Influence of partial and complete caponization on chicken meat quality

F. Sirri,[1] M. Bianchi, M. Petracci, and A. Meluzzi

Department of Food Science, Alma Mater Studiorum–University of Bologna, 40064 Ozzano dell'Emilia, Italy

ABSTRACT Caponization is a surgical technique adopted to alter the sexual maturation of male chickens with the aim of improving the quality characteristics of carcass and meat. Under commercial conditions within each flock, about 10% of the birds usually result with incomplete caponization and are called slips. A trial was conducted to compare quality traits of breast and thigh meat from capons (n = 12), slips (n = 12), and cocks (unoperated birds; n = 12) (Hubbard × Golden Comet) reared together and processed at 180 d old under commercial conditions. Capons exhibited the highest ($P < 0.01$) values of breast and thigh meat lightness and yellowness as well as the lowest values of redness ($P < 0.01$) compared with cocks and slips. These variations in meat color were related to a lower concentration of heme pigments in both breast and thigh meat from capons. Capons and slips presented lower Allo-Kramer shear values of cooked breast meat ($P < 0.05$) in comparison with cocks. As for chemical composition, capons showed a higher content of total lipid, cholesterol, and ash both in breast and thigh meat. Total saturated, monounsaturated, and polyunsaturated fatty acids were not strongly affected by caponization. However, capons exhibited a significantly higher ($P < 0.01$) content of linoleic and linolenic acids as well as a lower content of arachidonic, eicosapentaenoic, docosapentaenoic, and docosahexaenoic acids in respect to slips and cocks. Overall, this study indicated that caponization can affect the main meat quality traits with special regards to appearance (color), texture, and composition. Finally, it was found that slips present intermediate meat quality characteristics between capons and cocks.

Key words: capon, slip, cock, chicken, meat quality

2009 Poultry Science 88:1466–1473
doi:10.3382/ps.2008-00405

INTRODUCTION

Caponization is a surgical technique adopted to alter the sexual maturation of male chickens with the aim of improving the quality characteristics of carcass (i.e., fatness) and meat (i.e., flavor, juiciness, and tenderness). In Italy, capon production is a seasonal activity because most of the consumer demand for capon meat is concentrated during the Christmas time. In the past, heavy breeds were used for capon production and mainly grown in the farmyard to obtain birds of live weights ranging from 4 to 5 kg with a high carcass fatness (Mast et al., 1981). Nowadays, light birds such as males from slow-growing or intermediate breeds are reared for capon production, yielding leaner carcasses that better match the consumer attitudes of today.

According to the European Union regulation in force (European Commission, 1996), the removal of testicles for caponization purposes should be carried out at an early age, at least 77 d before slaughtering. Under practical conditions within each flock, about 10% of the birds usually result in incomplete caponization because 1 whole testicle or a part of it may remain in the body. These birds are called slips. In caponized cockerels, comb and wattles are cut and at slaughter they appear very small due to the lack of sexual hormone production. On the contrary, in slips, wattles regrow again due to the activity of remaining testicular tissue (Figure 1).

Both capons and slips reach heavier live weight and have better feed conversion than noncaponized cocks (Mast et al., 1981). In a previous study, York and Mitchell (1969) found that noncastrated birds gained significantly more weight than capons at 11 wk of age, whereas Rahman et al. (1984) found no BW differences between intact males and capons.

When slaughtered at the same live weight, capons had more abdominal, subcutaneous, and intermuscular fat than cocks, whereas slips presented intermediate values (Cason et al., 1988; Tor et al., 2002; Chen et al., 2006). Caponization was also found to affect the carcass composition by increasing breast and thigh yields and reducing drumstick yield in respect to intact males (Tor et al., 2002). Finally, caponization was found to improve breast and thigh meat tenderness (Cheng and

Received September 22, 2008.
Accepted March 2, 2009.
[1]Corresponding author: federico.sirri@unibo.it

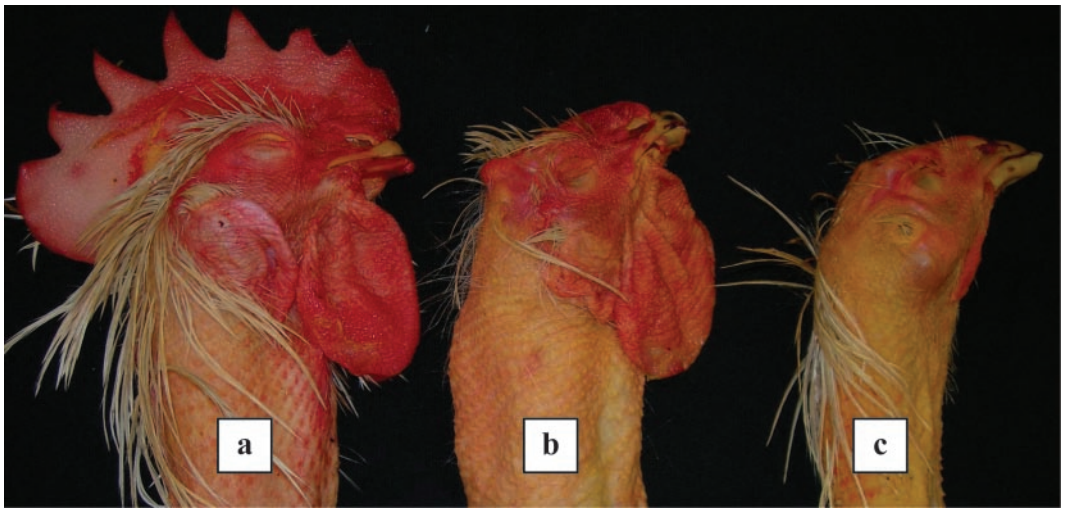

Figure 1. Comb and wattle appearance in intact male (cock, a) and partially (slip, b) and completely caponized (capon, c) birds at slaughter.

Hsu, 2002) and to increase the fat content of overall parts of the carcass (Tor et al., 2005).

Observations from capon producers indicate that when the same breed and slaughter age are considered, meat quality characteristics of capons and slips are similar. However, there is a lack of research studies to support this evidence; therefore, a study was conducted to compare meat quality attributes of capons, slips (partially caponized cockerels), and cocks (intact males).

MATERIALS AND METHODS

Birds and Experimental Design

The study was conducted on a flock of 1,400 male chickens obtained by the crossbred Hubbard (meat-type strain) × Golden Comet (egg-type strain), reared under commercial conditions in a poultry house and surgically caponized at the age of 45 d. Thirty birds were not caponized to obtain the intact males (cocks). All of the birds were reared in the same poultry house at a stocking density of 9 birds/m^2 with access to an outdoor pen (4 m^2/bird), until 180 d of age, and were fed ad libitum with corn-soybean diets (Table 1). At the end of the rearing period, as commonly occurs in the commercial practice, the flock included capons (n = 1,250), slips (n = 120), and intact birds (cocks; n = 30). Slips were identified according to bird morphology (color of feather, presence of comb and wattles; Figure 1).

Before slaughter, birds were subjected to a total feed withdrawal of 8 h, including a holding time at the processing plant of 2 h. The birds were subsequently processed under commercial conditions using electrocution (120 V, 200 Hz) as a stunning system. After chilling, 12 carcasses per group were randomly collected and used for subsequent meat quality analysis. Carcasses were deboned at 24 h postmortem and breast fillets (pectoralis major) were used to determine color profile, heme pigments content, pH, drip loss, cook loss, and Allo-Kramer (**AK**) shear values after cooking. Furthermore, moisture, protein, total lipid, ash, cholesterol content, and fatty acid composition were determined on pectoralis minor muscles. The same previous analyses, except for drip loss, were carried out on thigh meat (biceps femoris).

Analytical Methods

Color Measurements. The CIE (1978) system color profile of lightness (L*), redness (a*), and yellowness (b*); hue (H* = arctan b*/a*); and chroma (C* = $\sqrt{a^{*2} + b^{*2}}$) has been performed by a reflectance colorimeter (Minolta Chroma Meter CR-400, Minolta Italia S.p.A., Milan, Italy) using illuminant source C. The colorimeter was calibrated throughout the study using a standard white (reference number 1353123; Y = 92.7, x = 0.3133, and y = 0.3193) ceramic tile. Breast meat color was evaluated averaging 3 measurements taken on the medial surface of the fillet (bone side) in an area free of obvious color defects (bruises, discolorations, hemorrhages, full blood vessels, or any other condition that may have affected uniform color reading). Thigh meat color was determined by averaging 3 measurements taken across the muscle surface.

Heme Pigments Determination. The total heme pigments were determined using the method described by Hornsey (1956). Five grams of minced breast and thigh meat was homogenized together with 20 mL of acetone, 1 mL of deionized water, and 0.5 mL of concentrated HCl. The mixtures were then kept in the dark for 1 h, filtered through No. 4 Whatman filter paper (Whatman International Ltd., Maidstone, UK) and the absorbance measured at 640 nm against a blank. Hematin (hematin porcine, H3281, Sigma-Aldrich, St. Louis, MO) was used as standard and the heme pig-

Table 1. Ingredient composition and calculated analysis of the feed

Item	Prestarter (0 to 21 d of age)	Starter (22 to 70 d of age)	Grower (71 to 120 d of age)	Finisher (121 to 180 d of age)
Ingredients (%)				
Corn	40.62	46.03	41.36	41.10
Wheat	11.80	15.00	17.00	20.00
Soybean extracted meal	31.10	24.50	24.70	20.80
Soybean whole seeds	2.00	7.50	5.00	10.00
Wheat bran	4.35	—	—	—
Wheat shorts	5.00	—	—	—
Dicalcium phosphate	1.50	1.30	1.00	1.00
Calcium carbonate	1.30	1.10	1.00	1.00
Olive oil	0.50	2.80	5.10	4.30
Salt	0.23	0.29	0.28	0.20
Methionine hydroxyl analog	0.38	0.37	0.29	0.31
Lysine sulfate	0.35	0.33	0.18	0.23
Threonine	0.07	0.08	0.04	0.05
Vitamin-mineral premix[1]	0.70	0.70	0.70	0.70
Calculated nutrient content				
Energy (kcal of ME/kg)	3,080	3,090	3,180	3,180
DM (%)	88.2	88.0	88.1	87.8
CP (%)	22.34	19.45	19.28	19.14
Lipid (%)	6.62	6.06	7.39	7.94
Crude fiber (%)	2.73	2.92	2.66	2.68
Ash (%)	6.17	5.42	5.00	5.07

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

ments concentrations of the samples were calculated from the standard curve and reported as milligrams per kilogram of meat.

pH Measurement. Breast and thigh meat pH was measured using a modification of the iodoacetate method initially described by Jeacocke (1977). Approximately 2.5 g of meat was removed from the cranial end of pectoralis major or from biceps femoris muscles, minced by hand, and homogenized in 25 mL of a 5 m*M* iodoacetate solution with 150 m*M* of potassium chloride for 30 s and the pH of the homogenate was determined using a pH meter (pH meter Jenway 3510; equipped with electrode 924001, Bibby Scientific Ltd. T/As Jenway, Essex, UK) calibrated at pH 4.0 and 7.0.

Drip and Cook Loss Determination. Drip loss was carried out on 1 intact fillet from each of 12 birds/group kept suspended in a sealed glass box for 48 h at 2 to 4°C and calculated as percentage of weight loss during storage. Cook loss was measured by cooking intact muscles (pectoralis major and biceps femoris) on aluminum trays in a convection oven at 180°C until 80°C at core sample. The samples were then allowed to equilibrate to room temperature, reweighed, and cook loss was determined as percentage of weight loss.

Shear Value Determination. Shear values were determined using a TA.HDi Heavy Duty texture analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with an AK shear cell. Cooked meat samples (approximately 2 × 4 × 1 cm) were cut parallel with the muscle fibers direction from each fillet (pectoralis major: cranial position) and biceps femoris muscle and sheared with the blades at a right angle to the fibers using a 250-kg load cell and crosshead speed of 500 mm/min (Papinaho and Fletcher, 1996). Allo-Kramer shear values were reported as kilograms of shear per gram of sample.

Chemical Analyses. Proximate analysis (moisture, protein, lipid, and ash content) was carried out on both breast (pectoralis minor) and thigh (biceps femoris) meat. The percentage of moisture was determined in duplicate according to the AOAC procedure (AOAC, 1990). Proteins were determined using a standard Kjeldahl copper catalyst method (AOAC, 1990). Total lipids were measured using a modification of the chloroform:methanol procedure described by Folch et al. (1957). Ash was determined using the procedure described by the AOAC (1990). Cholesterol determination was carried out on total lipid extract according to Bortolomeazzi et al. (1990) by using a Shimadzu GC17A (Shimadzu Corp., Tokyo, Japan) gas chromatograph equipped with a Restek XTI-5 (Restek Corp., Bellefonte, PA) capillary column (30 m length, 0.25 mm i.d., 0.50-μm film thickness) and a flame ionization detector. The oven temperature was held at 300°C for the whole duration of the analysis, whereas the injector and detector were held at 330°C. Helium was used as carrier gas at the constant flow of 1.9 mL/min. The quantification of total cholesterol content was obtained by using β-sitosterol (Sigma-Aldrich) as internal standard.

Fatty Acid Composition Analysis. After the determination of total lipid, fatty acids of both breast and thigh meat were converted to methyl esters following the method described by Christopherson and Glass (1969). The separation of fatty acids was carried out by using a Shimadzu GC17A (Shimadzu Corp.) gas chromatograph with a WP-4 Shimadzu integration

Table 2. Effect of partial and complete caponization on breast meat quality traits and chemical composition

Item	Capon (n = 12)	Slip (n = 12)	Cock (n = 12)	SEM	Probability
Meat quality traits[1]					
pH	5.71[b]	5.83[a]	5.79[a]	0.02	0.001
Color parameters					
Lightness (L*)	53.58[a]	50.84[b]	47.99[c]	0.53	<0.001
Redness (a*)	1.70[c]	2.46[b]	4.88[a]	0.27	<0.001
Yellowness (b*)	12.34[a]	11.46[a]	4.35[b]	0.35	<0.001
Hue (H*)	1.43[a]	1.35[a]	1.07[b]	0.02	<0.001
Chroma (C*)	12.48[a]	11.76[ab]	10.18[b]	0.41	0.002
Heme pigments (mg/kg)	22.96[a]	31.31[b]	50.17[b]	3.28	<0.001
Drip loss (%)	0.99	1.00	0.99	0.05	0.999
Cook loss (%)	20.50	19.23	21.23	0.40	0.123
Allo-Kramer shear (kg/g)	2.64[b]	2.73[b]	3.00[a]	0.05	0.018
Chemical composition[2]					
DM (%)	26.51	26.13	26.20	0.43	0.372
Protein (%)	24.63	24.82	25.04	0.48	0.371
Lipid (%)	1.61[a]	1.16[b]	1.08[b]	0.07	<0.001
Ash (%)	1.99[a]	1.36[b]	1.46[b]	0.10	<0.001
Cholesterol (mg/100 g)	44.28[a]	40.07[b]	41.13[b]	3.89	0.021

[a–c]Means within a row followed by differing superscript letters differ significantly ($P \leq 0.05$).

[1]Determined on pectoralis major muscles.

[2]Determined on pectoralis minor muscles.

system, equipped with a Varian CP-SIL88 (Varian Inc., Walnut Creek, CA) capillary column (100 m length, 0.25 mm i.d., 0.20 μm film thickness) and a flame ionization detector. The operating conditions of the gas chromatograph were as follows: oven temperature was held at 170°C for 15 min, increased to 190°C at a rate of 1°C/min, then increased to 220°C at a rate of 5°C/min and held at this temperature for 17 min. The temperature of the injector was 270°C and of the detector was 300°C. Helium was used as a carrier gas at constant flow of 1.7 mL/min. The identification of individual fatty acids was carried out by using PUFA-2 (Matreya Inc., Pleasant Gap, PA) fatty acid methyl ester standards.

Statistical Analysis

The influence of type of bird (capon, slip, and cock) on meat quality traits was evaluated by using 1-way ANOVA and means were separated by Duncan's multiple range test (GLM; SAS Institute, 1988). Pearson correlation coefficients and probabilities were calculated to evaluate the relationships between the color parameters (L*, a*, b*, H*, and C*) and heme pigments concentrations of breast and thigh meat.

RESULTS

The results for meat quality and chemical composition of breast are reported in Table 2. As for meat color, caponization produced the highest ($P < 0.01$) values of lightness (palest meat) and the lowest ($P < 0.01$) values of redness compared with cocks and slips, with slips having intermediate values. Moreover, in respect to cocks, capons and slips had higher ($P < 0.01$) values of yellowness and hue. Capons exhibited higher ($P < 0.01$) chroma values than cocks, with slips being intermediate. These differences in meat color were consistent with the results obtained for heme pigment determination, which evidenced an increasing ($P < 0.01$) content of pigments from capons (22.96 mg/kg) to slips (31.31 mg/kg) and cocks (50.17 mg/kg).

The breast meat pH was lower ($P < 0.01$) in capons (5.71) in respect to cocks (5.79) and slips (5.83), which did not differ from each other; however, no differences were found for drip and cook losses. In regard to the AK shear of cooked breast meat, the cocks presented higher ($P < 0.05$) values (3.00 kg/g) in respect to capons and slips (2.64 and 2.73 kg/g, respectively). Regarding the chemical composition of breast meat, capons exhibited a higher content of total lipid, cholesterol, and ash compared with cocks and slips.

In Table 3, the effect of caponization on thigh meat quality attributes is reported. As for thigh meat color, capons exhibited the highest values of lightness in comparison with both slips and cocks (L* = 50.49 vs. 48.66 vs. 46.97, respectively; $P < 0.01$) as well as the lowest ($P < 0.01$) redness and the highest ($P < 0.01$) yellowness and hue. Chroma values did not show any significant difference. In Figure 2, the differences in appearance of both breast and thigh meat observed in the 3 groups are shown. According to the results found in breast meat, an increasing ($P < 0.01$) content of heme pigments in thigh meat was observed going from capons (46.07 mg/kg) to slips (107.79 mg/kg) and cocks (149.46 mg/kg). These values appeared about 3 times higher than those observed in breast meat. Finally, thigh meat pH, cook loss, and AK shear values were not affected by caponization.

The more relevant differences in the chemical composition of thigh meat were lipid, DM, ash, and cholesterol. Lipid, DM, and ash contents were higher ($P < 0.01$) in capons than cocks. Moreover, the cholesterol content of thigh meat gradually decreased from capons to slips

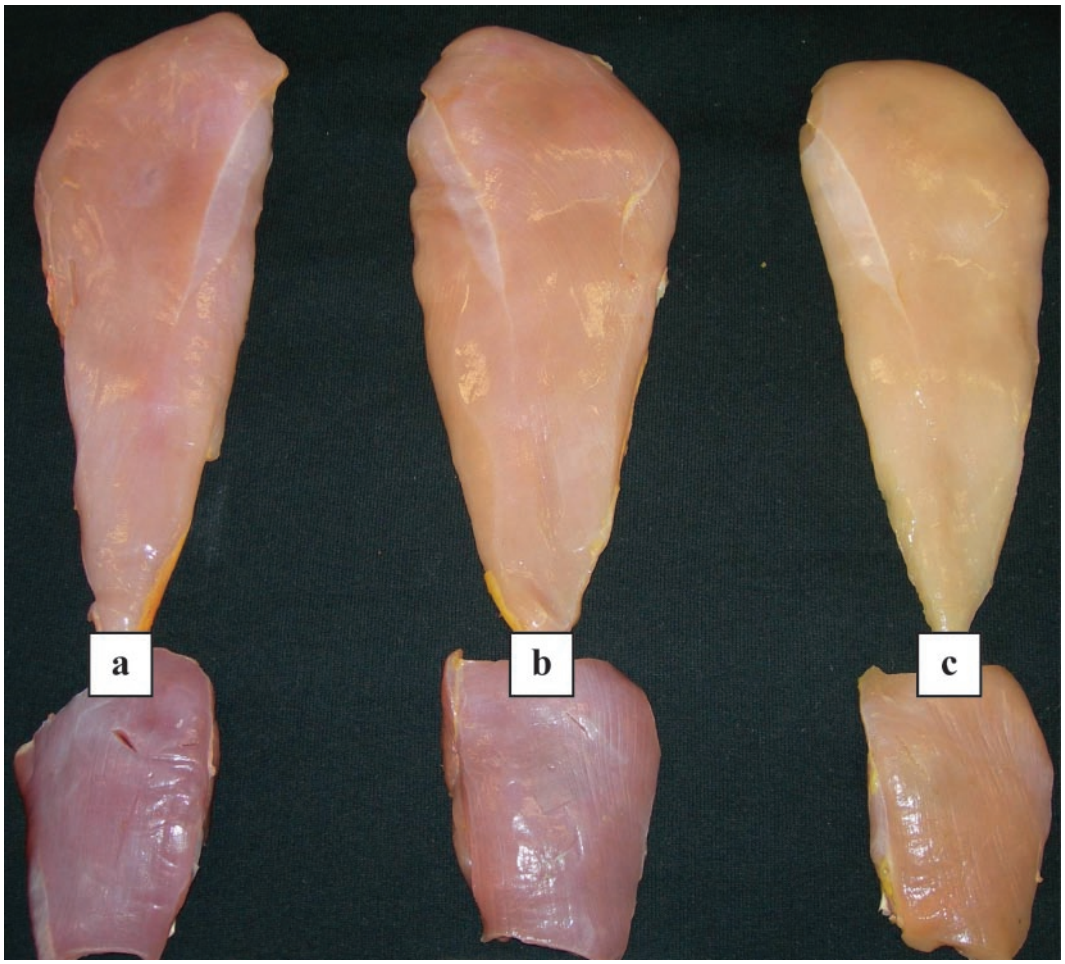

Figure 2. Appearance of breast (above) and thigh (below) meat from cock (a), slip (b), and capon (c).

and cocks (83.7, 71.1, and 60.0 mg/100 g, respectively; $P < 0.01$; Table 3).

In Tables 4 and 5, the fatty acid composition of breast and thigh meat is reported. As for breast meat, caponization significantly ($P < 0.01$) affected saturated fatty acid (**SFA**) content, with capons and slips showing higher values than cocks. Total monounsaturated fatty acids (**MUFA**) and polyunsaturated fatty acids (**PUFA**) as well as n-6 and n-3 PUFA contents were not affected by caponization. However, considering the single fatty acids, linoleic acid (**LA**) significantly decreased from capons to slips and to cocks, whereas arachidonic acid (**ARA**) significantly increased (Table 4). Moreover, in respect to cocks, capons exhibited a

Table 3. Effect of partial and complete caponization on thigh meat (biceps femoris muscle) quality traits and chemical composition

Item	Capon (n = 12)	Slip (n = 12)	Cock (n = 12)	SEM	Probability
Meat quality traits					
pH	5.98	5.98	5.95	0.01	0.347
Color parameters					
Lightness (L*)	50.49^{a}	48.66^{b}	46.97^{c}	0.39	<0.001
Redness (a*)	3.43^{c}	7.45^{b}	9.14^{a}	0.45	<0.001
Yellowness (b*)	8.90^{a}	3.61^{b}	−0.95^{c}	0.76	<0.001
Hue (H*)	1.20^{a}	0.45^{b}	−0.10^{c}	0.06	<0.001
Chroma (C*)	9.61	8.46	9.39	0.41	0.127
Heme pigments (mg/kg)	46.07^{c}	107.79^{b}	149.46^{a}	7.32	<0.001
Cook loss (%)	20.52	21.78	20.99	0.41	0.442
Allo-Kramer shear (kg/g)	5.95	5.62	5.66	0.11	0.442
Chemical composition					
DM (%)	25.81^{a}	25.24^{ab}	24.40^{b}	0.91	0.006
Protein (%)	21.44	21.93	21.91	1.12	0.406
Lipid (%)	2.69^{a}	2.22^{ab}	1.78^{b}	0.29	0.001
Ash (%)	1.30^{a}	1.17^{ab}	1.08^{b}	0.11	<0.001
Cholesterol (mg/100 g)	83.70^{a}	71.14^{b}	60.05^{c}	4.29	<0.001

$^{a–c}$Means within a row followed by differing superscript letters differ significantly ($P \leq 0.05$).

Table 4. Effect of partial and complete caponization on fatty acid composition (g/100 g of fat) of breast (pectoralis minor muscle) meat

Fatty acid[1]	Capon (n = 12)	Slip (n = 12)	Cock (n = 12)	SEM	Probability
SFA	26.54[a]	25.55[a]	24.36[b]	1.063	<0.001
MUFA	40.35	41.87	42.46	4.228	0.056
PUFA	32.95	32.37	32.91	3.047	0.672
Total n-6	29.83	29.20	29.73	3.376	0.672
LA	25.51[a]	23.43[b]	21.65[c]	0.984	0.003
ARA	4.23[b]	5.39[b]	7.82[a]	0.083	0.007
Total n-3	3.13	3.18	3.18	0.064	0.862
LNA	1.49[a]	1.23[ab]	0.73[b]	0.090	<0.001
EPA	ND[2]	ND	ND	—	—
DPA	0.69[c]	0.95[b]	1.27[a]	0.049	<0.001
DHA	0.94	0.99	1.10	0.042	0.202
n-6:n-3	9.60	9.22	9.49	1.205	0.686

[a–c]Means within a row followed by differing superscript letters differ significantly ($P \leq 0.05$).

[1]SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; LA = linoleic acid; ARA = arachidonic acid; LNA = linolenic acid; EPA = eicosapentaenoic acid; DPA = docosapentaenoic acid; DHA = docosahexaenoic acid.

[2]ND = not detected.

higher content of linolenic acid (**LNA**) and a lower content of docosapentaenoic acid (**DPA**). Slips showed intermediate values between capons and cocks (Table 4).

As for thigh meat, caponization did not affect the proportion of SFA, MUFA, PUFA, total n-6, and total n-3. However, capons had the highest values of LA and LNA and the lowest values of ARA, eicosapentaenoic acid, DPA, and docosahexaenoic acid (**DHA**) than cocks ($P < 0.01$). Again, slips showed intermediate figures (Table 5).

DISCUSSION

Caponization dramatically affected the breast and thigh meat color profile. Moreover, capons exhibited a lower total heme pigments content in respect to slips and cocks. It is well recognized that heme pigments concentration in muscles largely influences the appearance of poultry meat (Fletcher, 2002). The key role exerted by heme pigments on meat color measurements was confirmed by the strict positive correlations found between total heme pigments concentration and meat redness (a*) and the negative correlation between total heme pigments concentration and lightness (L; Tables 6 and 7). These results indicate that the lighter color and the less redness of both pectoralis major and biceps femoris muscles from capons were due to the decreased heme pigments concentration, which could be attributed to a different oxidative behavior of muscle fibers, with cocks and capons being the most and the lowest oxidative ones, respectively. It is well known that muscles with a higher fraction of oxidative fibers are characterized by a redder and darker color (Barbut, 2002). It can be argued that caponization may have determined a variation in muscle metabolism by a feminization of the birds, which induced a more pronounced glycolytic pattern of muscle fibers. This hypothesis is also supported by the lower pH of breast muscles obtained from capons. However, this result was not found for biceps femoris muscle. Despite the significant effect on breast meat pH, water-holding capacity properties (assessed by drip and cooking losses) did not differ among experimental groups.

Table 5. Effect of partial and complete caponization on fatty acid composition (g/100 g of fat) of thigh (biceps femoris muscle) meat

Fatty acid[1]	Capon (n = 12)	Slip (n = 12)	Cock (n = 12)	SEM	Probability
SFA	28.18	28.02	27.54	0.766	0.228
MUFA	34.50	35.43	34.73	3.143	0.421
PUFA	37.25	36.38	37.58	2.531	0.194
Total n-6	34.32	33.48	34.62	2.110	0.167
LA	31.68[a]	28.82[b]	25.95[c]	1.103	<0.001
ARA	2.19[c]	4.27[b]	8.27[a]	0.054	<0.001
Total n-3	2.92	2.90	2.96	0.079	0.896
LNA	2.17[a]	1.60[b]	0.84[c]	0.031	<0.001
EPA	0.03[b]	0.07[b]	0.24[a]	0.009	<0.001
DPA	0.28[c]	0.57[b]	0.99[a]	0.023	<0.001
DHA	0.44[b]	0.66[ab]	0.88[a]	0.042	<0.001
n-6:n-3	11.79	11.69	11.76	1.295	0.976

[a–c]Means within a row followed by differing superscript letters differ significantly ($P \leq 0.05$).

[1]SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; LA = linoleic acid; ARA = arachidonic acid; LNA = linolenic acid; EPA = eicosapentaenoic acid; DPA = docosapentaenoic acid; DHA = docosahexaenoic acid.

Table 6. Correlation coefficients among color attributes and heme pigments content of breast (pectoralis major muscle) meat

Item	L*	a*	b*	H*	C*	Heme pigments
Lightness (L*)	1.00					
Redness (a*)	−0.86**	1.00				
Yellowness (b*)	0.63**	−0.65**	1.00			
Hue (H*)	0.83**	−0.97**	0.79**	1.00		
Chroma (C*)	0.46	−0.42	0.96**	0.59**	1.00	
Heme pigments	−0.51**	0.59**	−0.66**	−0.67**	−0.59**	1.00

**$P \leq 0.01$.

The main objective of caponization is to enhance the meat sensory attributes by improving tenderness. This effect was confirmed by some authors, who reported that capons have a greater meat tenderness than intact birds (Mast et al., 1981; Lin and Hsu, 2002). In our trial, we observed lower shear values in breast meat of capons and slips compared with cocks, whereas no difference was found in thigh meat. Overall, these results seem to only partially confirm the positive effect of caponization on meat tenderness traits.

As for proximate analysis of breast and thigh meat, both lipid and cholesterol contents were higher in capons. Chen et al. (2007), studying the activity of malic dehydrogenase in the liver, concluded that caponization may positively regulate hepatic lipogenesis. This phenomenon is explained by a modification of the growth hormone secretion due to caponization (Pampori and Shapiro, 1994). Indeed, Tor et al. (2002) stated that capons show more abdominal, intermuscular, and s.c. fat than cocks both at the same slaughter age and live weight. Moreover, Tor et al. (2005) found that testes removal significantly increased the chemical fat content in all parts (breast, wings, thighs, and drumsticks). Mast et al. (1981), comparing capons with cocks and birds with right or left testicles removed, found that the only differences in proximate analysis for raw meat were related to the fat percentage of light and dark meat. Cholesterol content of thigh meat is twice as much as that of breast muscles in capons and 1.5 times in slips and cocks. Both breast and thigh muscles of capons had higher concentration of cholesterol than cocks and slips. Chen et al. (2006) found higher concentrations of both blood cholesterol and triacylglycerol in capons than intact males and attributed this pattern to the increase of the hepatic lipogenic activity as a consequence of the surgical removal of their testicles.

Another difference in the lipid profile of capons is related to the highest percentage of SFA in breast meat and the same proportion of MUFA and PUFA. Our results partially agree with those of Tor et al. (2005), who found in the thigh and drumstick of capons higher proportions of PUFA, MUFA, and lower contents of SFA but the same levels of n-6 and n-3 PUFA in breast and thigh. An interesting outcome is the different distribution of n-6 and n-3 PUFA both in breast and thigh muscles. Indeed, the proportions of n-6 PUFA are similar in the 3 experimental groups and LA in capons is far higher than slips and cocks, respectively, of 10 and 20%. On the contrary, ARA proportion of capons, synthesized starting from LA, is 50 and 25%, respectively, for slips and cocks. The same results were found for total n-3 PUFA, and for LNA, with capons showing a higher percentage of it and a lower proportion of the other long-chain fatty acids (eicosapentaenoic acid, DPA, and DHA) than cocks. These results were not influenced by the feeding regimen of the birds because they all were fed the same diets. It can be argued that caponization may affect the activity of Δ^6-desaturase, the enzyme involved in the elongation and desaturation processes of both n-6 and n-3 PUFA. Indeed, starting from the shortest dietary fatty acids of the n-6 and n-3 PUFA families (LA and LNA, respectively), there is an endogenous conversion into longer and more unsaturated fatty acids operated for both the families by the Δ^6-desaturase. The effect of Δ^6-desaturase in the metabolism of n-6 and n-3 PUFA for laying hens and broilers has been already described (Leskanich and Noble, 1997; Meluzzi et al., 2001; Cortinas et al., 2004). Considering the results obtained in this study, it appears that both complete and partial caponization can determine an inhibition of Δ^6-desaturase activity. Similarly, Clejan et al. (1982) observed a decrease of ARA and DHA in

Table 7. Correlation coefficients among color attributes and heme pigments content of thigh (biceps femoris muscle) meat

Item	L*	a*	b*	H*	C*	Heme pigments
Lightness (L*)	1.00					
Redness (a*)	−0.79**	1.00				
Yellowness (b*)	0.62**	−0.83**	1.00			
Hue (H*)	0.68**	−0.91**	0.97**	1.00		
Chroma (C*)	−0.30	0.15	0.17	0.20	1.00	
Heme pigments	−0.71**	0.88**	−0.82**	−0.86**	0.77	1.00

**$P \leq 0.01$.

castrated rats due to the lack of testosterone. The same authors found that the administration of testosterone to castrated rats was able to bring the ARA content to normal values.

In conclusion, caponization determined the modification of breast and thigh meat appearance, texture, and composition. Capons produced a paler, less red, and more yellow meat together with a lower content of heme pigments. The positive effect of caponization on meat texture (lower shear values) as well as the ability of this practice to increase the lipid and cholesterol contents of the meat was confirmed. Even if the main categories of fatty acids were not strongly affected by caponization, it was observed that LA and LNA levels were higher in capons. Overall, slips presented intermediate quality characteristics between capons and cocks. Further studies should be carried out to elucidate the role of sexual hormones on muscle fibers and lipid metabolism in caponized birds.

ACKNOWLEDGMENTS

We thank the Agricola Guidi Company (Roncofreddo, Italy) for providing birds and technical assistance. Furthermore, we acknowledge Stefano Pignata for his valuable technical support.

REFERENCES

AOAC. 1990. Meat and meat products. Pages 931–948 in Official Methods of Analysis. 15th ed. Vol. 2. Association of Official Analytical Chemists, Washington DC.

Barbut, S. 2002. Meat color and flavor. Pages 429–463 in Poultry Products Processing. An Industry Guide. S. Barbut, ed. CRC Press, New York, NY.

Bortolomeazzi, R., N. Frega, and G. Lercker. 1990. Rapid determination of free and esterified sterols using pre-packed silica columns. Ital. J. Food Sci. 4:265–268.

Cason, J. A., D. L. Fletcher, and W. H. Burke. 1988. Research note: Effects of caponization on broiler growth. Poult. Sci. 67:978–981.

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

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

Cheng, L. Y., and J. C. Hsu. 2002. Effects of surgical caponization on growth performance, fibre diameter and some physical properties of muscles in Taiwan country chicken cockerels. Asian-australas. J. Anim. Sci. 15:401–405.

Christopherson, S. W., and R. L. Glass. 1969. Preparation of milk methyl esters by alcoholysis in an essentially non-alcoholic solution. J. Dairy Sci. 52:1289–1290.

CIE. 1978. International Commission on Illumination recommendations on uniform colour spaces, colour difference equations, psychometric colour terms. CIE Publication [No.15 (E-1.3.1) 1971/(TO-1.3)] Suppl. 15. Bureau Central de la CIE, Paris, France.

Clejan, S., M. Castro-Magana, J. Platon, E. J. Collipp, and T. M. Vaddanahally. 1982. Effects of zinc deficiency and castration on fatty acid composition and desaturation in rats. Lipids 17:129–135.

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

European Commission. 1996. Regulation 1000/96 of 4th June 1996 amending Regulation (EEC) 1538/91 introducing detailed rules for implementing Council Regulation (EEC) 1906/90 on certain marketing standards for poultry. Off. J. 134:9.

Fletcher, D. L. 2002. Poultry meat quality. World's Poult. Sci. J. 58:131–145.

Folch, J., M. Lees, and G. H. Sloane-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497–509.

Hornsey, H. C. 1956. The colour of cooked cured pork. I. Estimation of the nitric oxide-haem pigments. J. Sci. Food Agric. 7:534–540.

Jeacocke, R. E. 1977. Continuous measurement of the pH of beef muscle in intact beef carcasses. J. Food Technol. 12:375–386.

Leskanich, C. O., and R. C. Noble. 1997. Manipulation of the n-3 polyunsaturated fatty acid composition of avian eggs and meat. World's Poult. Sci. J. 53:155–183.

Lin, C. Y., and J. C. Hsu. 2002. Effects of surgical caponization on growth performance, fiber diameter and some physical properties of muscles in Taiwan country chicken cockerels. Asian-australas. J. Anim. Sci. 15:401–405.

Mast, M. G., H. C. Jordan, and J. H. Macneil. 1981. The effect of partial and complete caponization on growth rate, yield, and selected physical and sensory attributes of cockerels. Poult. Sci. 60:1827–1833.

Meluzzi, A., F. Sirri, N. Tallarico, and A. Franchini. 2001. Effect of different vegetable lipid sources on the fatty acid composition of egg yolk and on hen performance. Arch. Geflugelkd. 65:207–213.

Pampori, N. A., and B. H. Shapiro. 1994. Testicular regulation of sexual dimorphism in the ultradian profiles of circulating growth hormone in the chicken. Eur. J. Endocrinol. 131:313–318.

Papinaho, P. A., and D. L. Fletcher. 1996. The effect of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. Poult. Sci. 75:672–676.

Rahman, M. A., S. D. Ross, R. C. Fanguy, and D. T. Hyatt. 1984. The influence of gonadal development on lipid accretion in commercial broilers. Poult. Sci. 63(Suppl. 1):167. (Abstr.)

SAS Institute. 1988. SAS®/STAT Guide for Personal Computers. Version 6.03 Edition. SAS Institute Inc., Cary, NC.

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

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

York, L. R., and J. D. Mitchell. 1969. The effect of estradiol-17-β-monopalmitate and surgical caponization on production efficiencies, yields, and organic characteristics of chickens broilers. Poult. Sci. 48:1532–1536.