system after sexual maturity has a more reddish color and a firmer texture in breast and leg cuts. With sexual maturity, the meat of female birds has more fat and a lower shelf life. Hence, it was concluded from our findings that female birds have more yellowish meat in the breast than male ones.

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