PROCESSING, PRODUCTS, AND FOOD SAFETY

The Influence of Genotype, Market Live Weight, Transportation, and Holding Conditions Prior to Slaughter on Broiler Breast Meat Color

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ABSTRACT A study was conducted to determine the influence of genotype, market live weight, transportation time, holding time, and temperature on broiler breast fillet color under commercial processing in Italy. Color was evaluated using a Minolta Chroma Meter (Minolta Chroma Meter CR-300, Minolta Italia S.p.A., Milano, Italy) on a total of 6,997 broiler breast fillets (Pectoralis major muscle) from 79 different flocks chosen at random during a 6-mo period. The flocks were represented by Ross 508 and Cobb 500 genotypes of both genders, processed at different ages, and subjected to different antemortem conditions during transport and holding. Ross 508 broilers exhibited a lower hue angle (H*) than did Cobb 500 (45.12 vs. 48.52; $P < 0.01$). With regard to the market live weight of broilers, the heavier birds (>3.3 kg) produced a darker breast meat (L* = 51.67) than did the lighter birds (<3.0 and 3.0 to 3.3 kg; L* = 52.63 and 52.84, respectively) ($P < 0.001$). The breast fillets from birds transported for the shortest distance (<40 km) exhibited a higher ($P < 0.01$) breast meat redness (a*; 3.59) when compared with transport distances of 40 to 210 or >210 km (a* = 3.28 and 3.04, respectively). The shortest holding time (<6 h) produced the highest ($P < 0.05$) L* values (52.84) compared with holding periods of 6 to 9 h and >9 h (L* = 52.12 and 52.04, respectively). Furthermore, an increase of both meat a* and saturation (C*) was observed with the advance in holding time. The holding temperature significantly affected the meat color. Breast fillets from birds held at <12°C was darker (L* = 51.32) than fillets from birds held at 12 to 18°C (L* = 52.85) or >18°C (L* = 53.11) ($P < 0.001$). Moreover, the increase in holding temperature (<12°C vs. 12 to 18°C vs. >18°C) also determined a lower breast meat a* (3.77 vs. 3.12 vs. 2.72, respectively; $P < 0.001$), b* (3.72 vs. 3.41 vs. 3.37, respectively; $P < 0.05$), C*, and H*. In conclusion, the holding time and temperature exerted the most important effect on broiler breast meat color. However, other factors, such as genotype, live weight, and transportation, may influence breast meat color.

Key words: genotype, live weight, transportation, holding, broiler breast meat color

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INTRODUCTION

It is generally recognized that poultry meat appearance is critical for both initial selection of a product by the consumer as well as final product satisfaction. Therefore, poultry producers go to great lengths to produce products with the appropriate color for a particular market and to avoid appearance defects that will negatively affect product selection or price (Fletcher, 2002). The color variation is a major problem in poultry meat retail because the consumers are more sensitive to color variations than to absolute color; therefore, they tend to reject the multiple-packaged fillets with noticeable color differences (Fletcher, 1999). Some researches have indicated that significant variations in breast meat color exist during processing as well as at the retail level, depending on the flock, type of birds, processing factors, and seasonality (Barbut, 1997; Owens et al., 2000; Wilkins et al., 2000; Woelfel et al., 2002; Petracci et al., 2004). Age and genetic strain can also affect meat color. As a general rule, animal age may play a key role because myoglobin increases with age, shifting the meat color toward darker and redder tonalities (Nishida and Nishida, 1985). However, Smith et al. (2002) compared breast fillets from birds processed at various ages (from 42 to 52 d) and reported that breast meat color is not affected by age. Genetics also has been reported as a relevant factor for determining color characteristics of the meat (Berri et al., 2001; Debut et al., 2003). Factors other than biological variations have been considered to affect poultry meat color. Environmental conditions such as preslaughter stress, feed withdrawal duration, and transportation distance may affect the color of final products (Lyon et al., 2004). The environmental conditions during transport and holding of the birds have been shown to affect processing yield and meat quality (Northcutt, 1994; McKee and Sams, 1997; Petracci et al., 2001; Bianchi et al., 2004). During the summer months, high antemortem temperatures affect the postmortem

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Table 1. Effect of genotype on breast meat color

	Genotype			
	Ross 508	Cobb 500	SEM	*P*
Flocks, no.	33[1]	46[2]		
Lightness	52.15	52.48	0.13	0.217
Redness	3.39	3.19	0.07	0.137
Yellowness	3.40	3.59	0.06	0.110
Saturation	4.82	4.82	0.07	0.983
Hue	45.12[a]	48.52[b]	0.62	0.006

[a,b]Means within a column followed by different superscript letters are significantly different ($P < 0.05$).

[1]2,805 breast fillets.

[2]4,191 breast fillets.

metabolism of muscle and subsequent meat quality via adrenal or other physiological responses or simply by fatigue of the birds (Lambooij, 1999; Warriss et al., 1999).

Recently, several researchers have studied the relationships between raw breast meat color and functional properties of poultry meat (Van Laack et al., 2000; Qiao et al., 2001; Bianchi et al., 2004, 2005), suggesting that lightness (**L***) measurements can be used as an indicator of poultry breast meat quality for further processing as well as for the estimation of the incidence of pale, soft, and exudative (**PSE**)-like condition (Wilkins et al., 2000; Barbut, 2002; Woelfel et al., 2002; Galobart and Moran, 2004; Petracci et al., 2004). Fletcher et al. (2000) also reported that variations in raw breast meat color are sufficient to cause variations in cooked product appearance.

In a previous study (Petracci et al., 2004), we evaluated the variation in broiler breast meat color that normally occurs during processing in Italy and how it is affected by season. The objective of this study was to evaluate the influence of genotype, market live weight, transportation of the birds from the farm to the processing plant, holding time, and holding temperature on broiler breast meat color.

MATERIALS AND METHODS

Experimental Design and Analyses

The study was conducted in a single major commercial processing plant in Italy on a total of 6,997 broiler breast fillets (pectoralis major muscle) from 79 different flocks chosen at random during a 6-mo period. A variable number of flocks and breast fillets were available on each day of sampling. The number of fillets from which color measurements were taken ranged from 46 to 119 per flock. The flocks were represented by Ross 508 and Cobb 500 genotypes of both genders. According to the Italian conventional production system, female and male broilers were separately reared and slaughtered at approximately 47 and 56 d old, respectively. However, shifts in the age and weight at slaughter of the birds occurred during the trial according to commercial and market needs. In fact, females were slaughtered from 43 to 59 d of age, and males were slaughtered from 53 to 68 d. Differences in the live weight at slaughter were subsequently found in both female (1.85 to 3.49 kg) and male (2.56 to 4.04 kg) broilers. For commercial purposes, the influence of market live weight on the meat color was considered instead of age as main factor.

To study the effects of preslaughter conditions, the following data were also recorded for each flock: distance from farm to processing plant, holding time, and holding temperature (recorded at crate unloading).

Whole breasts were collected at random from the deboning line at 3 to 6 h postmortem, and the determination of color was carried out immediately on a single fillet from each breast. The International Commission on Illumination (1978) system color profile of L*, redness (**a***), and yellowness (**b***) was measured by a reflectance colorimeter (Minolta Chroma Meter CR-300, Minolta Italia S.p.A., Milano, Italy) using illuminant source C. The a* and b* coordinates were subsequently used to calculate the hue angle (**H***; $\tan^{-1}$ b*/a*) and saturation (**C***; $\sqrt{(a^*)^2 + (b^*)^2}$). The colorimeter was calibrated throughout the study using a standard white (Reference No. 1353123. Y = 92.7, x = 0.3133, and y = 0.3193) ceramic tile. Color was measured on the cranial, medial surface (bone side) in an area free of color defects (bruises, discolorations, hemorrhages, full blood vessels, picking damage, or any other condition that might affect color reading).

Statistical Analysis

Color data (L*, a*, b*, C*, and H*) were averaged per flock and subsequently analyzed by using the ANOVA

Table 2. Effect of market live weight on breast meat color

	Live weight (kg)				
	<3.0	3.0 to 3.3	>3.3	SEM	*P*
Flocks, no.	25[1]	25[2]	29[3]		
Lightness	52.63[a]	52.84[a]	51.67[b]	0.13	0.000
Redness	3.19	3.21	3.40	0.07	0.323
Yellowness	3.61[a]	3.29[b]	3.62[a]	0.06	0.036
Saturation	4.84	4.62	4.99	0.07	0.106
Hue	48.68	45.92	46.76	0.62	0.188

[a,b]Means within a column followed by differing superscript letters differ significantly ($P < 0.05$).

[1]2,295 breast fillets.

[2]2,240 breast fillets.

[3]2,462 breast fillets.

Table 3. Effect of antemortem transportation (distance from farm to processing plant) on breast meat color

	Transportation (km)				
	<40	40 to 210	>210	SEM	*P*
Flocks, no.	21[1]	28[2]	30[3]		
Lightness	52.02	52.37	52.54	0.13	0.294
Redness	3.59[a]	3.28[b]	3.04[b]	0.07	0.003
Yellowness	3.55	3.33	3.65	0.06	0.061
Saturation	5.07	4.70	4.77	0.07	0.114
Hue	44.80[b]	45.48[b]	50.23[a]	0.62	0.000

[a,b]Means within a column followed by differing superscript letters differ significantly ($P < 0.05$).

[1]2,028 breast fillets.

[2]2,476 breast fillets.

[3]2,493 breast fillets.

option of the GLM procedure of SAS software (SAS Institute, 1988), testing the main effects of genotype (Ross 508 vs. Cobb 500), market live weight, transportation (distance from farm to processing plant), holding time, and holding temperature. To study the influence of main effects on meat color, the flocks were divided into 3 different classes within each effect (except for genotype) to homogenize the number of flocks in the 3 categories of each treatment (live weight: <3.0, 3.0 to 3.3, >3.3 kg; transportation: <40, 40 to 210, >210 km; holding time: <6, 6 to 9, >9 h; and holding temperature: <12°C, 12 to 18°C, >18°C). Means were separated using Duncan multiple range test option of the GLM procedure (SAS Institute, 1988).

RESULTS AND DISCUSSION

Concerning the effect of genotype on broiler breast meat color (Table 1), no differences were found on color coordinates (L*, a*, or b*). Nevertheless, Ross 508 broilers exhibited a lower H* compared with Cobb 500 (45.12 vs. 48.52; $P < 0.01$). These results indicate that the 2 commercial genotypes used in this study did not exhibit relevant color differences in broiler breast meat. Stronger differences in the meat color were found when comparing commercial strains with experimental lines selected or not selected for increased BW and breast yield (Berri et al., 2001).

In Table 2, the effect of market live weight on breast meat color is reported. The heavier birds (>3.3 kg) produced darker breast meat (lower L*) than did lighter birds (<3.0 and 3.0 to 3.3 kg). Furthermore, a lower b* was observed in birds weighting 3.0 to 3.3 kg vs. the other groups.

Typically, poultry breast meat tends to become darker and redder as bird age increases because of increased contents of myoglobin in muscles (Fletcher, 2002). However, because in the present study no differences were found in the meat a*, the darker color could also be determined by differences in postmortem muscle metabolism between heavier and lighter birds with main emphasis to the acidification process. Furthermore, Smith et al. (2002), comparing straight-run broilers processed at various ages (from 42 to 52 d) reported that color of broiler breast meat was not affected by age. In the present study, the higher variability between age and live weight of the birds could have determined the significant differences in meat color among birds with different live weights.

Data on the effect of transportation on breast meat color parameters are presented in Table 3. A significant ($P < 0.01$) higher breast meat a* was observed on those birds transported for the shortest distance (<40 km) compared with the breast meat a* of birds transported distances of 40 to 210 and >210 km. Furthermore, breast meat from birds transported for the longest distance (>210 km) exhibited a higher H*. However, these color differences may not be of practical importance, as consumers may not be able to differentiate between fillets with such a slight difference in a* and H*. In a recent study, Debut et al.

Table 4. Effect of holding time on breast meat color

	Holding time				
	<6 h	6 to 9 h	>9 h	SEM	*P*
Flocks, no.	27[1]	31[2]	21[3]		
Lightness	52.84[a]	52.12[b]	52.04[b]	0.13	0.023
Redness	3.04[b]	3.30[ab]	3.54[a]	0.07	0.012
Yellowness	3.37	3.53	3.67	0.06	0.144
Saturation	4.56[b]	4.85[ab]	5.12[a]	0.07	0.009
Hue	47.99	46.86	46.31	0.62	0.552

[a,b]Means within a column followed by differing superscript letters differ significantly ($P < 0.05$).

[1]2,490 breast fillets.

[2]2,521 breast fillets.

[3]1,986 breast fillets.

Table 5. Effect of holding temperature on breast meat color

	Holding temperature				
	<12°C	12 to 18°C	>18°C	SEM	*P*
Flocks, no.	29[1]	33[2]	17[3]		
Lightness	51.32[b]	52.85[a]	53.11[a]	0.13	0.000
Redness	3.77[a]	3.12[b]	2.72[c]	0.07	0.000
Yellowness	3.72[a]	3.41[b]	3.37[b]	0.06	0.031
Saturation	5.31[a]	4.64[b]	4.35[b]	0.07	0.000
Hue	44.44[c]	47.43[b]	51.00[a]	0.62	0.000

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

[1]2,640 breast fillets.

[2]2,798 breast fillets.

[3]1,559 breast fillets.

(2003) found no differences in breast meat color between transported and non-transported broiler chickens. However, reports on the effect of transport on meat quality are sometimes contradictory, ranging from no differences to decreased muscle glycogen and increased ultimate pH levels after transport (Warriss et al., 1999; Savenije et al., 2002).

The effect of holding time on broiler breast meat color is reported in Table 4. Holding times >6 h (6 to 9 or >9 h) produced lower values of meat L* (52.12 and 52.04, respectively) in comparison with holding periods <6 h (L* = 52.84) ($P < 0.05$). It is well known that meat L* is pH dependent, in that lower meat pH as well as faster postmortem metabolism, leading to a decreased pH, generates light scattering and leads to increased paleness (MacDougall, 1982; Warriss and Brown, 1987). Warriss et al. (1999) reported that holding broilers at the processing plant for >1 h resulted in higher ultimate breast muscle pH (5.84 vs. 5.78). This result implies that breast muscle glycogen was depleted during holding at the plant, and glycogen depletion typically occurs when birds are active or stressed (Northcutt, 2001). In this study, holding times >6 h (6 to 9 and >9 h) could have caused a greater glycogen depletion than observed in birds held for the shortest period, thus producing a darker meat. Figure 1 shows the representation of the "truncation value" proposed by Barbut (2002) to evidence a shift toward higher L* values for breast fillets obtained from birds held for <6 h. When applying a truncation value of L* = 54 to 56, which was previously suggested to classify the paler-than-normal (or PSE-like) broiler breast meat (Woelfel et al., 2002; Petracci et al., 2004), it can be established that the occurrence of pale meat is greater when birds are held for <6 h with regard to the meat a* and C*, an increase of both parameters was observed with the advanced holding time ($P < 0.01$).

The effect of holding temperature on broiler breast meat color parameters is reported in Table 5. The temperature in the holding area significantly influenced the broiler breast meat color. Breast meat from birds held at <12°C was darker (L* = 51.32) than that from birds held at 12 to 18°C (L* = 52.85) or >18°C (L* = 53.11) ($P < 0.001$). Moreover, the increase in holding temperature (<12°C vs. 12 to 18°C vs. >18°C) also determined a lower breast meat

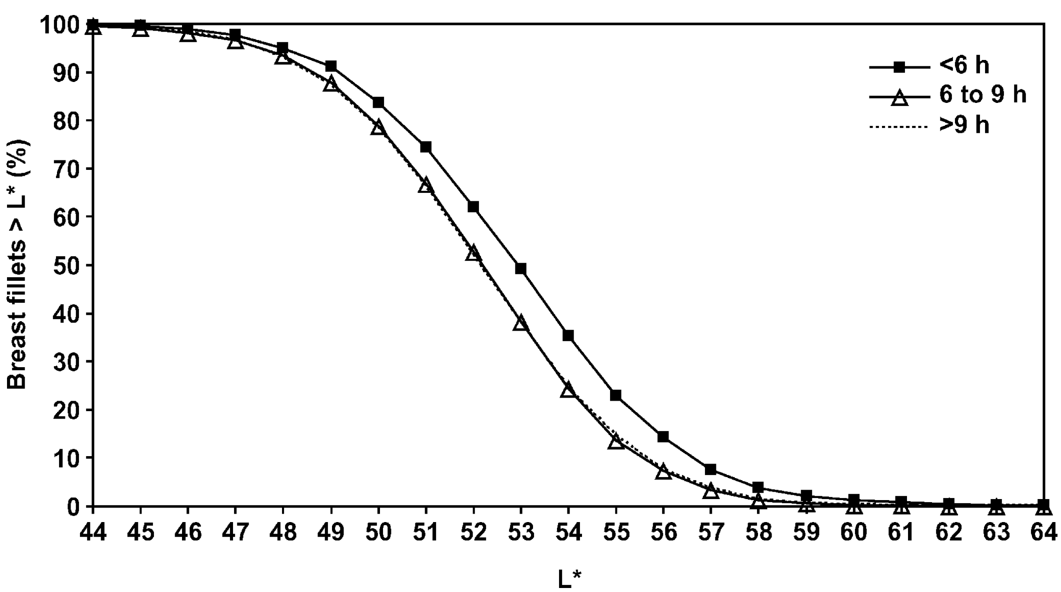

Figure 1. Effect of holding time on lightness (L*) value distribution of breast meat (<6 h, 27 flocks; 6 to 9 h, n = 31 flocks; >9 h, n = 21 flocks).

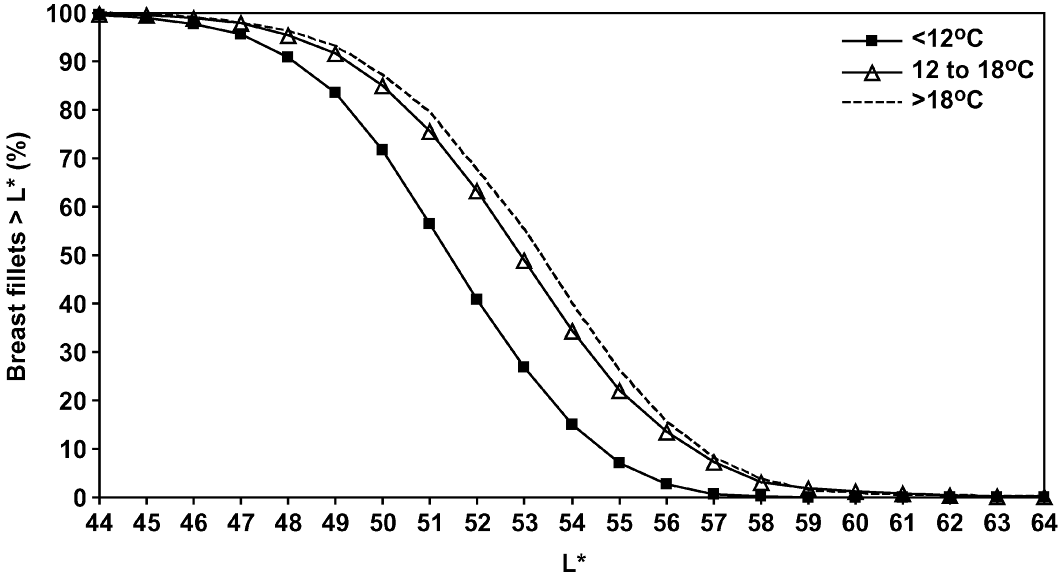

Figure 2. Effect of holding temperature on lightness (L*) value distribution of breast meat (<12°C, n = 29 flocks; 12 to 18°C h, n = 33 flocks; >18°C, n = 17 flocks).

a* (3.77 vs. 3.12 vs. 2.72, respectively; $P < 0.001$) and b* (3.72 vs. 3.41 vs. 3.37, respectively; $P < 0.05$).

It is well recognized that antemortem temperature stress and excitement just prior to slaughter affect poultry meat color. Babji et al. (1982) reported that heat stress results in significantly lower pH values for raw muscle and cooked meat, reduced water-holding capacity, and increased L* values. McKee and Sams (1997) observed that the seasonal heat stress accelerated postmortem metabolism and biochemical changes in the muscle, which produced PSE meat characteristics in turkey. These results agree with the report of McCurdy et al. (1996), who observed that turkey breast muscle exhibited highest L* values in the summer season. In a further study, Bianchi et al. (2004), by using the low resolution Nuclear Magnetic Resonance technique, concluded that paler color of turkey muscles during the summer compared with those collected in winter is also associated with differences in low resolution Nuclear Magnetic Resonance transversal relaxation properties of the water molecules of the muscle. Northcutt (1994) also reported that thermal preconditioning and heat shock in chickens resulted in breast meat that appeared PSE. However, no clear seasonal effect on meat color (L*) was observed in previous studies on broiler chickens (Wilkins et al., 2000; Woelfel et al., 2002). In Figure 2, it has been reported the "truncation value" determines the incidence of PSE-like meat among different holding temperatures. When applying a truncation value of L* = 56, which was previously suggested to classify the paler-than-normal (or PSE-like) broiler breast meat (Petracci et al., 2004), it was established that the occurrence of pale meat is greater when birds are held at temperatures >18°C (15.3%) in comparison with birds held at temperatures between 12 and 18°C (13.5%) and <12°C (2.8%). These results are consistent with those obtained by considering the effect of the season on the incidence of PSE-like broiler breast fillets as reported by Petracci et al. (2004).

The tendency of the breast meat to show a lower a* when L* increases observed in this study is consistent with previous studies (Qiao et al., 2001; Van Laack et al., 2000). Moreover, Petracci et al. (2001) also reported significantly lower breast meat a* (2.48 vs. 3.04) in broilers held at higher temperatures (34 vs. 25°C).

In conclusion, among the factors considered in this study, the holding time and temperature exerted the most important effect on broiler breast meat color. However, other factors, such as genotype, live weight, and transportation, may influence breast meat color.

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