Ann. Anim. Sci., Vol. 16, No. 3 (2016) 909–929 *DOI: 10.1515/aoas-2016-0009*

DE GRUYTER
OPEN

EFFECTS OF CAPONIZATION ON GROWTH PERFORMANCE, CARCASS AND MEAT QUALITY OF MOS BREED CAPONS REARED IN FREE-RANGE PRODUCTION SYSTEM*

Daniel Franco[1]♦, Mirian Pateiro[1], Diego Rois[2], Jose Antonio Vázquez[3], José Manuel Lorenzo[1]

[1]Centro Tecnológico de la Carne de Galicia, Rúa Galicia Nº 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900 Ourense, Spain
[2]Federacion de Razas Autóctonas de Galicia (BOAGA), Fontefiz, 32152 Coles (Ourense), Spain
[3]Grupo de Reciclado y Valorización de Residuos (REVAL), Instituto de Investigaciones Marinas (IIM-CSIC), R/ Eduardo Cabello 6, 36208 Vigo, Spain
♦Corresponding author: danielfranco@ceteca.net

Abstract

The effects of caponization on growth performance, carcass characteristics, meat quality and fatty acid profile of breast and drumstick of Mos and Sasso genotypes, reared in free-range production system were examined. A total of 47 birds of Mos breed (19 Castrated and 25 Entire) and 37 of Sasso X-44 (18 Castrated and 19 Entire) slaughtered at 32 weeks were used in this trial. The growth of broilers and the differences between genotypes and caponization effects were modelled by Weibull-growth equation. Capon's growth was higher than that obtained by roosters and Sasso weight was greater than Mos results (P<0.05). For both genotypes the chemical composition of breast and drumstick cuts showed significantly higher values of intramuscular fat (P<0.0001) and lesser values of moisture (P<0.0001) in capons in comparison with intact ones. In Mos breed, capons exhibited significantly (P<0.0001) higher values of breast and drumstick luminosity and yellowness, as well as lower values of redness. Regarding Warner-Braztler test (WB), there were no significant differences (P>0.05) by caponization effect, but hardness measured using textural profile analysis was lesser in meat from capons. Finally castration of animals led to important modifications in the intramuscular fat because meat from capons showed significantly lower values for total saturated fatty acids (SFA) and higher polyunsaturated fatty acids (PUFA). Nutritional indices were also more favorable in capon's meat, so overall fatty acid profile of capons was desirable from the viewpoint of human nutrition.

Key words: capons, free range, meat quality, fatty acid, Weibull-growth equation

Capons are castrated male chickens that are consumed in several Mediterranean countries, particularly in France. Also this product was very popular in Asia (Tor et

*Authors are grateful to Xunta de Galicia-Conselleria de Medio Rural (the Regional Government) for its financial support: FEADER 2009/11 and FEADER 2012/46.

al., 2002; Chen et al., 2007). Rearing of capons is a traditional and artisanal practice which was lost in the last decades because of more profitable broiler production. Capon is a delicacy and is cooked for special occasions, such as Christmas day. However, nowadays consumers demand poultry meat products of high quality and variety, because several studies have observed that they are tired of broiler meat (Wattanachant et al., 2004; Miguel et al., 2008). This is a product highly appreciated by the consumers who demand healthy and high quality food products. Its meat is appreciated for its organoleptic characteristics, especially its intensity of flavor and texture (Wattanachant et al., 2004; Miguel et al., 2008), parameters considered as important quality indicators and which have an impact on consumer acceptability (Koohmaraie, 1996).

The main effect of the caponization is the increasing of the overall fatness in different parts such as abdominal, subcutaneous and intramuscular (Tor et al., 2005). This fact allows improving sensorial quality of meat and hence the consumer acceptability. An important modification of the meat quality characteristics (Symeon et al., 2010) such as flavor, juiciness and tenderness is obtained (Chen et al., 2005; Sirri et al., 2009). Also, the quality characteristics of carcass are modified, increasing the yields of breast and thigh and reducing the yield of the drumstick (Sirri et al., 2009).

In addition, consumers require poultry production linked to raising and natural food, obtained with native breeds and traditional agricultural practices, related to environment, ecological and welfare aspects, because they associate meat from these animals with high quality products. In this sense, capons are traditionally fattened in free range conditions and slaughtered at a minimum age of 150 days (European Regulation, 2008) and often employing indigenous breeds that were not genetically selected, thus exhibiting slow-medium growth rate such as some reared in Spain: Castellana Negra (Miguel et al., 2008), Penedesca Negra (Tor et al., 2002; Tor et al., 2005), Extremeña Azul (Muriel, 2004) or Mos (Díaz et al., 2010; Díaz et al., 2012).

The Mos breed is a native breed of Galicia (NW Spain) characterized by a great rusticity that allows a perfect ability to adapt to the extreme conditions in winter. This breed is closely related to the environment and traditional rearing productions, contribuiting to the maintenance of biodiversity and sustainable agricultural production (Rois et al., 2011). Previous works with this breed have demonstrated the benefits from the carcass, meat and sensorial quality point of view against cocks genetically selected from Sasso lines (Franco et al., 2012 a, b; Franco et al., 2013). However these studies were developed under intensive rearing conditions, with uncastrated animals and at different slaughter ages, so information about this breed is not yet completed.

Thus the aim of this study was to evaluate the effects of caponization and genotype on growth performance, carcass composition and meat quality in breast and drumstick meat in Mos breed, reared in extensive conditions and slaughtered at 32 weeks, compared with one of the most commercial lines used in the production of chicken as Sasso.

Material and methods

Experimental design and animal management

This study was conducted in the experimental facilities of Zootechnical Resource Centre of Galicia (CRZG, Fontefiz, Ourense). A total of 81 birds (n=44 of Mos breed and n=37 of Sasso X-44) were reared under extensive indoor (barn reared) conditions as described by Commission Regulation 543/2008 (European Regulation, 2008). Mos breed birds were obtained from incubations performed of the existing breeder hens in the centre, while Sasso chicks (Sasso, France) were purchased from a local dealer (day 0). At birth the chicks were housed in a pen provided with a central hallway, several departments and natural ventilation with a density of 12 birds m^{-2}. At the 4th week of life, birds were sexed and accommodated in departments of second age with a density of 8 birds m^{-2}. As heat source heaters of 250 W at the ratio of 1 per 40 chicks were used. Heaters were partially removed at 4 weeks and completely after 6 weeks. From the 8th week of life until the slaughter, the chicks were moved to the definitive installation, with an indoor and outdoor density of 4 and 6 birds m^{-2}, respectively. Chickens for obtaining capons, were castrated by surgical procedure and the absence of testicular regeneration was determined by visual assessment and confirmed later after slaughtering. Caponization was performed when the birds had live weight in the range 1–1.5 kg. Thus, Sasso-X44 and Mos chickens were castrated at 6 and 8 weeks, respectively. Mortality rate was 2.8% for both genotypes in caponization process, while in the rest of rearing phase a value of 5.8% and 8.8% was obtained for Mos and Sasso X-44, respectively. Birds were fasted of feed but not water for 24 hours prior to surgery. Finally, we worked with 44 birds of Mos breed (19 Castrated; 25 Entire) and 37 Sasso X-44 (18 Castrated; 19 Entire). During the trial each group was kept in a separate aviary. Birds were fed *ad libitum* with a starter commercial diet (21% protein and 3000 kcal kg^{-1} ME) up to 4 weeks. From 4 to 16 weeks birds were fed a standard commercial growth diet (19% protein and 2900 kcal kg^{-1} ME). Finally from 16 to 32 weeks a finishing commercial diet (17% protein and 2850 kcal kg^{-1} ME) was used. All concentrates were provided by Piensos Biona (Lalin, Spain). Intakes of compound feed and live weight (LW) of birds in all treatment groups were recorded at birth and biweekly from 2 to 32 weeks.

The animals, at 32 weeks, were placed in crates and transported to an accredited abattoir, a journey time of approximately 2 hours. The birds were weighed, hung on shackles on a slaughter line, killed by manual exsanguination, plucked and eviscerated. The carcasses were chilled in a 4°C cool room for 24 h. The day after, the carcasses were weighed and the left side of the carcass was quartered according to the World's Poultry Science Association recommendations (Jensen, 1984). Carcass portions were obtained following Franco et al. (2013). Water holding capacity (WHC) and textural parameters were also determined for breast muscle due to sample size.

Meat quality attributes

The pH of the samples was measured using a digital portable pH-meter (Hanna Instruments, Eibar, Spain) equipped with a penetration probe. A portable colorimeter (Konica Minolta CM-600d, Osaka, Japan) with the next settings machine (pulsed

xenon arc lamp, angle of 0° viewing angle geometry, standard illuminant D65 and aperture size of 8 mm) was used to measure the meat color in the CIELAB space (CIE, 1976). Three measurements were performed for each sample in homogeneous and representative areas, free of intramuscular fat. Results were expressed as lightness (L*), redness (a*) and yellowness (b*). Heme iron was determined following Hornsey (1956). Moisture, protein and ash were quantified according to the ISO recommended standards 1442:1997, 937:1978 and 936:1998, respectively. The intramuscular fat (IMF) was extracted according to the AOCS Official Procedure Am 5-04 (AOCS, 2005). Collagen content was determined according to AOAC official method 990.26 (AOAC, 2000). For determination of total cholesterol in muscles, saponification, extraction and simultaneous identification was performed in normal phase following the procedure described by Prates et al. (2006).

Breast cuts were cooked according to Pateiro et al. (2013). All samples were cut perpendicular to the muscle fibre direction and were measured in a texture analyser (TA.XT.plus of Stable Micro Systems, Vienna Court, UK). WB and texture profile analysis (TPA) test were conducted following Pateiro et al. (2013). WHC was measured by cooking loss (CL). CL was evaluated by cooking breast (*pectoralis major* muscle) and was calculated by measuring the difference in weight between the cooked and raw samples.

Meat nutritional attributes

Total lipids were extracted from 50 g of ground meat sample, according to Bligh and Dyer (1959) procedure. Fifty mg of fat was used to determine fatty acid profile. Fatty acids were transesterified following the method described by Shehata et al. (1970) with the modifications proposed by Lorenzo et al. (2014). Organic phase (containing fatty acids methyl esters) was extracted with 2.5 mL of hexane. The fatty acid methyl esters (FAMEs) were stored at −80 °C until chromatographic analysis. Separation and quantification of FAMEs was determined following Domínguez and Lorenzo (2014).

Statistical analysis

Capon and uncastrated growth and mathematical modelling

The non-linear trends obtained for the capon and roosters' growth (G) were fitted to the Weibull growth equation (Vázquez et al., 2012):

$$G = G_m \left\{ 1 - exp\left[-ln2\left(\frac{t}{\tau} \right)^a \right] \right\} \quad [1]$$

Different kinetic parameters with well-known means can be also calculated from the previous equation (Murado and Vázquez, 2010; Vázquez et al., 2012). These parameters are interesting in order to characterize all the phases of animal growth:

$$v_m = \frac{aG_m}{\tau}\left(ln2\right)^{1/a} \beta^\beta e^{-\beta} \quad \text{with} \quad \beta = \frac{a-1}{a} \quad [2]$$

$$\lambda = \frac{\tau}{\sqrt[a]{ln2}}\left(\beta^{1/a} + \frac{e^{-\beta} - 1}{a\beta^{\beta}e^{-\beta}}\right) \quad [3]$$

$$t_m = \tau\left(\frac{a-1}{a\ ln2}\right)^{1/a} + \frac{G_m}{2v_m} \quad [4]$$

where:

G_m is the maximum capon or rooster growth (kg),
τ is the time required to achieve the half of the maximum growth (weeks),
v_m is the maximum rate of growth (kg weeks^{-1}),
a is the parameter related with the maximum slope of the growth (dimensionless),
t_m is the time required to achieve the maximum growth phase (G_m) (weeks),
λ is the lag phase (weeks).

The degree of maturity (DM) to 32 weeks (weight 32 weeks/G_m) was also quantified.

Numerical methods and statistical analysis

Growth of capon and roosters was modelled by minimization of the sum of quadratic differences between observed and predicted values, using the non linear least-squares (quasi-Newton) method provided by the macro *'Solver'* of the Microsoft Excel spreadsheet. Confidence intervals from the parametric estimates (Student's *t* test) and consistence of mathematical models (Fisher's F test) and residual analysis (Durbin-Watson test) were evaluated by *'SolverAid'* macro (Levie's Excellaneous website: http://www.bowdoin.edu/~rdelevie/excellaneous).

Carcass characteristic and meat quality and nutritional attributes of capons and uncastrated birds

For the statistical analysis of the results of carcass and meat quality an analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the SPSS package (SPSS 15.0, Chicago, IL, USA) was performed for all variables considered in the study. Fixed effect of breed and caponization was included in the model. The model used was:

$$Y_{ij} = \mu + B_i + C_j + (B \times C)_{ij} + \varepsilon_{ij} \quad [5]$$

where:

Y_{ij} is the observation of dependent variables,
μ is the overall mean, B_i is the effect of breed,
C_j is the caponization effect,
$B \times C$ is the interaction term,
ε_{ij} is the residual random error associated with the observation.

Within each genotype an ANOVA to quantify caponization effect was carried out. Correlations between variables ($P<0.05$) were determined by correlation analyses using the Pearson's linear correlation coefficient with SPSS 15.0 for Windows (SPSS 15.0, Chicago, IL, USA) software package.

Results

The experimental data of capon and roosters growth from Sasso and Mos genotypes are displayed in Figure 1. The profiles fitted to the experimental data according to the model [1] are also shown. Table 1 summarizes the values of the kinetic parameters and the statistical analyses performed on the numerical fittings. In the present study, the equation most appropriate for predicting growths was the cumulative function of Weibull's equation. The predictive ability of equation [1] to model the experimental data was almost perfect with a goodness of fit, in both cases, of 0.999. Lack of autocorrelation in the fittings was also observed for the two varieties (*d*-values).

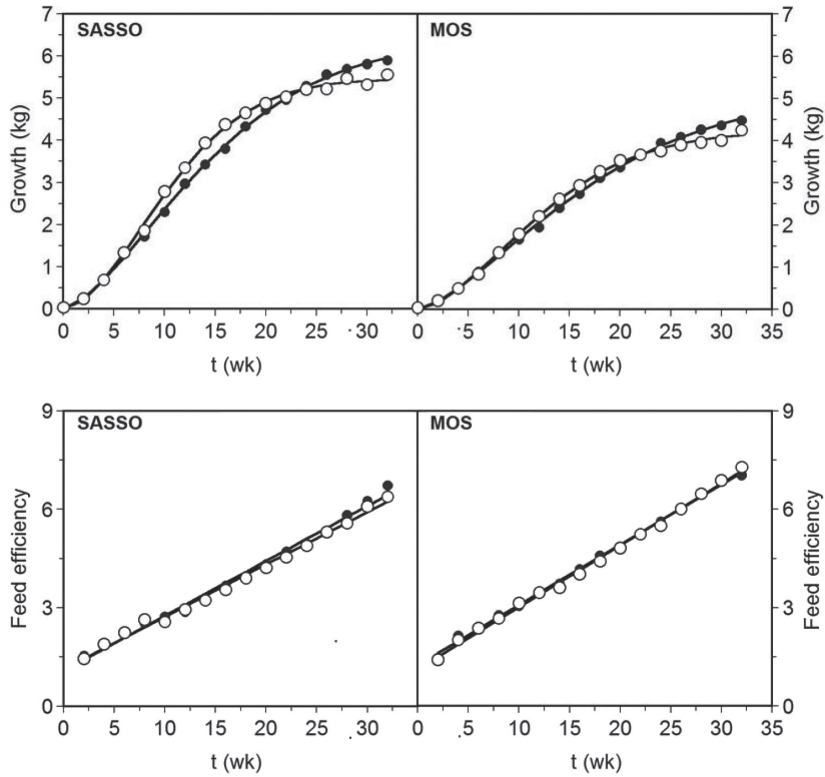

Figure 1. Growth and feed efficiency of capons (white) and roosters (black) for the two varieties studied (Sasso and Mos). Experimental data of growth (points) were fitted to equation [1] (continuous lines). Feed efficiency values were fitted to linear equation

Parametric estimations revealed the high statistical significance of the kinetic parameters (α=0.05), only the lag-phase (λ) in capons Mos growth was not significant because it did not show clear accommodation period previous to exponential phase. The highest maximum growths (G_m) were significantly found in Sasso genotype (P<0.05) and particularly in capons. Maximum growth rate (v_m) was also greater in Sasso but, in this case, the growth of rooster was faster than capon. Mos results for capon and rooster were similar compared to those obtained with Sasso. In addition, the time required to achieve the half of the maximum growth (τ) was lower for Sasso (capon and rooster) than Mos when comparing capons and roosters separately. The values of G_m were significantly superior in capons than roosters but v_m were higher in the case of roosters.

Table 1. Parametric estimations and confidence intervals (α=0.05) corresponding to the equation [1], [2] and [3] applied to predict the growth of capons and roosters.
NS: non-significant; R^2: coefficient of multiple determination. P-value from Fisher's *F* test (α=0.05) and *d*–value from Durbin-Watson test were also listed.

	Sasso capons	Sasso roosters	Mos capons	Mos roosters
G_m	6.38 ± 0.37	5.45 ± 0.11	5.10 ± 0.29	4.22 ± 0.11
v_m	0.287 ± 0.014	0.332 ± 0.020	0.200 ± 0.013	0.210 ± 0.012
λ_m	1.77 ± 1.57	1.84 ± 0.54	1.67 (NS)	1.43 ± 0.58
τ	13.06 ± 1.11	10.06 ± 0.30	14.68 ± 0.89	11.46 ± 0.37
a	1.52 ± 0.30	1.77 ± 0.12	1.46 ± 0.28	1.65 ± 0.10
t_m	20.61 ± 1.41	15.94 ± 0.69	23.06 ± 1.29	18.15 ± 0.93
DM	0.72	0.72	0.52	0.52
R^2	0.999	0.999	0.999	0.999
P-value	<0.001	<0.001	<0.001	<0.001
d-value	2.13	2.42	1.49	1.51

G_m is the maximum capon or rooster growth (kg).
τ is the time required to achieve the half of the maximum growth (weeks).
v_m is the maximum rate of growth (kg weeks^{-1}).
a is the parameter related with the maximum slope of the growth (dimensionless).
t_m is the time required to achieve the maximum growth phase (G_m) (weeks).
λ is the lag phase (weeks).
DM is the degree of maturity to 32 weeks (weight 32 weeks/G_m).

Finally, the feed efficiency for Sasso was significantly lower (slope values, *b*=0.167±0.009 kg of food consumed/kg of capon per wk and 0.160±0.008 kg of food consumed/kg of rooster per week) than Mos genotype (*b*=0.188±0.007 kg of food consumed/kg of capon per week and 0.184±0.005 kg of food consumed/kg of rooster per week) (Figure 1). It is revealed that no effect of caponization was found in feed efficiency (P>0.05).

Table 2. Effect of breed (Mos *vs.* Sasso X44) and caponization on carcass quality

	MOS			SASSO X–44			SEM	Breed	Caponization	B × C
	Castrated	Intact	P-value	Castrated	Intact	P-value		P-value	P-value	P-value
Live weight (kg)	4.35	4.24	0.289	5.57	5.55	0.904	0.049	<0.0001	0.507	0.665
Carcass weight (kg)	3.54	3.47	0.427	4.59	4.66	0.669	0.041	<0.0001	0.998	0.430
Dressing percentage	81.38	81.90	0.338	82.45	83.84	0.014	0.192	<0.0001	0.015	0.264
Commercial cuts (% in respect to carcass)										
Drumstick	14.37	14.21	0.677	12.82	12.90	0.827	0.131	<0.0001	0.865	0.652
skin	1.12	0.80	<0.0001	1.72	1.05	<0.0001	0.032	<0.0001	<0.0001	0.007
lean	9.58	10.13	0.056	8.27	8.70	0.116	0.098	<0.0001	0.014	0.742
bone	3.64	3.43	0.175	2.81	3.04	0.125	0.053	<0.0001	0.955	0.043
lean/bone	2.67	2.98	0.010	2.97	2.91	0.695	0.047	0.219	0.194	0.054
Thigh	15.61	19.00	<0.0001	16.31	17.91	0.001	0.129	0.445	<0.0001	0.001
Drumstick + thigh	29.99	33.22	<0.0001	29.31	30.81	0.024	0.221	<0.0001	<0.0001	0.082
Wing	9.23	9.24	0.941	8.40	7.99	0.065	0.068	<0.0001	0.152	0.127
Breast	18.01	15.64	<0.0001	18.14	16.77	0.011	0.155	0.047	<0.0001	0.114
Head	2.64	3.02	0.002	2.94	3.00	0.701	0.050	0.164	0.030	0.123
Neck	6.12	5.83	0.139	5.96	5.64	0.111	0.069	0.213	0.030	0.903
Legs	3.94	4.37	<0.0001	3.67	3.93	0.162	0.050	0.001	0.001	0.376
Carcass remainder	30.04	28.64	<0.100	31.72	31.82	0.924	0.338	0.001	0.342	0.270

SEM: Standard error of the mean.

Table 3. Effect of breed (Mos *vs.* Sasso X44) and caponization on meat quality (chemical composition and colour parameters)

	MOS			SASSO X-44			SEM	Breed	Caponization	B × C
	Castrated	Intact	P-value	Castrated	Intact	P-value		P-value	P-value	P-value
Drumstick										
pH	5.92	5.85	0.098	5.92	6.01	0.072	0.015	0.012	0.712	0.014
luminosity (L*)	44.32	38.88	<0.0001	43.51	41.25	0.100	0.429	0.366	<0.0001	0.069
redness (a*)	12.29	16.34	<0.0001	13.17	15.16	0.009	0.224	0.739	<0.0001	0.025
yellowness (b*)	14.09	9.24	<0.0001	14.28	9.34	<0.0001	0.222	0.745	<0.0001	0.927
moisture (%)	74.70	75.54	0.001	74.12	75.67	<0.0001	0.096	0.235	<0.0001	0.067
IMF (%)	2.47	1.57	0.002	4.00	2.48	0.001	0.123	<0.0001	<0.0001	0.217
protein (%)	21.19	20.36	<0.0001	20.35	20.31	0.916	0.084	0.010	0.013	0.020
ashes (%)	1.30	1.35	<0.0001	1.28	1.31	0.027	0.004	<0.0001	<0.0001	0.252
collagen (%)	0.90	0.78	0.015	1.05	0.88	0.034	0.021	0.006	0.002	0.608
Fe heme*	1.10	1.41	0.006	0.28	0.214	0.075	0.035	0.599	0.001	0.289
cholesterol	0.53	0.65	<0.0001	0.51	0.60	0.006	0.010	0.093	<0.0001	0.462
Breast										
pH	5.68	5.93	<0.0001	5.82	5.90	0.130	0.018	0.128	<0.0001	0.018
luminosity (L*)	52.84	46.65	<0.0001	49.07	46.89	0.040	0.338	0.011	<0.0001	0.004
redness (a*)	0.46	2.28	<0.0001	1.89	2.74	0.016	0.144	0.002	<0.0001	0.101
yellowness (b*)	12.18	6.84	<0.0001	11.93	7.01	<0.0001	0.235	0.942	<0.0001	0.657
moisture (%)	72.75	74.06	<0.0001	72.52	73.63	<0.0001	0.059	0.007	<0.0001	0.413
IMF (%)	0.15	0.09	0.044	0.58	0.25	0.005	0.028	<0.0001	0.003	0.006
protein (%)	25.56	24.30	<0.0001	25.63	24.56	<0.0001	0.066	0.214	<0.0001	0.472
ashes (%)	1.20	1.25	<0.0001	1.20	1.24	0.005	0.004	0.798	<0.0001	0.440
collagen (%)	0.58	0.31	<0.0001	0.59	0.36	<0.0001	0.015	0.342	<0.0001	0.461
Fe heme	0.18	0.32	<0.0001	0.25	0.29	0.246	0.010	0.334	<0.0001	0.017
cholesterol	0.41	0.14	<0.0001	0.39	0.15	<0.0001	0.009	0.046	<0.0001	0.393

*Fe heme and cholesterol are expressed as mg g^{-1} wet meat; SEM: Standard error of the mean.

Table 2 shows the effect of caponization and genotype on the carcass parameters measured. The effect of genotype did not affect thigh, head and neck percentage and lean/bone ratio in drumstick. The caponization affected all variables with the exception of live and carcass weight, drumstick, bone drumstick, wing and carcass remainder and lean/bone ratio in drumstick. The percentage of head (including the comb) was only significantly (P=0.002) affected by caponization in Mos breed. Regarding LW, once the stress of the surgical procedure has been overcome, caponization had no negative effect on this variable. The entire birds from Sasso genotype had higher dressing percentage (Table 2). The caponization resulted in a decrease of meat weight in the leg (thigh plus drumstick) for both genotypes (29.99 vs. 33.22 and 29.31 vs. 30.81 for Mos and Sasso X-44, respectively; P<0.0001). Wing percentage was not affected by the caponization in the present study. Chemical composition and colour parameters of drumstick and breast are shown in Table 3. Significant differences in pH, IMF, protein, ashes and collagen content between Sasso and Mos have been found for drumstick cut, whereas in breast the lightness, redness index, moisture, IMF and cholesterol were affected by genotype.

For both genotypes and commercial cuts, caponization affected all variables with the exception of pH. Comparing within Sasso genotype, there were no differences for luminosity, protein and Fe-heme content for drumstick piece and Fe-heme in breast piece. Meat from capons was characterized by higher luminosity and yellowness with a lesser redness index in the present study (Table 3). Indeed, we found a correlation between colour parameters and Fe heme content (drumstick r=–0.601, r=0.606 and r=–0.444, P<0.01 n=68 for L*, a* and b* with Fe-heme content, respectively; breast r=–0.588, r=0.396 and r=–0.583, P<0.01 n=68 for L*, a* and b* with Fe-heme content, respectively).

In our study the IMF amount in both muscles from castrated birds was greater than in entire animals. On the other hand, for both genotypes the capons had higher protein content (P<0.0001) in breast piece. Finally, for both genotypes and both commercial cuts, the ash content was significantly (P<0.0001) lower in capons than in roosters.

Cholesterol content of drumstick meat decreased from capons to roosters in both genotypes while in breast the trend was opposite (Table 3), showing mean values in drumstick of 59 and 55.5 mg/100g for Mos and Sasso, respectively, and 27.5 and 27 mg/100 g in breast for Mos and Sasso, respectively. Indeed, we found a negative correlation between cholesterol content and IMF for drumstick (r=–0.418 P<0.01 n=68) but not in breast piece.

WHC measured as CL showed significant differences between castrated and uncastrated birds for both genotypes, but especially for Mos breed (6.97 vs. 9.51; P<0.0001, Table 4). In our study we found significant differences in moisture content between capons and roosters. Thus, meat from birds with higher moisture showed the highest loss of water by cooking, indeed a positive correlation was found between moisture and CL (r=0.336; P<0.01 n=68).

Table 4. Effect of breed (Mos *vs.* Sasso X44) and caponization on water holding capacity and textural parameters of breast

	MOS			SASSO X-44			SEM	Breed	Caponization	B × C
	Castrated	Intact	P-value	Castrated	Intact	P-value		P-value	P-value	P-value
Cooking loss (%)	6.97	9.51	<0.0001	8.65	9.57	0.030	0.153	0.006	<0.0001	0.010
Textural parameters										
firmness (kg s^{-1})	0.53	0.58	0.173	0.62	0.56	0.188	0.014	0.180	0.787	0.061
total work (kg mm)	5.70	6.22	0.404	8.70	5.21	0.016	0.375	0.191	0.052	0.010
shear force (kg cm^{-2})	1.45	1.66	0.041	1.84	1.65	0.356	0.054	0.081	0.897	0.077
TPA-test										
hardness (kg)	4.32	5.56	<0.0001	5.12	6.22	0.002	0.102	0.001	<0.0001	0.708
springiness (mm)	0.50	0.52	0.107	0.50	0.50	0.572	0.005	0.211	0.323	0.099
cohesiveness	0.45	0.47	0.218	0.49	0.48	0.908	0.005	0.015	0.413	0.328
gumminess (kg)	1.98	2.63	<0.0001	2.54	3.04	0.023	0.061	0.000	<0.0001	0.546
chewiness (kg mm)	1.00	1.39	<0.0001	1.30	1.52	0.068	0.035	0.003	<0.0001	0.235

SEM: Standard error of the mean.

Table 5. Effect of breed (Mos *vs.* Sasso X44) and caponization on fatty acid profile (g $100g^{-1}$ of fat) of breast

	MOS			SASSO X-44		P-value	SEM	Breed	Caponization	B × C
	Castrated	Intact	P-value	Castrated	Intact			P-value	P-value	P-value
C16:0	18.47	26.78	<0.0001	20.92	27.74	<0.0001	0.243	0.001	<0.0001	0.130
C16:1	1.50	1.57	0.657	2.55	2.88	0.118	0.062	<0.0001	0.119	0.287
C18:0	9.39	9.28	0.543	8.64	7.70	<0.0001	0.068	<0.0001	<0.0001	0.004
C18:1*n9*c	29.41	30.01	0.483	34.51	34.62	0.880	0.285	<0.0001	0.533	0.674
C18:2*n6*	19.53	19.56	0.966	16.88	18.12	0.036	0.230	<0.0001	0.173	0.194
C20:1	0.25	0.21	0.055	0.29	0.21	<0.0001	0.005	00.076	<0.0001	0.067
C18:3*n3*	0.59	0.70	0.010	0.67	0.62	0.349	0.015	0.957	0.268	0.014
C20:2	0.30	0.17	<0.0001	0.22	0.11	<0.0001	0.007	<0.0001	<0.0001	0.549
C20:3*n6*	0.02	0.24	<0.0001	0.45	0.20	<0.0001	0.013	<0.0001	0.439	<0.0001
C20:4*n6*	13.36	5.45	<0.0001	8.40	3.73	<0.0001	0.265	<0.0001	<0.0001	0.003
C22:6*n3*	1.72	0.93	<0.0001	1.02	0.50	<0.0001	0.038	<0.0001	<0.0001	0.079
SFA	28.38	36.61	<0.0001	30.25	36.15	<0.0001	0.243	0.155	<0.0001	0.020
MUFA	31.18	31.80	0.518	37.37	37.73	0.673	0.320	<0.0001	0.444	0.841
PUFA	35.54	27.07	<0.0001	27.66	23.30	<0.0001	0.387	<0.0001	<0.0001	0.010
PUFA/SFA	1.27	0.74	<0.0001	0.92	0.64	<0.0001	0.022	<0.0001	<0.0001	0.004
n3	2.31	1.63	<0.0001	1.69	1.13	<0.0001	0.037	<0.0001	<0.0001	0.429
n6	32.92	25.26	<0.0001	25.74	22.06	<0.0001	0.358	<0.0001	<0.0001	0.007
n6/n3	14.42	15.65	0.074	15.47	19.74	<0.0001	0.242	<0.0001	<0.0001	0.003

SEM: Standard error of the mean.
SFA=∑ (C14:0+C16:0+C18:0); MUFA=∑ (C16:1+C18:1*n9*c+C20:1); PUFA=∑ (C18:2n6+C18:3*n3*+C20:2+C20:3*n6*+C20:4*n6*+C22:6*n3*).

Table 6. Effect of breed (Mos *vs.* Sasso X44) and caponization on fatty acid profile (g 100 g^{-1} of fat) of drumstick

	MOS			SASSO X-44			SEM	Breed	Caponization	B × C
	Castrated	Intact	P-value	Castrated	Intact	P-value		P-value	P-value	P-value
C14:0	0.67	0.63	0.202	0.78	0.83	0.160	0.012	<0.0001	0.871	0.057
C16:0	19.43	25.47	<0.0001	22.75	27.61	<0.0001	0.298	<0.0001	<0.0001	0.326
C16:1	2.13	1.86	0.155	3.95	3.64	0.277	0.084	<0.0001	0.089	0.932
C18:0	10.03	11.22	0.002	8.36	8.41	0.868	0.118	<0.0001	0.010	0.018
C18:1*n9*c	30.60	30.07	0.454	34.12	35.68	0.021	0.238	<0.0001	0.283	0.031
C18:2*n6*	22.51	22.17	0.672	18.37	19.67	0.056	0.255	<0.0001	0.348	0.114
C20:1	0.31	0.24	0.002	0.32	0.32	<0.0001	0.008	0.417	<0.0001	0.110
C18:3*n3*	0.74	0.81	0.063	0.74	0.72	0.607	0.014	0.141	0.322	0.088
C20:2	0.01	0.23	<0.0001	0.23	0.14	<0.0001	0.008	<0.0001	0.001	<0.0001
C20:3*n6*	0.40	ND	<0.0001	0.35	ND	<0.0001	0.004	0.009	<0.0001	0.009
C20:4*n6*	7.87	4.54	<0.0001	5.04	2.21	<0.0001	0.164	<0.0001	<0.0001	0.452
C22:6*n3*	0.88	0.53	<0.0001	0.56	0.19	<0.0001	0.019	<0.0001	<0.0001	0.753
SFA	30.14	37.34	<0.0001	31.90	36.86	<0.0001	0.293	0.280	<0.0001	0.061
MUFA	33.04	32.17	0.297	38.39	39.53	0.170	0.289	<0.0001	0.821	0.087
PUFA	32.42	28.31	0.001	25.32	22.94	0.007	0.351	<0.0001	<0.0001	0.220
PUFA/SFA	1.10	0.76	<0.0001	0.80	0.62	<0.0001	0.020	<0.0001	<0.0001	0.042
n3	1.62	1.35	<0.0001	1.31	0.92	<0.0001	0.022	<0.0001	<0.0001	0.160
n6	30.78	26.72	0.001	23.77	21.88	0.021	0.337	<0.0001	<0.0001	0.111
n6/n3	19.01	19.86	0.281	18.31	24.38	<0.0001	0.331	0.005	<0.0001	<0.0001

SEM: Standard error of the mean.
SFA=∑ (C14:0+C16:0+C18:0); MUFA=∑ (C16:1+C18:1*n9*c+C20:1); PUFA=∑ (C18:2*n6*+C18:3*n3*+C20:2+C20:3*n6*+C20:4*n6*+C22:6*n3*).

Regarding textural parameters, there were no significant differences (P>0.05) between genotypes by caponization effect, when assessed by WB test. Using other textural test such as TPA we noted that hardness, gumminess and chewiness were significantly greater in intact birds than in capons. In this study CL and moisture content have more influence on hardness than collagen content (r=0.363 between hardness and CL, and r=0.427 between hardness and moisture with n=68 and P<0.01 for both correlation tests). As chewiness is the product of hardness, cohesiveness and springiness results for this parameter are affected by the value of hardness (Table 4).

In Table 5 the fatty acid composition of breast is shown. The breed effect affected all SFA (C14:0, C16:0 and C18:0) but not SFA total content (P=0.155) with higher values in Sasso breed than in Mos for myristic and palmitic acid. For stearic acid, higher values were found in Mos breed. The mean total content of SFA was around 29.31% and 36.38% for capons and entire birds respectively, since the main SFA acid was palmitic (67.19% and 74.93% for capons and entire birds respectively) followed by stearic acid in importance. The caponization effect had a strong influence (P<0.001) on palmitic acid and hence on total SFA amount (Table 5).

Within monounsaturated fatty acids (MUFA), for all FA identified, values were always significantly higher in Sasso breed, since total MUFA were significantly affected by breed (37.55 vs. 31.49; P<0.0001). The mean total content of MUFA was around 34.27% and 34.76% for capons and entire birds respectively, since the main MUFA acid was oleic (93.25% and 92.82% for capons and entire birds respectively) followed by palmitoleic acid in presence. In this case, caponization had no effect on oleic acid and therefore in total MUFA content (P=0.444).

Finally, within PUFA, the two most abundant *n-6* FA (linoleic and arachidonic acid) were higher in Mos breed and independently of type of bird (capons or entire) there was no difference in linolenic acid content (P=0.957). The mean total content of PUFA was around 31.60% and 25.18% for capons and entire birds respectively, since the main PUFA acid was linoleic (57.61% and 74.82% for capons and entire birds respectively) followed by arachidonic, docosahexaenoic and linolenic acid. For linoleic acid, the caponization effect only had effect on Sasso breed (16.88 vs 18.12 for capons and castrated birds; P=0.036). In this sense arachidonic acid was significantly higher (more than double) in both types (capon and entire) against animals from Sasso genotypes. The same tendency can be observed for docosahexaenoic acid. Because of these differences *n-6* and *n-3* PUFA and the nutritional indices, PUFA/SFA (P/S) and *n-6/n-3* ratios, were significantly affected (Table 5). Differences in arachidonic acid were notable between genotypes (9.40 vs 6.06 for Mos and Sasso, respectively).

In Table 6, the fatty acid composition of drumstick is shown. Overall, analysis of the FA profile for this commercial cut was similar to that shown for breast for SFA, MUFA, PUFA, and nutritional indices (P/S and *n-6/n-3* ratios). Briefly, breed effect affected all saturated fatty acids (C14:0, C16:0 and C18:0) but not SFA total content (P=0.280) with higher values in Sasso breed than in Mos for myristic and palmitic acid. The mean total content of SFA was around 31.02% and 37.10% for capons and entire birds respectively, since the main SFA acid was palmitic (67.98% and 71.53% for capons and entire birds respectively). As in *pectoralis* muscle, castration had

a significant effect (P<0.001) on palmitic acid and in total SFA amount. Concerning MUFA, for palmitoleic and oleic acid, values were always consistently higher in Sasso breed, hence MUFA total content was significantly higher in Sasso breed (38.96 vs 32.60; P<0.0001). In this case, caponization only had significant effect on oleic acid for Sasso breed, however total MUFA content was not affected by castration effect for both genotypes (Table 6).

Finally, within PUFA, the total content was around 28.87 and 25.62% for capons and entire birds respectively, since the main PUFA component was linoleic acid followed by arachidonic and linolenic acid. The two most abundant *n-6* FA (linoleic and arachidonic acid) were higher in Mos breed than in selected line, independently of type of bird and there was no influence of caponization on linolenic acid content (P=0.348).

To assess the nutritional index of breast and drumstick meat fat, the PUFA/SFA ratio (P/S) was determined. P/S ratio was always significantly higher in castrated animals and for Mos breed for both muscles studied. For all cases P/S ratio remained up to minimum recommendation of 0.4 (Wood et al., 2004), with the highest values of 1.10 and 1.27 for drumstick and breast of Mos breed. Contemporary changes in human nutrition are characterized by increasing consumption of fat and vegetable oils rich in *n-6* PUFAs together with decrease in *n-3* PUFA-rich foods, resulting in an *n-6/n-3* ratio of 10–20/1 in Western diet for a ratio around 1/1 in the diet of our ancestors. In this sense, the *n-6/n-3* ratio was under 20 for all cases with the exception of drumsticks of Sasso X-44.

Discussion

The type of experimental profile obtained for capons was not completely sigmoid but more of hyperbolic so that Weibull's equation was more appropriate in comparison with the logistic equation used to describe rooster production (Franco et al., 2012 a, b) (comparisons not shown). The model [1] is sometimes more flexible than logistic equation in terms of simulation of non-linear curves, mainly when they are not sigmoid, and better for explaining the data found here (Vázquez et al., 2012).

Other authors studying the effect of caponization have used the Gompertz to predict the growth of Castellana Negra native Spanish cocks and capons (Miguel et al., 2008) and Redbro broilers (Symeon et al., 2010). Although, such equation is well-known and widely reported in zootechnics literature, in our case its predictive ability was worse than equation [1] (data not shown).

The differences obtained between capons were in agreement with those previously obtained by roosters from Sasso T-44 and Mos genotypes (Franco et al., 2012 a). Thus, caponization had clear positive effect in the growth of both genotypes. These findings are in accordance with other authors (Rahman et al., 2004; Chen et al., 2006), but in other works the effect of caponization in live weight was negative (Symeon et al., 2010) or null (Miguel et al., 2008). The capons here obtained were heavier than those reported by Rodríguez (2010) and Miguel et al. (2008) using Mos

and another Spanish variety of Castellana Negra. However, for the latter the degree of maturity was higher.

Regarding feed efficiency, similar outcomes were described in previous reports (Chen et al., 2005; Symeon et al., 2010).

Similar results for carcass parameters were previously reported in both genotypes reared in intensive conditions at different ages (Franco et al., 2012 a, b; Franco et al., 2013). The effect of castration on LW of poultry is controversial. In this sense, several authors reported higher values in uncastrated birds (Cason et al., 1988; Miguel et al., 2008) while others have shown that for the same slaughter age. The LW of capons were either similar (Zanusso et al., 2001; Chen et al., 2010; Symeon et al., 2012) or higher than those of cocks (Mast et al., 1981; Muriel, 2004). Diversity of these results could be attributed to breeding, feeding and rearing system and interaction between nutrition and genetics used in these researches. Also entire birds from Sasso genotype had higher dressing percentage, contrary to results shown by York and Mitchell (1968) in castrated chicken when the LW was not significantly different between castrated and entire birds.

The leg weight reduction observed can be due to testosterone which is well documented (Tor et al., 2002; Hsu and Lin, 2003). This hormone is known to induce protein synthesis so its reduction level by caponization, probably resulted in the diminution of amount of muscles in the legs of capons. Other authors have reported about the effects of caponization on thighs, breast and drumstick percentages (Muriel, 2004; Symeon et al., 2012). Concerning breast, this is an important fact, because this is one of the most highly valued pieces of the poultry industry, while the sum of thigh and drumstick provides an idea of the ratio between the weight of the edible products and the bones, which gives a good image of carcass quality as a whole (Ricard, 1972). As in the present study, similar results have been reported by other authors in Spanish native breeds such as Penedesca Negra (Tor et al., 2002), Extremeña Azul (Muriel, 2004) and Castellana Negra (Miguel et al., 2008). According to Muriel (2004), the caponization causes changes in the metabolism due to a lack of hormones that lead to an earlier development of the *pectoralis major* muscle in capons. The results of wing percentage were in agreement with other researches (Miguel et al., 2008; Symeon et al., 2012). Other works have reported either increased wing percentage (Hsu and Lin, 2003; Muriel, 2004) or decreased (Tor et al., 2002) as a result of caponization.

Differences between these two types of breed were previously indicated for entire birds in pH, moisture, protein, ash and Fe-heme content for animals reared in intensive conditions and slaughtered at different ages: 6, 8 and 10 months (Franco et al., 2012 a, b; Franco et al., 2013).

Colour parameters obtained in the present study (Table 3) corroborate previous works in the literature (Miguel et al., 2008; Sirri et al., 2009; Symeon et al., 2010) explained by the lower level of heme pigments reported for capons (Sirri et al., 2009).

One of the main effects of caponization is to increase intramuscular fat accumulation (Chen et al., 2005). This result for *pectoralis major* muscle is in agreement with those reported by other researchers (Tor et al., 2002; Miguel et al., 2008). Fatness level plays an important role in meat quality due to IMF content being positively related with chicken meat quality (Welter, 1976). On the other hand, the higher protein

content obtained in breast piece of capons implied that caponization improved muscle growth and nitrogen retention in agreement with Chen et al. (2007). The results obtained for ash for both genotypes and both commercial cuts agreed with Chen et al. (2007) who indicated that caponization could minimize mineral retention in muscle.

Our cholesterol results partially agree with those of Sirri et al. (2009) who found in the thigh and breast of capons higher amounts of cholesterol. An explanation for this discrepancy could be due to differences in IMF contents, because Sirri et al. (2009) showed values of 1.61% for breast in capons, while we reported values of 0.15% and 0.58% for Mos and Sasso, respectively (Table 3).

Although we believe that the lack of agreement between the two commercial pieces might be due to the low values presented for the breast, certainly, there is no agreement in the available literature as to the relationship between fat content in meat and the amount of cholesterol. A high level of adiposity in meat is not always linked to high cholesterol concentration, as cholesterol is present in large quantities in its free form in cell membranes (Karp, 2005). Mean values of cholesterol found in drumstick and breast are lesser that those found by Sirri et al. (2009) in Hubbard × × Golden Comet crossbred and also in broiler meat (Konjufca et al., 1997). This is an interesting nutritional point for this breed, because the daily intake of cholesterol currently recommended must not exceed 300 mg (www.nal.usda.gov/fnic/foodcomp/search). Therefore, the knowledge about cholesterol content in foods is important, especially in poultry meat because consumption is currently increasing, due to healthy recommendations and price.

The findings of CL are contradictory to those previously published (Lin and Hsu, 2002; Miguel et al., 2008; Sirri et al., 2009). In these studies, the authors did not find significant differences in water content by caponization effect; hence a possible explanation for this fact could be that WHC is related to moisture content. This inverse relationship between moisture content and CL has been widely reported in bovine (Jeremiah et al., 2003; Franco et al., 2009).

Despite the fact that an increase of IMF resulted in a significant decreasing of shear force values in chicken as reported by Zhao et al. (2007) or even in other species such as bovine (Vestergaard et al., 2007; Franco et al., 2009) and pigs (Van Laack et al., 2001), in the present study we did not find this association between IMF and shear force values. Regarding TPA, the parameters are related very closely to the connective tissue, specifically in collagen solubilization (Martens et al., 1982) and cross linking of the collagen (Aberle et al., 2001). The association found on hardness between CL and moisture content was previously confirmed by Ruíz-Ramírez et al. (2005) in dry-cured muscles.

Exact results were previously found in cocks of both genotypes, reared in intensive system and slaughtered at 6 months (Franco et al., 2012 a), 8 months (Franco et al., 2013) and 10 months (Franco et al., 2012 b). The caponization effect had a strong influence ($P<0.001$) on palmitic acid and hence in total SFA amount (Table 5). However other authors did not find this outcome (Tor et al., 2005; Sirri et al., 2009).

Regarding MUFA, these results were previously confirmed in above mentioned works with this breed (Díaz et al., 2012; Franco et al., 2012 a, b; Franco et al., 2013).

Also in other poultry genotypes, such as broilers, oleic acid was the major MUFA compound (Cortinas et al., 2004; Crespo and Esteve, 2002).

PUFA outcomes were reported in Mos and Sasso T44 capons studied by Díaz et al. (2012). Once again, these results have been previously indicated for both breeds in breast (Franco et al., 2012 a, b; Franco et al., 2013). From an initial and similar level of linoleic acid in the muscle in both genotypes it seems that Mos breed is more efficient in the process of elongation/desaturation and the mechanism implicated in the incorporation of long PUFA in the muscles than Sasso line as suggested Schiavone et al. (2004) with ducks.

In Table 6, the fatty acid composition of drumstick is shown. For drumstick there are no previous works in the literature for Mos breed with the exception of the work published by Díaz et al. (2012), who worked with Mos and hybrid lines of Sasso (T-44 and X-44). Díaz et al. (2012) also have reported significant differences in stearic acid but not in myristic neither palmitic acid, with higher values in Mos breed. As in *pectoralis major* muscle, castration had a significant effect ($P<0.001$) on palmitic acid and in total SFA amount in agreement with Tor et al. (2005) working with Penedesca Negra capons and uncastrated birds slaughtered at 28 weeks of age. In this case, caponization only had significant effect on oleic acid for Sasso breed, however total MUFA content was not affected by castration effect for both genotypes (Table 6). These results agree with those of Sirri et al. (2009) and Miguel et al. (2008), but are in disagreement with Tor et al. (2005).

On the contrary, Díaz et al. (2012) reported higher values for linoleic acid in Mos capons than in hybrid lines from Sasso strain with levels of arachidonic acid significantly higher in castrated animals. Also our results are in agreement with Díaz et al. (2012) who reported significantly higher contents of PUFA in Mos breed than in hybrid lines, Sasso X-44 and T-44. These results cannot be related to diet practices because all birds were fed with the same commercial diets. It can be argued that castration may affect the delta-6-desaturase enzyme activity involved in the elongation/desaturation process of both *n-6* and *n-3* PUFA. Our results are in contradiction with those supported by Sirri et al. (2009), who found that caponization process led to an inhibition of delta-6-desaturase enzyme in *biceps femoris* muscle.

For breast, P/S ratio was greater than those reported by Tor et al. (2005) and Sirri et al. (2009) for Penedesca Negra capons (0.67) and similar to capons from Hubbard × Golden Comet (1.24), respectively. Previously, Díaz et al. (2012) found P/S values of 0.77 and 0.76 for breast and drumstick, respectively. Our values for *n-6/n-3* were higher than those shown by Sirri et al. (2009) in crossbred capons from Hubbard × Golden Comet strains (11.79 and 9.60 for drumstick and breast, respectively) and lesser than those reported by Tor et al. (2005) in Penedesca Negra capons.

Conclusions

In the light of our results, capons and roosters had different maximum growths (significantly higher in capons) and the comparison between genotypes revealed the greater productivity of Sasso.

There were expectable differences in carcass characteristics between genotypes as we indicated in previous works, so rearing conditions had less importance than

genetic factor. For both genotypes, capons exhibited higher percentages of breast and lower percentages of thighs with drumstick, while wing percentage was not affected by the caponization.

As expected, regarding meat composition there was a higher intramuscular fat content and lesser moisture content in meat of capons than in the roosters, resulting in that capons meat was more tender than cocks when textural profile analysis was conducted. In addition caponization provided a brighter and yellower meat due to differences in heme content in both muscles.

Main fatty acid acids such as palmitic, stearic and arachidonic were strongly affected by caponization, resulting in a meat with better nutritional indices (lower SFA, *n-6/n-3* ratio and higher PUFA and P/S ratio). In addition cholesterol content was not increased at least in drumstick pieces, so changes in meat quality (texture and colour) and nutritional aspects related to caponization were positive in Mos and Sasso genotypes.

Overall, caponization is a practice that produces a different meat product, specifically increasing intramuscular fat levels and improving tenderness levels so it will be of great interest in traditional breeds compared to industrial ones.

References

Aberle E., Forrest J., Gerrard D., Mills E., Hedrick H., Judge M. (2001). Principles of Meat Science. Iowa, Kendall–Hunt Publishing Company.

AOAC (2000). AOAC official method 990.26. Hydroxyproline in meat and meat products. 39.1.27. In: Official methods of analyses. Association of Official Analytical Chemists, Arlington, VA, USA.

AOCS (2005). AOCS Official Procedure Am 5–04. Rapid determination of oil/fat utilizing high temperature solvent extraction. American Oil Chemists Society, Urbana, IL.

Bligh E.G., Dyer W.J. (1959). A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol., 37: 911–917.

Cason J.A., Fletcher D.L., Burke W.H. (1988). Effects of caponization on broiler growth. Poultry Sci., 67: 979–981.

Chen K.L., Chi W.T., Chiou P.W.S. (2005). Caponization and testosterone implantation effects on blood lipid and lipoprotein profile in male chickens. Poultry Sci., 84: 547–552.

Chen K.L., Hsieh C.Y., Chiou P.W.S. (2006). Caponization effects on growth performance and lipid metabolism in Taiwan country chicken cockerels. Asian-Austral. J. Anim. Sci., 19: 438–443.

Chen K.L., Chi W.T., Chu C., Chen R.S., Chiou P.W.S. (2007). Effect of caponization and testosterone impantation on hepatic lipids and lipogenic enzymes in male chickens. Poultry Sci., 86: 1754–1759.

Chen T.T., Huang C.C., Lee T.Y., Lin K.J., Chang C.C., Chen K.L. (2010). Effect of caponization and exogenous androgen implantation on muscle characteristics of male chickens. Poultry Sci., 89: 558–563.

CIE (1976). Colorimetry: Official recommendations of the International Commission on Illumination, CIE No. 15 E–1.3.1. International Commission on Illumination, Paris.

Cortinas L., Villaverde C., Galobart J., Baucells M.D., Codony R., Barroeta A.C. (2004). Fatty acid content in chicken thigh and breast as affected by dietary polyunsaturation levels. Poultry Sci., 83: 1155–1164.

Crespo N., Esteve E. (2002). Nutrient and fatty acid deposition in broilers fed different dietary fatty acid profiles. Poultry Sci., 81: 1533–1542.

Díaz O., Rodríguez L., Torres A., Cobos A. (2010). Chemical composition and physico--chemical properties of meat from capons as affected by breed and age. Span. J. Agric. Res., 8: 91–99.

Díaz O., Rodríguez L., Torres A., Cobos A. (2012). Fatty acid composition of the meat from Mos breed and commercial strain capons slaughtered at different ages. Grasas Aceites, 63: 296–302.
Domínguez R., Lorenzo J.M. (2014). Effect of genotype on fatty acid composition of intramuscular and subcutaneous fat of Celta pig breed. Grasas Aceites, 65: 1–11.
Franco D., Bispo E., González L., Vázquez J.A., Moreno T. (2009). Effect of finishing and ageing time on meat quality attributes from Holstein-Friesian cull cows. Meat Sci., 83: 484–491.
Franco D., Rois D., Vázquez J.A., Purriños L., González R., Lorenzo J.M. (2012 a). Breed effect between Mos rooster (Galician indigenous breed) and Sasso T-44 line and finishing feed effect of commercial fodder or corn. Poultry Sci., 91: 487–498.
Franco D., Rois D., Vázquez J.A., Lorenzo J.M. (2012 b). Comparison of growth performance, carcass components and meat quality, between Mos rooster (Galician indigenous breed) and Sasso T-44 line slaughtered at 10 months. Poultry Sci., 91: 1227–1239.
Franco D., Rois D., Vázquez J.A., Lorenzo J.M. (2013). Carcass morphology and meat quality from roosters slaughtered at eight months affected by genotype and finishing feeding. Span. J. Agric. Res., 11: 382–393.
Hornsey H.C. (1956). The colour of cooked cured pork. I. Estimation of the nitric oxide–haem pigments. J. Sci. Food Agric., 7: 91–97.
Hsu J.C., Lin C.Y. (2003). Influence of caponization on the carcass characteristics in Taiwan country chicken cockerels. Asian–Australas. J. Anim. Sci., 16: 575–580.
Jensen J.F. (1984). Method of dissection of broiler carcasses and description of parts. World Poultry Science Association, Working group V, Frederiksberg C, Denmark.
Jeremiah L.E., Dugan M.E.R., Aalhus J.L., Gibson L.L. (2003). Assessment of the chemical and cooking properties of the major beef muscle and muscle groups. Meat Sci., 65: 985–992.
Karp G. (2005). Cell and Molecular Biology: Concepts and Experiments. John Wiley and Sons, New Jersey, USA.
Konjufca V.H., Pesti G.M., Bakalli R.L. (1997). Modulation of cholesterol levels in broiler meat by dietary garlic and copper. Poultry Sci., 76: 1264–1271.
Koohmaraie M. (1996). Biochemical factors regulating the toughening and tenderization process of meat. Meat Sci., 43: S193–S201.
Lin C.Y., Hsu J.C. (2002). Effects of surgical caponization on growth performance, fiber diameter and some physical properties of muscles in Taiwan country chicken cockerels. Asian-Austral. J. Anim. Sci., 15: 401–405.
Lorenzo J.M., Fonseca S., Gómez M., Domínguez R. (2015). Influence of the salting time on physico-chemical parameters, lipolysis and proteolysis of dry-cured foal "cecina". LWT-Food Sci. Technol., 60: 332–338.
Martens H., Staburvik E., Martens M. (1982). Texture and colour changes in meat during cooking related to thermal denaturation of muscle proteins. J. Texture Stud., 13: 291–309.
Mast M.G., Jordan H.C., Macneil J.H. (1981). The effect of partial and complete caponization on growth rate, yield, and selected physical and sensory attributes of cockerels. Poultry Sci., 60: 1827–1833.
Miguel J.A., Ciria J., Asenjo B., Calvo J.L. (2008). Effect of caponization on growth and on carcass and meat characteristics in Castellana Negra native Spanish chickens. Animal, 2: 305–311.
Muriel A. (2004). The effect of caponization on production indices and carcass and meat characteristics in free-range Extremeña Azul chickens. Span. J. Agric. Res., 2: 211–216.
Murado M.A., Vázquez J.A. (2010). A mathematical model for the characterization and objective comparison of antioxidant activities. J. Agric. Food Chem., 58: 1622–1629.
OJ (2008). Commission Regulation (EC) No 543/2008 laying down detailed rules for the application of Council Regulation (EC) No 1234/2007 as regards the marketing standards for poultry meat. Official Journal of the European Union L 157 17/06/2008.
Pateiro M., Lorenzo J.M., Díaz S., Gende J.A., Fernández M., González J., García L., Rial F.J., Franco D. (2013). Meat quality of veal: discriminatory ability of weaning status. Span. J. Agric. Res., 11: 1044–1056.
Prates J.A., Gonçalves M.A., Branquinho R.J., Andrade C., Mateus C. (2006). Simultaneous HPLC quantification of total cholesterol, tocopherols and β-carotene in Barrosã-PDO veal. Food Chem., 94: 469–477.

Rahman M.M., Islam M.A., Ali M.Y., Khondaker M.E.A., Hossain M.M. (2004). Effect of caponization on body weight, hematological traits and blood cholesterol concentration of Nara chicken. Int. J. Poultry Sci., 3: 284–286.

Rodríguez L. (2010). Efectos de la raza, edad de sacrificio y alimentación en los parámetros de calidad de la canal y carne del capón de Villalba. PhD Thesis, University of Santiago de Compostela, Lugo, Spain.

Rois D., Rivero C.J., Fernández M., Justo J.R., López C., Lorenzo J.M., Lama J.J., García-Fontán M.C., Franco D., Arias A., Feijóo J., Adán S. (2011). Crecimiento de pollos Mos en diferentes estaciones del año: comparación con una estirpe industrial. Arch. Zootec., 60: 329–332.

Ruíz-Ramírez J., Arnau J., Serra X., Gou P. (2005). Relationship between water content, NaCl content, pH and texture parameters in dry-cured muscles. Meat Sci., 70: 579–587.

Schiavone A., Romboli I., Chiarini R., Marzoni M. (2004). Influence of dietary lipid source and strain on fatty acid composition of Muscovy duck meat. J. Anim. Physiol. An. N., 88: 88–93.

Shehata A.Y., DeMan J.M., Alexander J.C. (1970). A simple and rapid method for the preparation of methyl esters of fats in milligram amounts for gas chromatography. Can. I. Food Technol. J., 3: 85–89.

Sirri F., Bianchi M., Petracci M., Meluzzi A. (2009). Influence of partial and complete caponization on chicken meat quality. Poultry Sci., 88: 1466–1473.

Symeon G.K., Mantis F., Bizelis I., Kominakis A., Rogdakis E. (2010). Effects of caponization on growth performance, carcass composition, and meat quality of medium growth broilers. Poultry Sci., 89: 1481–1489.

Symeon G.K., Mantis F., Bizelis I., Kominakis A., Rogdakis E. (2012). Effects of caponization on growth performance, carcass composition and meat quality of males of a layer line. Animal, 6: 2023–2030.

Tor M., Estany J., Villalva D., Molina E., Cubiló M.D. (2002). Comparison of carcass composition by parts and tissues between cocks and capons. Anim. Res., 51: 421–431.

Tor M., Estany J., Francesch A., Cubiló M.D. (2005). Comparison of fatty acid profiles of edible meat, adipose tissues and muscles between cocks and capons. Anim. Res., 54: 413–424.

Van Laack R.L., Stevens S.G., Stalder K.J. (2001). The influence of ultimate pH and intramuscular fat content on pork tenderness and tenderization. J. Anim. Sci., 79: 392–397.

Vázquez J.A., Lorenzo J.M., Fuciños P., Franco D. (2012). Evaluation of non-linear equations to model different animal growths with mono and bi-sigmoid profiles. J. Theor. Biol., 314: 95–105.

Vestergaard M., Madsen N.T., Bligaard H.B., Bredahl L., Rasmussen P.T., Andersen H.R. (2007). Consequences of two or four months of finishing feeding of culled dry dairy cows on carcass characteristics and technological and sensory meat quality. Meat Sci., 76: 635–643.

Wattanachant S., Benjakul S., Ledward D.A. (2004). Composition, color, and texture of Thai indigenous and broiler chicken muscles. Poultry Sci., 83: 123–128.

Welter J.F. (1976). The effects of surgical caponization on production efficiency and carcass yield of roosters. Poultry Sci., 55: 1372–1375.

Wood J.D., Nute G.R., Richardson R.I., Whittington F.M., Southwood O., Plastow G. (2004). Effects of breed, diet and muscle on fat deposition and eating quality in pig. Meat Sci., 67: 651–667.

York L.R., Mitchell J.D. (1968). The effect of estradiol-17β-monopalmitate and surgical caponization on production efficiencies, yields and organic characteristics of chicken broiler. Poultry Sci., 48: 1532–1536.

Zanusso J., Remignon H., Auvergne A., Mollete C., Manse H., Babile R. (2001). Performance characteristics and quality of chicken meat: comparisons between males, females and capons. Brit. Poultry Sci., 42: 42–43.

Zhao G.P., Chen J.L., Zheng M.Q., Wen J., Zhang Y. (2007). Correlated responses to selection for increased intramuscular fat in a Chinese quality chicken line. Poultry Sci., 86: 2309–2314.

Received: 31 X 2015
Accepted: 16 II 2016