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Effect of caponisation on physicochemical and sensory characteristics of chickens

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The meat fats content associated to nutritional and sensory characteristics are the most important concerns of consumers. To study the effect of caponisation on the meat quality of two different breed chickens, slaughtered at 18 weeks of age, raised under the same conditions, the physicochemical and sensory characteristics of capons (castrated males at 8 weeks of age) and roosters' meat of native Amarela Portuguesa *and native* Pedrês Portuguesa *breeds were evaluated. Forty* Amarela *(20 roosters and 20 capons), 40* Pedrês *(20 roosters and 20 capons) chickens, and also, six free-range chicken and six broilers were evaluated. The pH, water-holding capacity, Warner-Bratzler shear force, moisture content, ash, myoglobin, collagen, CP, total fat and fatty acids profile were evaluated in breast and leg meat, according to standard procedures. Leg meat capon showed greater intramuscular fat content (*$P \leqslant 0.05$*), monounsaturated fatty acids (MUFA) and CP (*$P \leqslant 0.001$*) than leg roosters. Caponisation increased the content of myoglobin and MUFA (*$P \leqslant 0.05$*) and reduced the moisture content in the leg (*$P \leqslant 0.05$*). The main fatty acids found were oleic acid (C18:1), palmitic acid (C16:0) and linoleic acid (C18:2). The greatest value of C18:1 was observed in capon's breast (*$P \leqslant 0.01$*). Sensory analysis was made to compare the* Amarela *and* Pedrês *meat with a free-range chicken and a broiler. The sensory taste panel classified the capon's meat (*Amarela *and* Pedrês*) as juicier, less fibrous and tougher than rooster's meat. The broiler was in general juicier, tenderer and less fibrous than the other birds. The results of sensory analysis complement those obtained in physicochemical analysis, suggesting that caponisation promotes an overall improvement in meat quality.*

Keywords: Portuguese chickens, caponisation, meat quality, sensorial evaluation

Implications

This study provides practical and useful information on chicken breast and leg meat quality attributes. It will also be useful to define the differences on physical, chemical and sensory characteristics of roosters and capons, and between breeds. From a nutritional point of view, capon meat could be considered healthier in relation to their fatty acid profile (high monounsaturated fatty acids content and ratio between unsaturated/saturated fatty acids content).

Introduction

In recent years the requirement of consumers per different cuts of poultry meat with better quality and sensory characteristics has been increasing, highlighting the capon meat. Caponisation is surgical removal of the testicles of male chickens before reaching sexual maturity (Sirri *et al*., 2009) between 8 and 10 weeks of age. Removal of the testes produces a change in the animal's metabolism that affect the growth (Symeon *et al*., 2012), behaviour, tissue composition, carcass composition (Miguel *et al*., 2008), chemical composition and organoleptic quality of meat (Miguel *et al*., 2008; Sirri *et al*., 2009; Lin and Hsu, 2013), lipid content and fatty acid profile (Tor *et al*., 2005). Because of the resultant androgen deficiency, male secondary sexual characters including the comb, wattle, fighting behaviour, vocalisation degenerate and maturity regresses to an immature stage (Chen *et al*., 2005). The most important metabolic effect of caponisation is the reduction of plasma testosterone level that increases the accumulation of fat in subcutaneous and intramuscular tissue (Chen *et al*., 2005; Tor *et al*., 2005). Increased fat deposition has been connected to increased hepatic lipogenesis capacity, increased blood lipid concentrations (Hsieh *et al*., 2001) and alterations in lipoprotein profile (Hsieh *et al*., 2001; Chen *et al*., 2005). Several authors have found significant changes in the fatty acid profile of poultry meat after caponisation (Tor *et al*., 2005; Sirri *et al*., 2009). Therefore, decreasing the level of

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saturated fatty acids (SFA) and increasing unsaturated fatty acids, in particular polyunsaturated fatty acids (PUFA) content in poultry meat would be of commercial interest. Caponisation increases the content of lipids in meat, which plays an important role in meat quality, because it enhances flavour, texture and juiciness of meat, compared to intact roosters (Chen *et al*., 2005; Lin and Hsu, 2013; Calik *et al*., 2015). However, reports on the caponisation effects on the quality of poultry meat are inconsistent. The objective of this study was the comparison of the physicochemical and sensory characteristics of capons and roosters.

Material and methods

Animals and sampling

Forty chickens of *native Amarela Portuguesa* breed (20 roosters and 20 capons) and 40 of native *Pedrês Portuguesa* breed (20 roosters and 20 capons) were used. All birds were caponised at 8 weeks of age that is 16 weeks before the sexual maturation. Feed and water was removed 12 h before the surgical operation. The feathers around the site of incision located between the last two ribs were removed and the skin was disinfected. An incision of 1.5 cm was made and the testes removed using a ribs retractor. The site of incision was then disinfected and stitched. No cases of unsuccessful or incomplete caponisation (slips) of birds were recorded during experimental period and only one bird died just the moment of caponisation.

Birds were housed under free range conditions in one pens with 20 m^2 with a density of four animals per m^2. The basal diets were commercial concentrate (Table 1) with *ad libitum* feed and water. At 18 weeks of age the chickens, were slaughtered in a local commercial broiler slaughterhouse. In sensory analysis free-range chickens and broilers, bought in a supermarket and from a well-known commercial brand were used.

Carcasses were taken to the Carcass and Meat Technology and Quality Laboratory of the Agriculture School (Bragança, Portugal) 24 h after slaughter and were divided in two halves. The right one was reserved for the physicochemical analysis and the left to meat sensory analysis. Then all samples were vacuum packed and frozen at −21°C until analysed. The day before physical and chemical analysis, samples were thawed at 4°C. Physicochemical determinations were performed on breast (*Pectoralis major* muscle) and leg (thigh and drumstick). Meat dissection separating the skin, meat and bones was executed. All analyses were made in triplicate.

Instrumental analysis

The pH was measured 24 h after slaughter in *Pectoralis major* muscle using the equipment HANNA, pH meter HI 99163 and a FC 232D spear electrode. Water-holding capacity was evaluated according to the Honikel procedure (Honikel, 1998). Shear force was evaluated, using an INSTRON 5543J-3177 equipped with a Warner-Bratzler device. *Pectoralis major* muscles were cooked inside plastic bags in a 70°C water bath until reaching to 70°C in muscle centre. Half an hour after, four muscle sub-samples (2 cm^2 cross-section) were taken from each *Pectoralis major* muscle for shear force evaluation. The measurement was recorded as the average yield force in kg required to shear perpendicularly to the direction of the fibres.

Table 1 *Composition of the diets during the experiment*

	Diets by age	
	0 to 4 weeks	5 to 18 weeks
Analytical components (%)		
CP	19.0	15.0
Crude fibre	3.50	3.20
Phosphorus	0.53	0.70
Methionine	0.37	0.20
Sodium	0.20	0.10
Calcium	1.20	1.50
Crude fat	5.00	3.20
Crude ash	6.60	7.00
Lysine	0.99	0.70
Additives		
Amino acids (mg/kg)		
Hydroxy analogue of methionine[1]	0.08	
L-Lysine		48.0
Vitamins (U.I./kg)		
Vitamin A	12 500	15 000
Vitamin D3	3000	3000
Vitamin E	30.0	40.0
Biotin (mg/kg)		0.20
Trace elements (mg/kg)		
Cupper (cupric sulphate pentahydrate)	8.00	11.0
Manganese (manganese oxide)	100.0	75.0
Zinc (zinc oxide)	80.0	75.0
Iron	515.0[2]	81.0[3]
Iodine (calcium iodate anhydrous)	0.99	2.00
Cobalt (basic cobalt carbonate (II) monohydrate)	0.06	0.50
Selenium (sodium selenite)	0.30	0.20

[1]Acids content 85%; acid monomer 65%.
[2]Iron (III) oxide–425 mg/kg and iron (II) sulphate monohydrate – 90 mg/kg.
[3]Iron (II) carbonate.

Chemical analysis

Moisture content, protein, ash, myoglobin, hydroxyproline, fat determination and fatty acid profile were evaluated. Total SFA, total monounsaturated fatty acids (MUFA) and total PUFA were computed. Myoglobin was obtained using the reflectance of the exposed surface by spectroscopy using a Spectronic Unicam 20 Genesys. The method is based on the muscle pigment content (Hornsey, 1956). Protein (Kjeldahl $N \times 6.25$), moisture, total ash and hydroxyproline determinations were carried out according to Portuguese norms (NP) with recommended standards by International Organization for Standardization (ISO) correspondences: NP 1612:2002 – ISO 937:1978; NP 1614:2002 – ISO 1442:1197; NP 1615: 2002 – ISO 936:1998 and NP 1987:2002 – ISO 3496:1994, respectively. Fat determination was performed using the BÜCHI

Fat Determination System (AOAC International) described by Teixeira and Rodrigues (2013).

Sensory analysis

Meat sensory analysis of breast, thigh and drumstick samples of *Amarela* and *Pedrês* breed roosters and capons, respectively, free-range chicken and broilers, was made by a trained taste panel of nine members. Panel members were selected and trained according to Portuguese guidelines (NP 8586-1:2001 – ISO 8586-1:1993). The day before the sensory session, samples were thawed at 4°C. Samples were separated in breast, thigh and drumstick, deboned and dissected. Samples were wrapped individually in aluminium foil and coded randomly with three digit numbers, then placed in the oven until it reached an internal temperature of around 75°C (NP 8586-1:2001 – ISO 8586-1:1993). Immediately after cooking, samples were divided into $2 \times 2 \times 1\,cm^3$ pieces, wrapped in aluminium foil, identified, placed in a preheated oven at 60°C to 70°C, and evaluated within 10 min. The panel members were seated in individual booths in a temperature and light controlled room. In all sessions, the room temperature was 20°C to 22°C, with 60% to 70% humidity and booths had red light.

After a training period of six sessions, evaluating, describing and discussing chicken meat quality characteristics, panellists were asked to assess each sample for the sensory attribute: odour intensity (odour associated with raw meat, animal species or cooked chicken meat), off-odour (an odour that is not natural or up to standard owing to deterioration or contamination) intensity, colour (colour perceived between whitish and yellowish), toughness (the force needed to chew), juiciness (water perceived during mastication), fibrousness (fibres perceived during mastication), taste intensity (taste of raw meat, associated with the animal species or cooked chicken meat), off-taste intensity, flavour intensity (flavour associated with raw meat, animal species or cooked chicken meat) and off-flavour intensity. An unstructured scale of 10 cm, anchored at the extremes (0 – sensation absence and 10 – extremely intense sensation) was used. Panellists were asked to indicate a point on the scale corresponding to the perceived intensity for each attribute. The sensory evaluation consisted of 10 sessions, where panellists evaluated nine samples of nine different treatments combining breed (*Amarela*, *Pedrês*), caponisation (capon and rooster), B, and FRC and anatomical part (breast, thigh and drumstick). Samples were always presented in the same conditions for all panellists, randomly in each session.

Statistical analysis

Physicochemical analysis. The data were analysed using as a 2×2 factorial design using the GLMs procedure of SPSS statistical package version 20. Data were analysed by ANOVA with sex and breed as fixed effects. The least square means were calculated and the Tukey test was used to determine significant differences. All statistical differences were considered significant at a level of $P \leqslant 0.05$.

Discriminant analysis. To know which variables would be more useful to classify and distinguish the groups (*Amarela* capon, *Amarela* rooster, *Pedrês* capon and *Pedrês* rooster), a discriminant analysis was performed using the linear, common covariance and the stepwise variable selection methods. For this analysis only the chemical composition of the breast was used, as this is the most representative part of the carcass. The efficiency of the discriminant power of the models selected was assessed by the test of the Wilks' λ value. Results were analysed in terms of the absolute assignment of individuals to the pre-assigned group, the variance explained by each canonical likelihood and by the analysis of the standardised scoring coefficients. Statistical analysis was performed using the statistical package JMP Pro version 10 (Statistical Analysis Systems, 2012).

Sensory analysis. The model used was a completely randomised factorial design with six groups of bird (*Amarela* capon, *Amarela* rooster, *Pedrês* capon, *Pedrês* rooster, free-range chicken and broiler) and three anatomical joints (breast, thigh and drumstick) as fixed factors with no random effects. Chickens were assigned to 18 groups according to their specie and anatomic part. Generalised procrustes analysis, a powerful multivariate technique extensively used in sensory evaluation, was performed. The analysis minimises differences between assessors, identifies agreement between them, and summarises the sets of three-dimensional data (objects, characteristics and assessors). Data matrices of 18 meat samples by 10 sensory attribute by nine assessors were matched to find a consensus. These data sets were analysed using XLSTAT software (Addinsoft, 2013).

Results

Meat physical and chemical characteristics

Table 2 shows the effect of chicken sex and breed on physical and chemical composition of breast and chemical composition of leg meat. *Pedrês* breed presented smaller ($P \leqslant 0.001$) Warner-Bratzler shear force (WBSF) than *Amarela*. Capons had higher breast CP ($P \leqslant 0.001$) and intramuscular fat (IMF) percentage ($P \leqslant 0.05$) than roosters. *Amarela* breed had significantly higher breast moisture and ashes ($P \leqslant 0.001$), smaller breast myoglobin ($P \leqslant 0.01$) and IMF% ($P \leqslant 0.001$) than *Pedrês*. In the leg meat, roosters had higher ($P \leqslant 0.05$) moisture content but lower ($P \leqslant 0.05$) myoglobin than capons. *Amarela* had higher moisture, ashes ($P \leqslant 0.001$), CP ($P \leqslant 0.05$), but smaller ($P \leqslant 0.01$) myoglobin and IMF content than *Pedrês*. Significant interactions between sex and breed indicated bigger differences on breast ashes between roosters and capons in *Amarela* breed than *Pedrês*. The breast WBSF of *Amarela* roosters was higher than capons, while *Pedrês* roosters had smaller breast WBSF than capons.

Fatty acid composition

Table 3 shows the effect of chicken sex and breed on fatty acid profile of breast intramuscular fat. Roosters had higher

Table 2 *Effect of chicken sex and breed on physical and chemical composition of breast meat (Pectoralis major muscle) and chemical composition of leg meat*

	Sex (S)		Breed (B)			*P*-value		
	Roosters	Capons	*Amarela*	*Pedrês*	SEM	S	B	S × B
Physical composition								
Breast								
pH_{24}	5.81	5.83	5.84	5.81	0.01	Ns	Ns	Ns
WHC								
Cooking loss (%)	14.98	15.88	15.59	15.32	0.37	Ns	Ns	Ns
Textural parameter								
WBSF (kg/cm^2)	2.66	2.36	3.13	1.93	0.14	Ns	***	*
Chemical composition								
Breast								
Moisture (%)	73.24	73.22	73.92	72.60	0.11	Ns	***	Ns
Ash (%)	1.71	1.92	2.26	1.42	0.04	Ns	***	*
CP (%)	23.92	24.36	24.20	24.11	0.05	***	Ns	Ns
Myoglobin[1]	0.53	0.58	0.47	0.63	0.02	Ns	**	Ns
Hydroxyprolin (%)	0.05	0.06	0.06	0.06	0.00	Ns	Ns	Ns
Collagen (%)	0.44	0.47	0.46	0.45	0.02	Ns	Ns	Ns
IMF (%)	1.97	2.23	1.91	2.29	0.04	*	***	*
Leg								
Moisture (%)	74.38	73.82	74.68	73.53	0.12	*	***	*
Ash (%)	1.70	1.87	2.26	1.35	0.04	Ns	***	*
CP (%)	20.10	20.11	20.26	19.96	0.05	Ns	*	Ns
Myoglobin[1]	1.25	1.66	1.18	1.72	0.07	*	**	Ns
Hydroxyprolin (%)	0.12	0.16	0.17	0.12	0.01	Ns	Ns	Ns
Collagen (%)	0.97	1.26	1.32	0.94	0.06	Ns	Ns	Ns
IMF (%)	5.38	5.91	5.17	6.11	0.13	Ns	**	*

pH_{24} = muscle pH 24 h *postmortem*; WHC = water-holding capacity; WBSF = Warner-Bratzler shear force; IMF = intramuscular fat.
[1]Results are expressed in mg myoglobin/g fresh muscle.
Ns = no significant difference ($P > 0.05$); * $P \leqslant 0.05$; ** $P \leqslant 0.01$; *** $P \leqslant 0.001$.

Table 3 *Effect of chicken sex and breed of fatty acid profile in intramuscular fat of breast meat (%)*

	Sex (S)		Breed (B)			*P*-value		
	Roosters	Capons	*Amarela*	*Pedrês*	SEM	S	B	S × B
C4:0	2.05	1.66	2.27	1.45	0.08	*	***	Ns
C8:0	6.79	5.51	6.17	6.08	0.11	***	Ns	Ns
C12:0	0.32	0.15	0.05	0.39	0.04	Ns	**	Ns
C14:0	5.43	4.62	3.37	6.53	0.47	Ns	*	Ns
C16:0	15.77	16.95	17.37	15.48	0.27	Ns	*	Ns
C16:1	2.63	2.55	1.39	3.70	0.20	Ns	***	Ns
C18:0	4.93	4.00	3.42	5.41	0.16	Ns	***	*
C18:1	19.36	22.15	20.94	20.70	0.35	**	Ns	Ns
C18:2	8.58	9.72	8.62	9.68	0.24	Ns	Ns	Ns
C20:4	0.91	0.49	0.29	1.06	0.11	Ns	*	Ns
SFA	35.30	32.89	32.64	35.34	0.41	Ns	*	*
MUFA	21.99	24.71	22.33	24.39	0.42	*	*	*
PUFA	9.49	10.21	8.91	10.74	0.27	Ns	*	Ns
PUFA/SFA	0.27	0.31	0.28	0.31	0.01	*	Ns	Ns
MUFA + PUFA/SFA	0.89	1.08	0.97	1.01	0.02	***	Ns	Ns

SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
Ns = no significant difference ($P > 0.05$); * $P \leqslant 0.05$; ** $P \leqslant 0.01$; *** $P \leqslant 0.001$.

butyric acid (C4:0) and caprylic acid (C8:0) than capons but no differences were found for total SFA. Roosters had smaller oleic acid (C18:1) content and total MUFA than capons. The ratios PUFA/SFA and MUFA + PUFA/SFA were higher in capons than roosters. *Pedrês* had higher SFA and MUFA contents, particularly lauric acid (C12:0), myristic acid

Table 4 *Effect of chicken sex and breed on fatty acid profile in intramuscular fat of leg meat (%)*

	Sex (S)		Breed (B)			*P*-value		
	Roosters	Capons	*Amarela*	*Pedrês*	SEM	S	B	S × B
C4:0	0.85	0.62	0.88	0.59	0.03	***	***	*
C8:0	2.54	2.05	2.31	2.26	0.06	***	Ns	Ns
C12:0	0.76	0.83	0.84	0.76	0.04	Ns	Ns	Ns
C14:0	3.19	3.86	4.53	2.62	0.16	Ns	***	Ns
C16:0	19.32	19.48	19.20	19.59	0.16	Ns	Ns	Ns
C16:1	5.86	6.61	6.20	6.30	0.09	**	Ns	Ns
C18:0	5.13	4.71	4.83	4.99	0.09	Ns	Ns	Ns
C18:1	30.35	31.65	29.75	32.20	0.36	Ns	**	Ns
C18:2	14.51	14.65	14.46	14.70	0.16	Ns	Ns	Ns
C20:4	1.01	0.81	0.96	0.86	0.10	Ns	Ns	Ns
SFA	31.78	31.46	32.59	30.81	0.22	Ns	**	Ns
MUFA	36.09	38.42	35.87	38.64	0.37	*	**	*
PUFA	15.52	15.47	15.41	15.55	0.20	Ns	Ns	Ns
PUFA/SFA	0.49	0.49	0.47	0.51	0.01	Ns	Ns	Ns
MUFA + PUFA/SFA	1.63	1.72	1.58	1.76	0.02	*	***	Ns

SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.
Ns = no significant difference ($P > 0.05$); * $P \leqslant 0.05$; ** $P \leqslant 0.01$; *** $P \leqslant 0.001$.

Table 5 *F values of all variables used in the discriminant analysis of breast meat from the four different groups of chicken*

Variable	*F* ratio	*P*-value
Moisture (%)	5.289	<0.004
CP (%)	5.831	<0.002
IMF (%)	4.200	<0.012
C8:0	12.401	<0.001
C12:0	3.464	<0.026
C14:0	9.152	<0.000
C18:0	17.983	<0.000
C18:2	3.394	<0.028
MUFA + PUFA/SFA	8.901	<0.000

IMF = Intramuscular fat; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; SFA = saturated fatty acids.

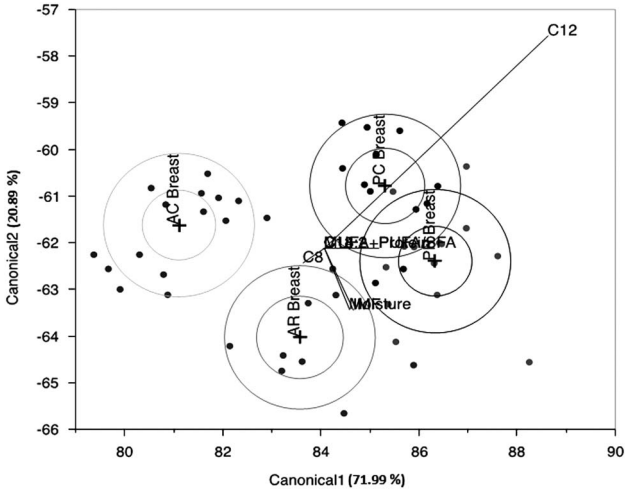

Figure 1 Scatter plot of the first two canonical variables, of the four chicken groups breast meat considered. (*AC* = *Amarela* capon; *AR* = *Amarela* rooster; *PC* = *Pedrês* capon; *PR* = *Pedrês* rooster).

(C14:0), palmitoleic acid (C16:1) and stearic acid (C18:0), but lower values for C4:0, palmitic acid (C16:0) and arachidonic acid (C20:4) than *Amarela*.

Roosters had higher ($P \leqslant 0.001$) C4:0 and C8:0 g/100 g leg meat sample, but lower C16:1 ($P \leqslant 0.01$) MUFA and MUFA + PUFA/SFA ($P \leqslant 0.05$) than capons (Table 4). *Amarela* breed expressed higher C4:0, C14:0 and SFA than *Pedrês* but *Pedrês* had higher values for MUFA, particularly C18:1, explaining higher value for MUFA + PUFA/SFA ratio.

Discriminant analysis

Table 5 shows the *F* values of the variables used to discriminate the breast meat of the four chicken groups. The stepwise method selected the following variables in nine steps: C18:0, C8:0, C14:0, MUFA + PUFA/SFA, protein, moisture, IMF, C12:0 and linoleic acid (C18:2). Scatter plot of the first two canonical variables, of the four chicken groups considered (Figure 1) showed that groups were discriminated with great accuracy with a total of 92.88% of variance explained. A total of 90% individuals of each group were assigned in the correct pre-assigned group, for 92.9%, 83.3%, 90.0% and 92.9% of classified correctly *Amarela* capon, *Pedrês* capon, *Amarela* rooster and *Pedrês* rooster, respectively. The model is highly significant ($P < 0.0001$) for 0.047 Wilks' Lambda value. Analysing the standardised discriminant scores the most important variables were ratio MUFA + PUFA/SFA, C14:0 and C18:0 in the first canonical variable, the IMF, moisture and C8:0 in the second canonical variable and the protein content, C18:2 and C12:0 in the third canonical variable. Results show that

the fatty acid profile could be an accurate tool to discriminate and distinguish different meat from different breed and sexes.

Sensory analysis

The taste panel used ten attributes to describe the differences between the three anatomical parts (breast, thigh and drumstick) of the different groups of chickens (*Amarela* capon, *Amarela* rooster, *Pedrês* capon, *Pedrês* rooster, free-range chicken and broiler). Procrustes analysis of Variance for chicken meat sensory analysis (Table 6) shows that all the data transformation steps were efficient since all presented a high significance ($P < 0.0001$).

Residuals by group of chicken (Figure 2) show that breast of the *Amarela* capon, *Pedrês* rooster, broiler and free-range chicken had the lowest value followed by *Amarela* rooster with greater consensus among evaluators, whereas the *Amarela* rooster thigh (greatest residue) has the lowest consensus. Assessor 5 showed the greater residue, which means that their evaluations do not match the consensus (Table 7). Assessors 1, 2, 5, 8 and 9 tend to use a wider scale in their evaluation because they presented scaling factors >1 (Table 7). The others, with scaling factors smaller than one, focus on a narrower part of the scale.

The next results correspond to the Principal Component analysis step. The first two axes represent 86.8% of the total variability; the first dimension explains 73.15% of the variability and the second 13.69%. When the variability is divided by assessors (Table 7) it was noted that the results are consensual among all the panellists except 2, 6 and 9, which show less variability explained by Factor 1, showing greater variability for Factor 2.

Generalised procrustes analysis was used to obtain a consensus (Figure 3). The points are all near the first Cartesian axis, explaining the fact that 73.15% of variability is concentrated in the first dimension. The different groups of chickens were clearly discriminated and identified by the panellists. Breast evaluation is clearly different of drumstick and thigh, mainly on juiciness, flavour intensity and colour. The breast of *Amarela* and *Pedrês* capons generated less consensus among panellists, presenting similar organoleptic characteristics. Flavour intensity and colour intensity are related with the *Pedrês* capon thigh. Free-range chicken thigh obtained the greatest value of juiciness. In general juiciness is associated with leg (thigh and drumstick) of free-range chicken and broiler. Drumstick of *Amarela* rooster had the greatest toughness and fibrousness, once the vectors representing them direct to the coordinates of *Amarela* rooster. The breast and thigh of broiler are characterised by having lower toughness and fibrousness. Broiler had the greatest value of juiciness and lower toughness and fibrousness (Figure 3). *Amarela* roosters' meat showed lower juiciness, than the other groups of chickens. The *Pedrês* rooster group had the greatest off-taste intensity, and toughness and fibrousness are also correlated with this group. Caponisation has influenced the *Pedrês* capon off-taste, whereas colour intensity was associated with *Amarela* capons. Caponisation has also improved the lipid profile and meat characteristics, making it juicier, tenderer and less fibrous.

Table 6 *Procrustes analysis of variance (PANOVA) for chicken meat sensory analysis*

Source	d.f.	ss	MS	*P*-value
Residuals after scaling transformation	992	537.743	0.542	
Scaling transformation	8	83.929	10.491	<0.0001
Residuals after rotation	1000	621.672	0.622	
Rotation	360	473.669	1.316	<0.0001
Residuals after translation	1360	1095.341	0.805	
Translation	80	1409.533	17.619	<0.0001
Corrected total	1440	2504.873	1.739	

ss = sum of squares.

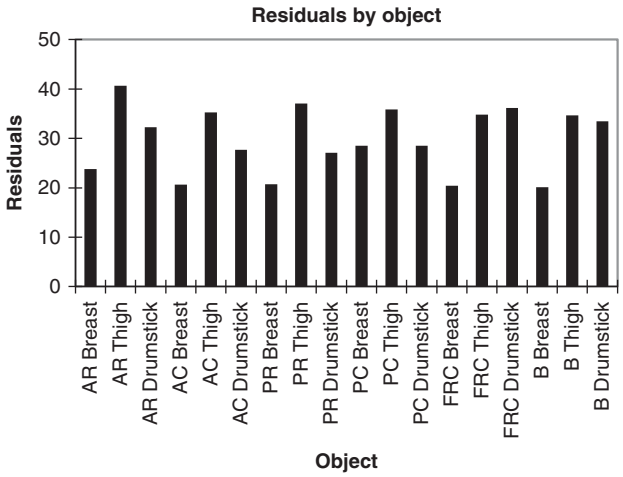

Figure 2 Residual variance for each meat sample (group of chickens and anatomical part) for sensory analysis. (*AC* = *Amarela* capon; *AR* = *Amarela* rooster; B = broiler; FRC = free-range chicken; *PC* = *Pedrês* capon; *PR* = *Pedrês* rooster).

Table 7 *Residual variance, scaling factors, and percentage variation explained by the first two principal components for each assessor for each chicken meat group sensory analysis*

Assessor	Residual	Scaling factor	F1 (%)	F2 (%)
1	50.930	1.180	65.894	13.586
2	63.404	1.200	54.223	24.956
3	50.515	0.875	76.935	8.611
4	58.712	0.857	76.871	6.423
5	69.865	1.193	59.531	13.153
6	65.901	0.977	54.510	26.539
7	63.744	0.730	59.758	12.545
8	48.301	1.578	64.530	16.864
9	66.370	1.039	58.603	23.949

F1 = first principal component of generalised procrustes analysis (GPA); F2 = second principal component of GPA.

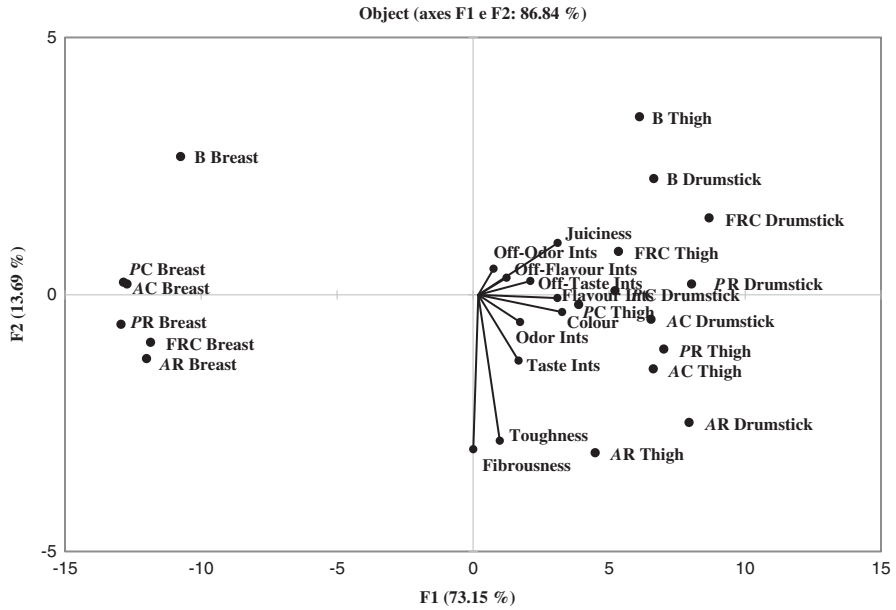

Figure 3 Consensus configuration: joint representation of correlation between sensory traits and first two dimensions and groups of chicken's meat coordinates for anatomical parts of the group of chicken's sensory analysis. (F1 = first principal component of generalised procrustes analysis (GPA); F2 = second principal component of GPA; *AC* = *Amarela* capon; *AR* = *Amarela* rooster; B = broiler); FRC = free-range chicken; *PC* = *Pedrês* capon; *PR* = *Pedrês* rooster).

Discussion

Meat physical and chemical characteristics

The pH values found were within the expected limits of 5.75 and 5.96 at the end of the *postmortem* process according to Castellini *et al.* (2002). The effect of chicken sex and breed on physicochemical composition of breast meat (Table 2) indicates that WHC (cooking loss) and pH were not affected by sex nor breed. Miguel *et al.* (2008) and Symeon *et al.* (2010) in capons with 29 weeks (caponisation 8 weeks) and 18 to 24 weeks (early caponisation 3 weeks), respectively, reported that caponisation had no effects on pH and WHC. There were no sex differences for texture, confirming the results obtained by Symeon *et al.* (2010) and Calik *et al.* (2015) in capons with 18 and 24 weeks of age, respectively. However, Sirri *et al.* (2009), Symeon *et al.* (2010) and Lin *et al.* (2011), observed that caponisation decreases texture values in capons with 180 days, 24 and 28 weeks of age, respectively. Breed differences were found and the *Amarela* had tougher meat than *Pedrês*. Texture may be associated with stress, quantity, distribution of connective tissue, as well as smaller content of IMF. According to Lyon and Lyon (1991) meat with shear force values <3.62 kg/cm^2 is very tender meat, confirming that samples of the present study can be considered very tender, highlighting the *Pedrês* breed.

Breast moisture (72% to 73%) and protein content (23% to 24%) are within the range values reported by several authors, in cock and capon of Castellana Negra (Miguel *et al.*, 2008), in hybrid broiler (Sirri *et al.*, 2009) and Taiwan country chickens (Lin *et al.*, 2011). Breast meat capon showed greater CP content and IMF, in comparison with roosters, but no differences were found for moisture, myoglobin, ash and collagen contents in contradiction with Miguel *et al.* (2008), Sirri *et al.* (2009) and Volk *et al.* (2011) that have reported that caponisation had no effect on moisture and CP contents. Miguel *et al.* (2008) and Calik *et al.* (2015) indicated no differences between sexes for ash content, whereas Sirri *et al.* (2009) registered that caponisation increased its content, which was also found in the present work. Lin and Hsu (2013) shown that moisture and ash contents were lower in capon (caponised with 10 weeks) of native Taiwan Country chicken with 28 weeks of age. Miguel *et al.* (2008), Symeon *et al.* (2012) and Lin and Hsu (2013), confirming that caponisation (early and traditional and slaughter between 26 and 34 weeks) increased IMF content in breast, same resulted was observed in present study (18 weeks). Nevertheless, Volk *et al.* (2011) and Calik *et al.* (2015) have found no differences in IMF content of breast between cocks and capons, castrated at 8 weeks and slaughtered at 24 weeks of age. *Amarela* showed greater moisture, ash and IMF contents and smaller myoglobin than *Pedrês*. No differences were found between breeds for CP and collagen content. The moisture content found in the present study was lower than the value reported by Wattanachant *et al.* (2004) studying hybrid broiler breeds for meat production and Franco *et al.* (2013) in indigenous breeds.

The effect of chicken sex and breed in chemical composition of leg meat (Table 2) indicates that caponisation decreased the moisture content (Sirri *et al.*, 2009; Lin *et al.*, 2011; Lin and Hsu, 2013) and myoglobin content (Sirri *et al.*, 2009). No differences were found for ash (Miguel *et al.*, 2008; Lin *et al.*, 2011; Volk *et al.*, 2011) CP (Miguel *et al.*, 2008; Volk *et al.*, 2011) and collagen contents. According to Miguel *et al.* (2008),

Volk *et al.* (2011) and Calik *et al.* (2015) results, in capons with 24 to 29 weeks of age, found no differences between sexes for the moisture content of leg meat. However, Sirri *et al.* (2009) in crossed Hubbard with 180 days of age found that caponisation (7 weeks) promotes the increase of moisture and ash. The leg IMF content was not affected by caponisation, according to Calik *et al.* (2015) in Taiwan country capons with 28 weeks of age, contradicting Miguel *et al.* (2008), Sirri *et al.* (2009) and Lin and Hsu (2013) that reported no differences in IMF content in later slaughter. *Amarela* breed presented greater moisture content and ash, as well as greater CP content than *Pedrês* that had greater myoglobin and IMF content. There were no differences between breeds for collagen content.

Fatty acid composition

The effects of sex and breed on fatty acid profile of IMF in breast and leg meat are shown in Tables 3 and 4, respectively. Caponisation did not affect the content of SFA and PUFA, however, capon had greater MUFA content, improving the ratio PUFA/SFA in breast and the relationship MUFA + PUFA/SFA in breast and leg than rooster. Caponisation decreased C4:0 and C8:0 contents breast and leg, however increased C18:1 and C16:1 contents on breast and leg, respectively, improving profile of MUFA content in capon meat. Our results are not in accordance toTor *et al.* (2005) studying the effect of caponisation (8 weeks) on 28 weeks chickens of Penedesenca Negra breed found no differences in the SFA, PUFA and MUFA + PUFA/SFA contents in breast, however observed decreased of SFA and increased MUFA, PUFA and MUFA + PUFA/SFA contents in leg. Also Sirri *et al.* (2009) studying hybrid chickens, found no caponisation effect on SFA, MUFA and PUFA contents in thigh, but increased of SFA content in breast.

Greater content of SFA, MUFA and PUFA was found in breast meat of *Pedrês* than *Amarela* breed (Table 3). *Amarela* features better SFA profile (lower C12:0, C14:0 and C18:0, higher values for C4:0 and C16:0) than *Pedrês*. Respecting unsaturated fatty acids, *Pedrês* obtained higher C16:1 and arachidonic acid (C20:4) contents in relation to *Amarela.* Also Wattanachant *et al.* (2004) reported differences of SFA, MUFA and PUFA contents between broiler chicken and Thai indigenous breed. However, Franco *et al.* (2013) only found differences in MUFA and PUFA content between the Mos indigenous and T-44 breeds. In IMF of leg's meat *Amarela* breed had greater SFA and lower MUFA contents than *Pedrês*, but no differences were found for PUFA content. *Pedrês* presented lower C4:0 and C14:0 contents, however, highest C18:1 content and showed a better ratio MUFA + PUFA/SFA than *Amarela* (Table 4). Results agree with Díaz *et al.* (2013) who found no differences between the studied breeds but are inconsistent with those described by Wattanachant *et al.* (2004) who found differences in SFA, MUFA and PUFA contents.

Ten individual fatty acids were detected in the breast and leg (Tables 3 and 4). The main fatty acids were C18:1, C16:0 and C18:2, according to Tor *et al.* (2005), Díaz *et al.* (2013) and Franco *et al.* (2013). However, Miguel *et al.* (2008) reported that between 29 weeks cock and capon of Castellana Negra breed, C18:2 was predominant, followed by C16:0 and C18:1. Caponisation decreased the content of C4:0, C8:0 and increased C18:1 of breast meat. Caponisation also decreased the content of C4:0, C8:0 and increased C16:1 in leg meat. There were breed differences in contents of C4:0, C16:1 and C18:0, C12:0, C14:0, C16:0 and C20:4 in breast meat and in C4:0, C14:0 and C18:1 in leg meat. According to the World Health Organization (2003) recommendations, PUFA/SFA ratio should be above 0.4. In this study, the breast values were lower than the recommended.

Discriminant analysis

A discriminant analysis using the stepwise method was performed. The selected variables were C18:0, C8:0, C14:0, MUFA + PUFA/SFA, protein, moisture, IMF, C12:0 and C18:2 (Table 5), which allowed discriminating the four chicken breast meat groups with great correctness (92.88% of variance explained). Results show that the fatty acid profile could be an accurate tool to discriminate and distinguish different meat from different breed and sexes. Accordingly, Berzaghi *et al.* (2005) used the discriminant analysis to discriminate breast meat from different feeding sources based on the fatty acid composition. Several authors also used discriminant analysis to evaluate broiler chicken performance (Rosário *et al.*, 2008); to discriminate between chicken, turkey, pork, beef and lamb (Arnalds *et al.*, 2004); to classify poultry carcasses (Park *et al.*, 2002).

Sensory analysis

The training period allowed the assessors to standardise the evaluation methodology. However, no training can eliminate the variation between panellists (Stone and Sidel, 1985). The first two axes obtained after the principal component analysis step of the Generalised procrustes analysis represent 86.8% of the total variability (Figure 3). This value is superior to the 83.56% recorded by Rodrigues and Teixeira (2014) in pork meat, but lower than the 93% found by Rodrigues and Teixeira (2009) in goat meat of Cabrito Transmontano.

Breast evaluation is clearly different from drumstick and thigh, mainly on juiciness, flavour intensity and colour. *Amarela* and *Pedrês* capons' breast generated less consensus among panellists, presenting similar organoleptic characteristics. The disparity of the breast in relation to the thigh and drumstick was expected, due to its muscle constitution (white fibres), low collagen, IMF and myoglobin content. Flavour intensity and colour intensity are related with the *Pedrês* capon thigh. In general juiciness is associated with drumstick of free-range chicken and broiler. *Amarela* rooster drumstick had the greatest toughness and fibrousness. Broiler breast and thigh are characterised by lower toughness and fibrousness.

The *Pedrês* rooster group had the greatest off-taste intensity, toughness and fibrousness. Caponisation has influenced the off-taste in *Pedrês* capon, whereas colour intensity was associated with the *Amarela* capons. Miguel *et al.* (2008) for native breed Castellana Negra, found that

29 weeks capons were juicier and less fibrous than cocks, which might be due to the greater fat content in the capon. Conversely, uncastrated chickens were found to have higher flavour intensity and more conjunctive tissue than castrated ones. However, Lin *et al.* (2011) found that castrated chickens (28 weeks Taiwan country chicken cockerels) showed greatest flavour and tenderness in the breast, whereas the thigh obtained greater flavour and juiciness. Lin and Hsu (2013) in 28 weeks Taiwan native capons' meat found breast was more tender than roosters, as well as highest juiciness and flavour in meat of breast and leg. Calik *et al.* (2015) no differences observed for juiciness and tenderness in breast meat between capons and cocks (24 weeks native Greenleg Partridge), presenting capon's meat higher value of flavour. However, capon leg meat showed greater juiciness, tenderness and flavour than cocks. Caponisation has improved the lipid profile and characteristics of meat, making it juicier, more tender and less fibrous, improving capon's meat quality when compared with roosters raised together under the same production system.

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