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Effects of Strain on Performance, and Age at Slaughter and Duration of Post-chilling Aging on Meat Quality Traits of Broiler

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ABSTRACT : This study was conducted to investigate the effects of strain on broiler performance, and age at slaughter and post-chilling (PC) aging time on meat quality traits. A total of 500 one-day-old chicks (250 Hubbard classic and 250 Lohman) were reared under commercial conditions. Half of the broiler birds from each strain were slaughtered at 32 days and the other half at 42 days old. At each processing day, 168 carcasses were randomly selected (84 Hubbard and 84 Lohman) and divided into groups of 28 carcasses within each strain, and aged for 0, 4 and 24 h after chilling. Average weekly body weight was comparable between strains. Feed conversion ratio was higher ($p<0.05$) for the Hubbard strain during the second and third week of age. Initial carcass pH was significantly ($p<0.05$) affected by age where younger birds (32-d-old) had lower pH values than older (41-d-old) birds. Breast temperature was higher ($p<0.001$) for Lohman than Hubbard at 0, 2 and 4 h of PC. Younger birds had a lower breast temperature ($p<0.001$) at all measured times of PC. Thaw loss, cook loss and water holding capacity were not significantly affected by strain, age or aging time. Lohman strain had more tender meat ($p<0.05$) than Hubbard strain, and tenderness was improved with the increase of broiler age and aging time. Meats from Hubbard were lighter and less red than those from Lohman strain where younger birds had darker color. In conclusion, strain, age at slaughter and PC aging duration are critical to breast meat quality characteristics, and 4 h of aging are required before deboning in order to obtain more tender fillets. (**Key Words :** Broiler Breast Fillets, Age at Slaughter, Strain, Aging Time, Meat Quality)

INTRODUCTION

Poultry meat production has been very dynamic over the last decades with a continuous increase in the world production. Poultry now occupies the second place in the world meat production, just after pork. At the same time, the marketing of poultry has been greatly diversified with a significant increase in portions and processed products (Scheuermann et al., 2003). In Jordan, the demand for meat increased during the last decades. Self-sufficiency of red meat production is about 28%, while self-sufficiency of broiler meat (white meat) is approximately 96% (MOA, 2007). The success of poultry production has been strongly related to the improvements in growth performance and carcass yield and composition. Current commercial broiler chicken strains are the result of successful selection programs for rapid growth and body conformation, especially favoring the breast muscles. Because breast is the most valuable portion of the chicken carcass in the market, even small differences in breast yield among strain crosses could have a significant economic impact. For this reason, the broiler industry is constantly interested in evaluating the performance of the commercially available strain crosses, considering weight and yield of the breast meat as the most important variables (Scheuermann et al., 2003).

Several factors have been shown to affect carcass yield, carcass composition and the quality of meat. These factors include strain, nutrition, age, live weight and sex (Moran and Orr, 1969; Bouwkamp et al., 1973; Young et al., 2000). Several authors concluded that broiler strain, age at slaughter and post-chilling aging are main factors that affect meat quality parameters (color, tenderness, cooking loss, water-holding capacity and pH) (Lyon and Lyon, 1992; Mehaffey et al., 2006; Musa et al., 2006).

With the increase in cut up and further processing markets, aging periods have decreased to improve processing efficiency (Mehaffey et al., 2006). Aging is defined as the procedure of storing intact carcasses or breast

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halves for several hours at refrigerated temperature (<4°C) before deboning to allow the depletion of ATP and completion of rigor mortis (Sams, 1999). In recent years, deboning as early as 2 h or less pos-mortem has been commercially practiced, and this trend of shortened aging is likely to continue in the future. Because deboning prerigor meat can cause sarcomere shortening and tough meat, it has been recommended that carcasses be aged 4 to 6 h to allow rigor mortis development and prevent the toughening of meat (Dawson et al., 1987; Huezo et al., 2007; Battula et al., 2008). The objectives of this study were to investigate the effects of broiler age and strains on broiler performance, and the effects of post-chilling aging on carcass and meat quality characteristics.

MATERIALS AND METHODS

Broilers and diets

Two commercial broiler strains (Hubbard classic and Lohman) were used in this study to examine their growth performance, and to evaluate the effects of strain, age at slaughter, and post-chilling (PC) aging duration on broiler meat quality traits. A total of 500 one-day-old mixed sex broiler birds (250 birds from each strain), were obtained from a commercial hatchery and reared under standard commercial conditions up to market age. At day one of age, birds were randomly allocated into 20 floor pens 2×1.75 meters (10 pens for each strain, 25 birds per pen) covered with wood shavings. The floor pens were located in an open sided house. A pen was considered as an experimental unit for performance measurements. Birds were provided free access of feed and water for *ad libitum* consumption, with constant illumenation of 23 h light and 1 h dark per day during the entire growing period. Birds were fed a corn soybean meal based starter (3,150 Kcal ME, 22.8% CP for 0 to 21 days), and finisher diets (3,220 Kcal ME, 20.7% CP from 21 to 41 days). The diets were formulated to meet the birds' requirement as recommended by the National Research Council (NRC, 1994). The ingredients of the diets are 58% yellow corn, 28% soybean meal, 10% concentrate, 3% vegetable oil, 0.3% dicalicium phosphate, 0.5% Limestone, 0.1% methionine and 0.1 lysine for the starter, and 62.5% yellow corn, 23% soybean meal, 10% concentrate, 3.5% vegetable oil, 0.3% dicalicium phosphate, 0.5% Limestone, 0.1% methionine and 0.1 lysine for the finisher. Feed consumption and mortality were recorded daily and live weight was recorded at 1, 7, 14, 21, 28, 35 and 41 days of age for all replicates of each strain to determine the feed conversion ratio (FCR) and average daily gain (ADG).

Slaughtering procedure

Five hundred birds were processed at 32 and 42 days of age (250 birds on each processing day). Birds were transported 60 km to a processing plant and placed in the ventilated reception area 10 h prior to slaughter. During this period, birds were deprived from feed and water. Birds were weighed before slaughter, and then electrically stunned head to shank using a brine stunner with a fixed voltage of (50V AC) for 5 second, and a variable current of approximately (33 mA). Following the stunning, birds were immediately exanguniated by severing manually both the carotid arteries and at least one jugular vein with a knife and were allowed to bleed for 120 sec. After bleeding, birds were scalded at 59°C for 180 sec in rotary scolders, defeathered and manually eviscerated. Following evisceration, all carcasses were tumble chilled at 4°C for 15 minutes in chlorine water. The slaughter process was completed within 20 minutes from hanging the live birds and then all carcasses were entered to the air chilling room at 4°C and allowed to drip for 20 minutes. At each processing day 168 carcasses were randomly selected (84 Hubbard and 84 Lohman). Eighty four carcasses from each strain were divided into 3 groups of 28 carcasses by each aging time (PC aged at 0, 4 and 24 h), in a 4°C chillier before cutting them into forequarters and leg quarters as described by Hudspeth et al. (1973). Forequarters were cut into wings and breasts with a knife by severing the wings from the forequarter at the proximal ends of the humeral. The whole breasts from each carcass were individually placed in a labelled sealed polyethylene plate and wrapped in wax paper and placed in the freezer at -32°C. All samples were transported (<1 h) to the Meat Quality Laboratory at Jordan University of Science and Technology, where all meat quality measurements were performed.

Carcass pH and temperature measurements

Ten carcasses from each strain were also randomly selected and used to measure carcass pH and temperature post-mortem (PM) at each processing day. Internal muscle pH and temperature were measured at 0, 2, 4, 6, or 24 h of aging time with an incision made by a knife in the right pectoralis major muscle by means of a portable pH meter (pH spear, large screen, waterproof pH/temperature tester, double injection, model 35634-40, Eurotech instruments, Malaysia) and a digital thermometer (Electro-term, model TM99A, cooper instrument corporation, CT, USA).

Meat quality measurements

Measurements of meat quality characteristics made on the raw pectoralis major muscle of the broiler breast include pH, water holding capacity (WHC) and color coordinates (L*, a*, b*). The other meat quality characteristics include cooking loss (CL) and Warner-Bratzler shear force (SF) values were made on cooked meat samples. Twenty breasts were used for the measurement of meat quality

characteristics evaluation and eight breasts were used for chemical analysis from each group of twenty eight breasts. Frozen breasts were thawed over night in a chillier at 4°C while they were still in their plates. The breast weight was then recorded before and after thawing and then manually deboned left and right pectoralis major muscle according to the method described by Hamm (1981). After removing the breast skin, both pectoralis muscles were removed by severing the humeral-scapular joint and pulling downward to strip the meat from the breast. Then one pectoralis muscle was randomly selected and used for measuring color, pH and the WHC while the other one was used for measuring CL and SF values.

Raw meat quality measurements

pH after thawing : After thawing, pH values were determined in duplicate samples using the iodoacetate method as described by Jeacocke (1977) and Sams and Janky (1986). Raw meat samples (1 to 1.5 g) were collected from the pectoralis major muscle at 0, 4 or 24 h and put into plastic test tubes containing 10 ml of neutralized 5 mM iodoacetate reagent and 150 mM KCl, and homogenized using homogenizer (Ultra-Turrax T8, IKA Labortechnik, Janke & Kunkal GmbH & Co., Germany), then pH values of the solutions were recorded on a pH meter (pH Spear, Large screen, waterproof pH/temperature Tester, double injection, model 35634-40, Eurotech instruments, Malaysia) after rinsing the electrode with distilled water.

Meat color : Muscles were thawed overnight at chiller temperature (4°C). Color of the muscles was measured 24 h post-thawing, samples were placed on polystyrene trays with the fresh cut of the slice facing upward, and covered with plastic oxygen-permeable film and allowed to oxygenate for 3 h at 4°C. A colorimeter device (12MM Aperture U 59730-30, Cole-Parameter International, Accuracy Microsensors Inc., Pittsford, New York, USA) was used to objectively measure CIELAB (Commission International I' E Clairage) lightness (L*), redness (a*) and yellowness (b*). Hue angle was calculated as $\tan^{-1}$ (b^*/a^*), whereas chroma was calculated as $(a^{*2}+b^{*2})^{1/2}$ (Hunter and Harold, 1987). Random readings were taken at 3 different locations on the skinless surface at an area free of any noticeable color defects such as bruises or broken blood vessels of each sample.

Water holding capacity : The water holding capacity of the pectoralis major muscles were estimated by measuring the amount of water released from the muscle protein by the application of force (expressible juice) and by measuring the ability of muscle protein to retain water present in excess and under the influence of internal force. Water holding capacity was measured by using the method described by Graw and Hamm (1953) and modified by Saňudo et al. (1986), using approximately 5 g of raw meat (initial weight) from each sample, cut into small pieces covered with two filter papers (qualitative, 185 mm Φ circles, fine crystalline retention, Whatmam International Ltd, England) and two thin plates of quartz material and pressed with a weight of 2,500 g for 5 minutes, the meat samples were then removed from the filter paper and their weights were recorded (final weight). Water holding capacity was reported as the weight lost during sample pressing divided by the initial sample weight and expressed as a percentage.

Cooked meat quality measurements

Cooking loss : After breasts were deboned the pectoralis major muscles were weighed (initial weight) then placed in labelled polyethylene bags. Samples were cooked by immersing the bags in a thermostatically controlled water bath and cooked for 25 minutes at 85°C to achieve the maximum internal temperature of 80°C. The samples were then cooled at room temperature before opening the bags to drain the liquid. Cooked sample were dried with paper towels to remove excess surface moisture and re-weighed. Cooking loss was reported as the weight lost during cooking divided by the fresh sample weight and expressed as a percentage.

Tenderness : The samples used for CL were used to evaluate meat tenderness. Dried samples for 3 h were cut into 6 cores (20×13×13 mm) with similar sizes parallel to a line beginning at the humoral insertion and ending at the point adjacent to the keel including the complete depth of each cooked muscle sample. Each core was sheared perpendicular to the longitudinal orientation of the muscle fiber using a Warner-Bratzler shear blade with the triangular slot cutting edge mounted on Salter model 235 (Warner-Bratzler meat shear, G-R manufacturing Co. 1317 Collins LN, Manhattan, Kansas, 66502, USA) to determine the peak force (kg) when the samples were sheared. Shear force was determined as the average of the maximum force of the 6 replicates from each sample.

Statistical analysis

The data was analyzed as a 2×2×3 factorial design using the statistical analysis and the general liner model procedure of SAS (SAS Institute, 1990). Data was analyzed by the analysis of variance with broiler strain, age and PC carcass aging as main effects. Least square means were calculated for all measured variables using the LSMEANS statement.

RESULTS AND DISCUSSION

Growth performance

Live body weight (BW) data recorded at 1, 7, 14, 21, 28, 35 and 41 days of age for Hubbard and Lohman birds during the experimental period are summarized in Table 1.

Table 1. Least-squares means for weekly average live body weights (g) of Hubbard and Lohman broiler birds during the experimental period (1-41 day)

	Age (day)						
	1	7	14	21	28	35	41
Strain							
Hubbard	51.0	166.1[a]	451.8	863.2	1,373.9	1,978.6[a]	2,424.0
Lohman	51.1	159.9[b]	448.0	880.3	1,396.9	1,906.3[b]	2,372.3
SE	0.53	1.7	4.5	8.9	15.7	23.8	30.5
p-value	NS	*	NS	NS	NS	*	NS

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance.
NS = Non significant; * p<0.05.

Both Hubbard and Lohman birds had similar (p>0.05) initial live weights. However, at day 7 of age, Hubbard birds had higher (p<0.05) live BW than Lohman birds. During the age of 14 to 28 days, both strains had similar live BW. At the age of 35 days, Hubbard had a higher live BW (p<0.05) than Lohman. However, at the end of the experiment, both strains had similar live BW (p>0.05). These results are similar to those reported by Mehaffey (2006) who evaluated the five most commercially used strains by the poultry industry and found that there were significant differences in birds live BW between broiler strains at various ages. However, there was no significant difference in the average final BW among strains at week 7 of age. Korver et al. (2004) and Goliomytis et al. (2003) both found that there was no significant difference between commercial broiler strains for final BW at 42 days of age.

The average daily feed intake for Hubbard and Lohman birds during the experimental period are represented in Table 2. In general, Hubbard birds consumed more feed than Lohman birds except during the last week. Feed consumed by a Hubbard bird was approximately 1.1 g, 2.5 g and 3.7 g more (p<0.05) than that consumed by a Lohman bird during the first, second and third week, respectively. During week 4, Hubbard and Lohman birds consumed similar amounts of feed. At week 5, feed consumed by Hubbard birds was 16.3 g more (p<0.05) than Lohman birds. However, during the last week feed consumed by Lohman birds was greater (p<0.001) than feed consumed by Hubbard birds which represents a difference of 19.8 g. The overall feed intake for both Lohman and Hubbard birds was similar (p>0.05) with an average of 106 g/bird/day. These results are similar to those reported by Korver et al. (2004)

Table 2. Least-squares means of feed intake, average daily gain (ADG), and feed conversion ratio (FCR) for Lohman and Hubbard broiler birds during the rearing period (1-41 day)

	Age (day)						
	1-7	7-14	14-21	21-28	28-35	35-41	1-41
Feed intake (g/bird/d)							
Strain							
Hubbard	20.9[a]	54.8[a]	98.9[a]	132.8	180.4[a]	160.3[a]	106.7
Lohman	19.8[b]	52.3[b]	95.2[b]	131.6	164.1[b]	180.1[b]	105.4
SE	0.30	0.37	0.98	2.54	4.63	2.43	1.4
p-value	*	***	*	NS	*	***	NS
ADG (g/bird/d)							
Strain							
Hubbard	16.4[a]	40.8	58.8	73.0	86.4[a]	74.2	57.9
Lohman	15.5[b]	41.2	61.8	73.8	72.8[b]	77.7	56.6
SE	0.28	0.63	1.23	2.75	2.87	2.03	0.74
p-value	*	NS	NS	NS	**	NS	NS
FCR (feed/gain)							
Strain							
Hubbard	1.27	1.34[a]	1.69[a]	1.84	2.11	2.17	1.85
Lohman	1.27	1.27[b]	1.54[b]	1.80	2.27	2.33	1.86
SE	0.016	0.018	0.035	0.025	0.070	0.060	0.03
p-value	NS	*	**	NS	NS	NS	NS

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * p<0.05; ** p<0.01; *** p<0.001.

where overall feed intake was similar for 3 strains of broilers. Abdullah et al. (2010) reported that there was a significant difference in overall feed intake between strains with no differences between Hubbard and Lohman.

The average daily gain for Hubbard and Lohman birds during the experiment period indicated that both Hubbard and Lohman birds had similar ADG during the experimental period except in week 1 and week 5 of age (Table 2). During the first week, Hubbard birds gained more weight ($p<0.05$) than Lohman. Hubbard birds gained more ($p<0.01$) weight than Lohman during week 5. However, the overall ADG, was not significantly different between Hubbard and Lohman birds. Abdullah et al. (2010) reported that there was a significant difference in overall ADG between strains with no differences between Hubbard classic and Lohman strains. In contrast, Korver et al. (2004) reported that the overall ADG (from week 1 to week 6) of 3 strains of broilers was different ($p<0.05$).

The feed conversion ratio (g of feed/g of gain) data for Hubbard and Lohman birds showed that feed conversion ratio was significantly greater during week 2 ($p<0.05$) and week 3 ($p<0.01$) for Hubbard birds than for Lohman (Table 2). However, during week 1, week 4, week 5, week 6 and overall, both Hubbard and Lohman birds had a similar FCR ($p>0.05$). Abdullah et al. (2010) reported that there was no significant difference in the overall FCR between Hubbard classic and Lohman strains. In contrast, Elisabeth et al. (1998) and Korver et al. (2004) reported that the overall FCR of different strains of broiler were significantly different.

Post-chill carcass pH and temperature

The influence of strain and age at slaughter on PC carcass pH of the breast muscle is presented in Table 3. The pH values determined from breast samples were taken at 0, 2, 4, 6 and 24 h PC. There were no significant differences in pH values at 0, 2, 4, 6 and 24 h PC due to strain. In general, broilers of Lohman strain exhibited higher pH values at all PC sampling times than broilers of Hubbard strain, but the difference was not significant ($p>0.05$). These results are

Table 3. Least-squares means for broiler breast post-chill carcass pH and temperature as affected by strain and age at slaughter

Variable	Time post-chilling (h)				
	0	2	4	6	24
pH					
Strain					
Lohman	6.30	6.22	6.21	6.20	6.14
Hubbard	6.26	6.20	6.17	6.18	6.11
SE	0.038	0.034	0.018	0.014	0.020
p-value	NS	NS	NS	NS	NS
Age at slaughter					
32 days	6.23	6.15[a]	6.17[a]	6.13[a]	6.16[a]
42 days	6.32	6.27[b]	6.21[b]	6.26[b]	6.08[b]
SE	0.038	0.034	0.018	0.014	0.020
p-value	NS	*	*	***	**
Interaction					
Strain*Age	NS	NS	***	NS	NS
Temperature (°C)					
Strain					
Lohman	15.0[a]	13.8[a]	12.9[a]	9.0[a]	7.3
Hubbard	13.1[b]	12.0[b]	12.0[b]	10.8[b]	7.5
SE	0.08	0.10	0.01	0.24	0.12
p-value	***	***	***	***	NS
Age at slaughter					
32 days	13.1[a]	12.6[a]	12.4	8.7[a]	6.1[a]
42 days	15.0[b]	13.2[b]	12.6	11.1[b]	8.7[b]
SE	0.08	0.10	0.01	0.24	0.12
p-value	***	***	NS	***	***
Interaction					
Strain*Age	***	***	***	NS	***

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

similar to those of Hector (2002) who studied the effects of strain on performance and meat quality characteristics of broiler pectoralis muscles and indicated there were no significant differences among strains in Pectoralis major muscle pH at any PM time period (0.25, 4, or 24 h). However, Mehaffey (2006) reported that strain had significant effect on PM pH at 2 and 4 h PM. Musa et al. (2006) found that broiler breast meat pH was significantly affected by bird strain. Thus, the PC pH values difference between strains could be related to the variation in BW between selected strains, while in this study both broiler strains had similar weights at each day of processing. Studies involving chickens diverging in growth rate revealed that the breast muscle of rapid growth genotypes exhibited higher rates of pH decline and lower ultimate pH values when compared to a slower growing genotype (Schreurs et al., 1995).

Comparing pH values within different ages of slaughter at different PC times (Table 3) showed that there were significant ($p<0.05$) differences in the PC pH decline of the breast muscles at all PC times except at 0 h aging time. Compared with birds slaughtered at 32 days, PC pH values for birds slaughtered at 42 days were significantly higher at 2 h ($p<0.05$), 4 h ($p<0.05$) and 6 h ($p<0.001$). However, at 24 h PC birds slaughtered at 32 days had a higher ($p<0.01$) PC pH value than birds slaughtered at 42 days of age. The results indicated that the initial pH (0 h) tended to increase while the final pH (24 h) tended to decrease with an increasing age of the bird at slaughter. These results are consistent with those reported by Hector (2002) who indecated that broilers processed at 53 days of age had significantly higher initial pH values than those slaughtered at 42 days of age. In addition, pH at 24 h PM was significantly lower in older (53 days) broilers than in younger (42 days) broilers. Sanntiago et al. (2005) observed lower muscle pH at 0.25 and 4 h PM in birds slaughtered at 42 days compared with those slaughtered at 53 days. These results suggested that the differences in ultimate pH values might be related to changes in the muscle PM metabolism that resulted in differences in the rate of pH decline. It appears that the rate of pH decline of the breast muscle tends to increase as the birds increase in age. As differences in PM pH were more marked due to age at slaughter, it is possible that environmental factors prior to or at the day of processing may have contributed to these differences. A significant difference in breast pH at 4 h PC due to strain by age at slaughter interaction was observed as shown in Figure 1A. Breast pH increased in Lohman broilers as age at slaughter increased while Hubbard broiler breasts pH decreased as age at slaughter increased.

Breast temperature affected by strain and age at slaughter recorded at 0, 2, 4, 6, and 24 h PC is presented in Table 3. There were highly significant differences in breast meat temperature between Lohman and Hubbard birds at all PC times except at 24 h. Lohman breast meat had a higher ($p<0.001$) temperature at 0, 2 and 4 h PC compared with Hubbard. At 6 h PC Hubbard breast meat had a higher ($p<0.001$) temperature than Lohman breast meat. These results are similar to those of Berri et al. (2001) who reported that breast muscle temperature at 0.25 and 1 h PM

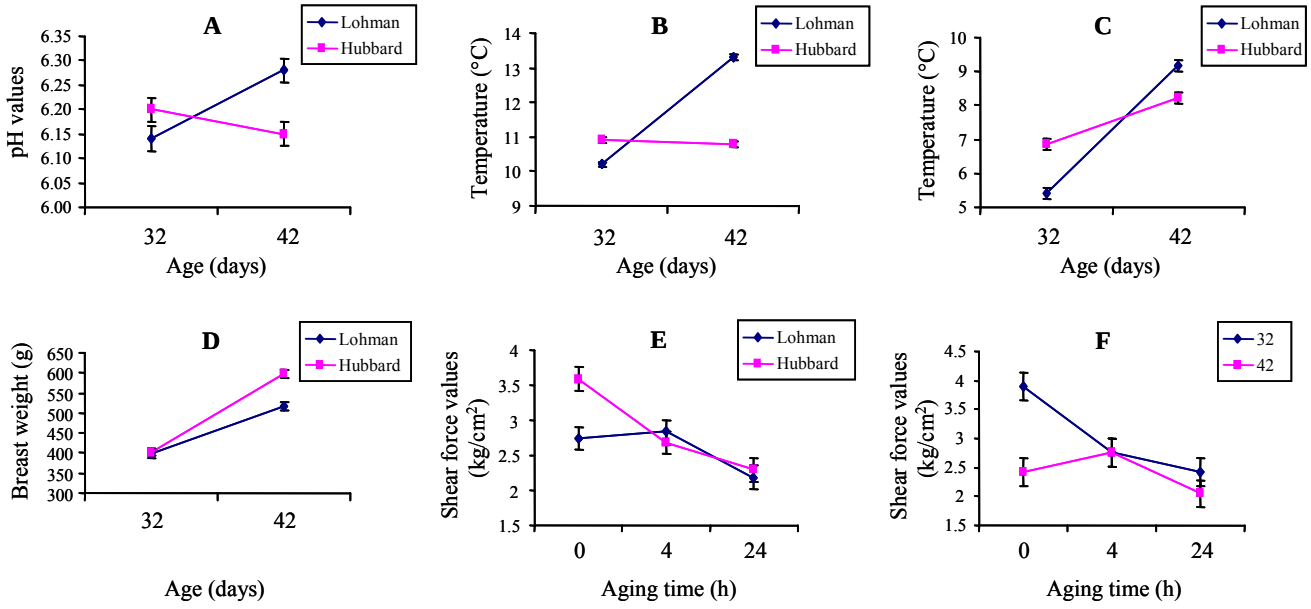

Figure 1. Showing the interaction effects of the breast muscle pH values at 4 h post-chilling (A), breast temperature values at 0 h (B) and 24 h (C), breast muscle weights of different broiler strains as affected by their interaction with age at slaughter (D), and the interactions of Warner-Bratzler shear force values for breast fillets of the different strains (E) and for different ages (F) as affected by their interaction with different aging time.

was significantly higher in a commercial selected line for high breast meat yield than in its corresponding control line. However, in this study at 24 h PC both Lohman and Hubbard had similar (p>0.05) breast meat temperature. In contrast, Hector (2002) reported that there were no significant differences in breast muscle temperature at any of the PM times recorded (0.25, 4 and 24 h PM) due to strain.

Temperature of the breast muscle showed significant differences at all PC times due to age at slaughter except at 4 h PC (Table 3). At 0, 2, 6 and 24 h PC, breast meat temperatures for birds slaughtered at 42 days of age were higher (p<0.001) than those slaughtered at 32 days. These results are similar to those reported by Hector (2002). Temperature of the breast muscle showed significant differences at all PM times recorded at 0.25, 4 and 24 PM due to age at slaughter. This difference in breast temperature between birds slaughtered at different ages is possibly due to the higher BW and relatively heavier breast weights exhibited by birds slaughtered at older age. A significant difference in breast muscle temperatures at 0, 2, 4 and 24 h PC was observed due to the strain by age at slaughter interaction. Breast muscle temperature of the Lohman birds was significantly lower than those of the Hubbard birds at 32 days of age. However, at 42 days of age, breast muscle temperature of Lohman birds was significantly higher than those of Hubbard birds (Figure 1B). Breast muscle temperature at 24 h PC increased in both strains as age at slaughter increased. Breast muscle temperature of Lohman birds was significantly lower than those of the Hubbard birds at 32 days of age. However, the increase in temperature of the breast muscle from 32 to 42 days was greater in birds of the Lohman strain when compared to those of the Hubbard strain (Figure 1C).

Initial and post-thawing breast weights and thawing loss percentage

Table 4 shows initial and post-thawing breast weights and thawing loss % as affected by strain, age and aging time. Hubbard birds had a higher (p<0.001) initial and post-thawing breast weight than Lohman birds. However, strain had no effect on thawing loss % (p>0.05). Birds slaughtered at 42 days of age had a higher (p<0.001) initial and post-thawing breast weight compared with those slaughtered at 32 days of age. These results for increased breast weight with age were expected due to the growth of breast with age. The thawing loss % was not differed between birds slaughtered at either 32 or 42 days of age. Aging time had no significant effect on initial and post-thawing breast weights and thawing loss % for all aging times (0, 4 and 24 h). There were significant differences in breast weight due to strain by age interaction as depicted in Figure 1D. Breast muscle weights of the Hubbard birds were similar to those of the Lohman birds at 32 days. However, at 42 days Hubbard birds had higher (p<0.001) breast weights than Lohman.

Table 4. Least-squares means for initial and post-thawing broiler breast weights and thawing loss % as affected by strain, age at slaughter and aging time

Variable	Initial breast weight (g)	Thawing breast weight (g)	Thawing loss %
Strain			
Lohman	458.9[a]	436.8[a]	4.6
Hubbard	499.7[b]	483.3[b]	3.4
SE	7.0	7.9	0.7
p-value	***	***	NS
Age at slaughter			
32 days	401.0[a]	387.2[a]	3.5
42 days	557.6[b]	532.9[b]	4.5
SE	7.0	7.9	0.8
p-value	***	***	NS
Aging time (h)			
0	482.5	463.3	4.1
4	487.7	462.6	5.0
24	467.7	454.3	2.9
SE	8.7	9.8	0.9
p-value	NS	NS	NS
Interactions			
Strain*Age	***	***	NS
Strain*Aging	NS	NS	NS
Age*Aging	NS	NS	NS
Strain*Age*Aging	NS	NS	*

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * p<0.05; *** p<0.001.

Post-thawing pH, CL percentage, WHC percentage and SF values of breast muuscle

Table 5 shows that there was no significant difference (p>0.05) in pH post-thawing due to strain. However, pH post-thawing was significantly affected by age at slaughter and aging time (p<0.05). Breast muscle from birds slaughtered at 32 days of age had higher pH values than those of birds slaughtered at 42 days of age. pH values for breast muscles aged 0 h were similar to those aged 4 h, but differed from breast muscles aged 24 h (p<0.05).

The results in Table 5 showed no differences (p>0.05) in WHC % and CL % due to strain age at slaughter or aging time. The obtained results were in agreement with Mehaffey et al. (2006); Souza et al. (2005) and Liu et al. (2004) in showing that WHC % and CL % were not significantly affected by strain, age at slaughter or aging time. However, Northcutt et al. (2001); and McNeal and Fletcher (2003) reported that broiler breast muscle CL % increased with

Table 5. Least squares means for broiler breast pH (post-thawing), cooking loss %, water holding capacity % (WHC) and Warner-Bratzler shear force values (WBSF) as affected by strain, age at slaughter and aging time

Variable	pH (post-thawing)	Cooking loss %	WHC %	WBSF (kg/cm^2)
Strain				
Lohman	6.17	26.1	19.6	2.56 [a]
Hubbard	6.14	26.2	19.9	2.81 [b]
SE	0.014	0.41	0.45	0.09
p-value	NS	NS	NS	*
Age at slaughter				
32 days	6.18 [a]	26.6	20.0	3.03 [a]
42 days	6.13[b]	25.7	19.4	2.34 [b]
SE	0.014	0.41	0.45	0.09
p-value	*	NS	NS	***
Aging time (h)				
0	6.13[a]	26.4	20.2	3.17 [a]
4	6.16[ab]	25.8	19.7	2.68 [b]
24	6.19[b]	26.3	19.4	2.21[c]
SE	0.017	0.50	0.56	0.11
p-value	*	NS	NS	***
Interactions				
Strain*Age	NS	NS	NS	NS
Strain*Aging	NS	NS	NS	**
Age*Aging	NS	NS	NS	***
Strain*Age*Aging	NS	NS	NS	**

[a,b,c] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * p<0.05; ** p<0.01; *** p<0.001.

increasing aging time. With introducing aging time, breast muscle pH declined. However, Lyon et al. (1983) reported that broiler breast meat CL % decreased significantly as the age of the bird increased. With an increased age of birds, muscle fat content increased which leads to an increase in WHC % and a decrease in CL %. In the present study, age at slaughter had no significant (p>0.05) effect on WHC and CL. This might be due to little difference in age at slaughter for birds slaughtered at 32 and 42 days of age.

Breast meat of Lohman birds had a lower (p<0.05) SF value than those of Hubbard birds (Table 5). The SF values average mean were 2.56 and 2.81 (kg/cm^2) for Lohman and Hubbard birds, respectively. Similar results were reported by Pandey et al. (1985), Mehaffey (2006) and Musa et al. (2006) who studied the effect of bird strain on broiler breast meat tenderness and found that strain significantly affected breast meat tenderness. Shear force values for birds slaughtered at 32 days were higher (p<0.001) than those for birds slaughtered at 42 days of age (3.03 and 2.34 (kg/cm^2)). These results were in agreement with those reported by Ngoka et al. (1982) who reported that SF in turkey breast meat decreased significantly with increased bird's age from 16 to 20 weeks. The muscle fiber cross-sectional area increases with age. This increase is associated with an increase in the number of giant fibers, which typically have a cross-sectional area three to five times larger than the normal (Dransfield and Sosnicki, 1999). Therefore, smaller fiber diameters for birds slaughtered at lower ages might allow a higher packing density and an increased toughness for their muscles. Northcutt et al. (2001) reported that Warner-Bratzler SF values for fillets from 37, 49 and 51 days old broilers were found to be similar, whereas SF values for fillets from 39, 42, 44 and 46 days old broilers were found to be similar. However, Poole et al. (1999) studied the tenderness of broiler breast fillets on birds slaughtered at 5, 6, 7 and 8 weeks of age and found that Warner-Bratzler SF values increased with age. Dawson et al. (1987) indicated that the bird's age did not significantly affect breast meat tenderness harvested from broiler slaughtered at 63 or 68 days old. These results might be due to little difference in age at slaughter. Shear force values obtained in the present study were lower than those reported by Liu et al. (2004); Northcutt et al. (2001) and Lyon et al. (1992). This could be due to the rapid growth of birds used in the present study. Dransfield and Sosnicki (1999) suggested that the selection for rapid growth in broiler birds

has resulted in improving meat tenderness compared to meat obtained from slow growing birds. Differences in the bird age, muscle region used, or genetic background of birds were also used for explaining the differences in meat tenderness.

It is well documented that meat tenderness increases with an increase in aging time prior to deboning (Dawson et al., 1987; Cavitt et al., 2004). Therefore, as expected, breast meat aged to 4 and 24 h had significantly ($p<0.001$) lower SF values than those aged to 0 h (Table 5). Shear force values decreased from 3.17 kg/cm^2 at 0 h to 2.21 kg/cm^2 at 24 h of aging time. These results are in agreement with previous results that SF values decreased with the introducing of PC aging (Souza et al., 2005; Thielke et al., 2005; Mehaffey et al., 2006). Meat tenderness was greatly affected by the enzymatic processes during aging. The observed increase in tenderness was suggested as a result of enzymatic degradation of muscle tissue. Enzymatic degradation is caused by proteolytic enzymes such as calpains and lysosomal proteases (Koohmaraie et al., 2002). However, the majority of the research suggested that sarcomere shortening is the causative factor of the decrease in tenderness of muscles from the time of slaughter to 24 h PM.

There was a significant difference in SF values due to strain by aging time interaction as shown in Figure 1E. Shear force values of Hubbard breast meat were higher than those of Lohman at 0 h aging time. At 4 h aging time, Hubbard breast meat had lower SF values compared with Lohman breast meat. At 24 h of aging, SF values for Hubbard breast meat were higher than Lohman SF values. A significant interaction in SF values ($p<0.001$) between age and aging time (Figure 1F). Breast meat from birds slaughtered at 32 days of age had higher SF values than those of birds slaughtered at 42 days of age at 0 h of aging time. At 4 h of aging time, breast meat for both birds slaughtered at 32 and 42 days of age had similar SF values (2.8 kg/cm^2). Breast meat SF values decreased for both groups slaughtered in 32 and 42 days of age. However, at 24 h of aging time, breast meat for birds slaughtered at 42 days had lower SF values than those of birds slaughtered at 32 days of age.

Breast muscle color measurements

Table 6 shows breast color measurements affected by strain, age at slaughter, and aging time. There were significant differences in lightness (L*), redness (a*) and Chroma due to strain ($p<0.05$). Lohman birds breast meat had lower L* values than those of Hubbard birds. The average mean of L* values were 51.14 and 53.32 for Lohman and Hubbard birds, respectively. Barbut (1997) reported an average L* value for broiler breast fillets of

Table 6. Least-squares means for broiler breast color measurements as affected by strain, age at slaughter and aging time

Variable	L*	a*	b*	Chroma	Hue
Strain					
Lohman	51.14[a]	2.22[a]	13.88	81.02	14.09
Hubbard	53.32[b]	1.79[b]	13.48	82.35	13.62
SE	0.63	0.70	0.34	0.45	0.35
p-value	*	*	NS	*	NS
Age at slaughter					
32 day	51.11[a]	1.89	13.45	81.95	13.62
42 day	53.35[b]	2.11	13.91	81.42	14.09
SE	0.63	0.12	0.34	0.46	0.35
p-value	*	NS	NS	NS	NS
Aging time (h)					
0	51.35	2.16	13.77	81.07	13.97
4	52.80	1.84	13.58	82.32	13.73
24	52.55	2.00	13.70	81.67	13.86
SE	0.78	0.15	0.42	0.56	0.42
p-value	NS	NS	NS	NS	NS
Interactions					
Strain*Age	NS	NS	NS	NS	NS
Strain*Aging	NS	NS	NS	NS	NS
Age*Aging	NS	NS	NS	NS	NS
Strain*Age*Aging	NS	NS	NS	NS	NS

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * $p<0.05$.

47.1 ranging from 43.5 to 51.5. However, the average of L* values are similar to the findings of Wilkins et al. (2000) who reported L* values ranging from 45.0 to 67.3 with an average of 55.2. Hector (2002) reported that L* values were significantly different among strains. Redness (a*) was higher in breast meat of Lohman birds compared with those of Hubbard birds. However, there were no significant differences ($p>0.05$) in either yellow (b*) nor Hue vales due to strain. The difference in lightness and redness due to strain was not expected because there was no difference in pH between Lohman and Hubbard breast meat. Bendall (1973) reported that the decrease in pH results in the denaturation of sarcoplasmic proteins increasing light scattering and meat paleness. Similarly, Owens et al. (2000) indicated that lower ultimate muscle pH is associated with higher L* values. There were no significant differences in breast meat redness (a*), yellow (b*), Chroma and Hue due to age at slaughter (Table 6). However, breast meat for birds slaughtered at 32 days had lower ($p<0.0.5$) L* values than those slaughtered at 42 days. Similar results were reported by Ngoka et al. (1982) who found that breast meat lightness significantly increases with an increase in age from 16 to 20 weeks for turkey, but redness and yellowness were not affected. Smith et al. (2002) evaluated meat color on broiler breast meat slaughtered at 42, 43, 44, 45, 49, 50, 51 and 52 days of age. They reported that the bird's age did not significantly affect breast meat color. The difference in L* values from the present experiment was expected because birds slaughtered at 42 days had a lower ($p<0.05$) ultimate pH than those slaughtered at 32 days. Previous reports indicated that lower ultimate muscle pH is associated with higher L* values (Owens et al., 2000).

There were no significant differences ($p<0.05$) in all color measurements due to aging time (Table 7). Lightness increased from 51.35 at 0 h PM to 52.55 at 24 h PC, but the difference was not significant. These results differed from those reported by Petracci and Fletcher (2002) and Souza et al. (2005) that meat color was significantly affected by aging time. Interactions were not significant ($p>0.05$) on all measured color parameters. Meat color varies according to the concentration of pigments, pigments chemical state, or the way that light is reflected off the meat.

Chemical composition of breast meat

Moisture, ether extract and ash % for breast muscle were not affected ($p<0.05$) by neither strain nor age at slaughter (Table 7). However, crude protein percentage was only affected ($p>0.05$) by age at slaughter. Breast meat from birds slaughtered at 32 days had a higher ($p<0.05$) crude protein percentage compared with breast meat from birds slaughtered at 42 days of age. Our results for breast meat chemical composition were similar to those reported by Fletcher et al. (2002). Abdullah et al. (2010) found that there was no significant difference ($p>0.05$) in body composition (moisture, crude protein and ash %) between Lohman and Hubbard classic broiler strains; however, ether extract % differed significantly ($p<0.05$). Abeni and Bergolio (2000) found that there was no significant difference ($p>0.05$) for breast meat composition (moisture, protein and fat) from three broilers strains, except in ash content. The little difference in age between birds slaughtered at 32 and 42 days of age might not be big enough to have an effect on breast meat composition of those birds.

CONCLUSION

Live weight was comparable among the strains studied, except at week 2 and 5. The FCR was better in Lohman at weeks 2 and 3; however, overall FCR was comparable between the two strains.

Hubbard strain had higher initial and post-thawing breast weights, lighter color, and their breast meat was tougher compared to Lohman; but, thawing loss, WHC and

Table 7. Least-squares means for broiler breast chemical composition % (on fresh basis) as affected by strain and age at slaughter

Variable	Moisture %	Crude protein %	Ether extract %	Ash %
Strain				
Lohman	74.9	22.6	1.0	1.2
Hubbard	74.8	22.7	0.9	1.2
SE	0.04	0.05	0.07	0.01
p-value	NS	NS	NS	NS
Age at slaughter				
32 days	74.8	22.8[a]	0.9	1.2
42 days	74.9	22.5[b]	1.0	1.2
SE	0.04	0.05	0.07	0.01
p-value	NS	*	NS	NS

[a,b] Means within the same column with different superscripts differ according to the indicated level of significance within each main effect.
NS = Non significant; * $p<0.05$.

CL percentages were comparable. Initial and thawing breast weights, lightness of meat and tenderness were higher for birds slaughtered at 42 days of age, but thawing loss, WHC and CL percentages were comparable. Aging improved tenderness of breast meat of both strains at both slaughter ages. Improvement in tenderness resulted after 4 h of aging. In general, breast meat from Lohman carcasses are slightly tenderer than breast meat from Hubbard carcasses, with birds slaughtered at 42 days, having more tender meat compared with birds slaughtered at 32 days. As a result strain, age at slaughter and PC aging duration are critical to breast meat quality characteristics and 4 h of aging are required before deboning in order to obtain more tender fillets. Such information is of importance to all poultry processing plants.

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