PAT December, 2024; 20(2): 51-64 ISSN: 0794-5213

Online copy available at www.patnsukjournal.org

Publication of Nasarawa State University, Keffi

ORIGINAL ARTICLE

GENETIC VARIABILITY OF BROILER MEAT QUALITY AS INFLUENCED BY STRAINS AND COOLING METHODS

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Abstract

A research was conducted to investigate the influence of cooling method (CM) on meat quality traits as it affects broiler strains Pectoralis major and minor muscles. A total of 120, male broilers strains of Abor acres++ (strain A), Ross 308 (strain B), Cobb 500 (strain C), Marshall (strain D) and Hubbard (strain E). The carcasses from each strain processed were cooled for 4 h either using refrigerator to freeze (5°C) or ice-cold water (0°C) and pectoralis muscles harvested. Colour and pH were measured at 6 h (post chill) and 24 h (after storage for 20 h at 5°C) on both muscles. Meat samples were analysed for water holding capacity (WHC) and expressible moisture (EM). The rate and extent of pH decline, colour, and WHC of both muscles differed significantly ($p<0.05$) between strains. Strain A exhibited an accelerated rate of glycolysis which resulted in muscles with lower initial and final pH, higher L* values and reduced WHC. The P. minor muscles exhibited higher ultimate pH, lower L* values and superior WHC than the P. major muscles in all the strains. The effects of CM on pH, colour, and WHC differed ($p<0.05$) among muscles. Ice – cold water cooling method resulted in higher ultimate pH and L* values in P. major muscles. Ice – cold water cooling significantly ($p<0.05$) reduced the WHC of the P. minor muscle. A considerable variation in post-mortem metabolism, pH, colour attributes, and water holding properties exist among commercial strains. Cooling conditions and muscle type can also have a substantial influence on these traits.

Keywords: Commercial broiler strains, expressible moisture, post-mortem metabolism

Introduction

Meat preservation became essential during transportation of meat for long distances without spoiling of texture, colour and nutritional value after the development and rapid growth of supermarkets (Nychas *et al.*, 2008). Traditional methods of meat preservation such as drying, smoking, brining, fermentation, refrigeration and canning have been replaced by new preservation techniques such as chemical, bio-preservative and non-thermal techniques (Zhou *et al.*, 2010). Immediately after slaughter, the temperature of animal carcasses is around 40°C, which is a favourable environment for most of the spoilage and pathogenic bacteria (Thompson, 2002). Therefore, rapid chilling of carcasses to inhibit the growth of bacteria is an important hazard control point for abattoirs; and since most bacteria prefer a high moisture environment, a higher water activity during chilling is not conducive to the control of bacteria.

Considering the meat quality implications, the deep-freezing process before rigor onset was almost abandoned, due to the production of very tough meat caused by the abnormally shortened myofibrils. As a result, slow chilling and delayed chilling were explored in many studies to produce good quality lamb and

beef. Such approaches allowed carcasses to enter rigor at higher temperatures, such as 12 to 35°C as defined by Meat Standards Australia (Thompson, 2002) or 14 to 19°C. In contrast to this, very fast chilling that challenged the traditional concept of "cold shortening," also gained a lot of attention by meat scientists, as evidenced by the concerted action supported by the European Union to coordinate investigations on very fast chilling of beef in 1994. More than 75% of further-processed chicken products are frozen for distribution. Many of these products are thawed prior to preparation. Ice crystals alter muscle cell integrity and enable fluid losses that vary with the nature of crystallization. Separately, the colour and appearance of meat are important aspects of quality (Van Laack *et al.,* 2000; Qiao *et al.,* 2001). Light reflectance has been used to measure meat colour, and the lightness (L*) of fillets is negatively related to the ultimate pH and moisture loss with refrigeration and cooking (Qiao *et al.,* 2001; Woelfel *et al.,* 2002). Alterations to fillets as a consequence of freezing and thawing have received little attention. Preslaughter stress, sex, age, and genetics all influence fillet colour (Fletcher, 1999; Berri *et al.,* 2001). Broilers have breast fillets with L* values that range from dark to light. Particularly light or pale fillets are usually of poor quality because of their soft character and extensive water loss, which is similar to the pale, soft, and exudative (PSE) condition in swine white muscle. The L* of fillets from broilers has been shown to increase after death (Qiao *et al.,* 2001; Alvarado and Sams, 2003) and generally plateau by 24 h post-mortem (PM) (Woelfel *et al.,* 2002). Cooking results in a substantial increase in L* value as well as considerable reduction in the variance of values from the raw state (Fletcher *et al.,* 2000). Alteration to light reflectance associated with freezing and thawing are unknown.

Maintaining the quality of the broiler meat has become a major concern for the meat sector of the poultry industry. The emergence and increased incidence of turkey and broiler breast meat with pale, soft and exudative characteristics analogous to the condition in pork has become one of the major problems affecting the poultry industry today. The abnormal pale colour and excessive exudate that characterizes this meat is unacceptable to consumers and adversely affects market potential. Furthermore, the use of this type of meat in the manufacturing of further processed products frequently results in poor processing yields and quality and sometimes weight loss is one of the major economic losses during the chilling process. This research assessed the effects of freezing and ice - cold water on meat quality characteristics on the pectoralis major and minor muscles of five commercial broiler strains.

Materials and Methods

Experimental site

The study was conducted at the Federal College of Forestry, Jos – Plateau State. The state is located on latitude and longitude 9.8965° N, 8.8583° E and has average temperatures range from 15.5 °C to 18.5 °C in the coolest months to 27.5 °C to 30.5 °C during the hottest months usually occur in the dry season months of March and April. Rainfall ranges from 2,000 mm per year in the southwest to 1,500 mm or less in the drier northeast. Rainfall for the town of Jos averages 1,411 mm per year *(*Onimisi, 2014).

Experimental animals and their management:

A total of 120, male broilers of five commercial strains (Abor acres++, Ross 308, Cobb 500, Marshall, Hubbard) representing A, B, C, D and E, were obtained at day old. The broilers were reared according to industry standards using wood shavings litter, and fed commercial-type corn-soybean based diets. The birds were selected and pen at random, and transported (< 3 h) to the Federal College of Forestry, Jos – Plateau State where the study was performed. Broilers were held in transportation crates without feed and water for 12 h prior to processing.

Procedure

Prior to slaughter, birds were weighed, wing-banded, and randomly assigned to one of two cooling method treatments: air-chilling and ice-cold water. Processing was carried out in groups of eight birds per 15 min period to allow adequate time to perform all PM measurements. The birds were hung in killing cones and killed without stunning by allowing them to bleed for 90s after a unilateral neck cut severing the carotid

artery and jugular vein was made. Electrical stunning was not used since it has been shown to delay the rigor mortis process by inhibiting the metabolism of ATP, creatinine phosphate and glycogen in muscles (Papiano and Fletcher, 1995). After exsanguination, birds were scalded, mechanically picked, and manually eviscerated and carcasses were cooled either by air-chilling (5°C) or ice-cold water (0°C). The refrigerator temperature was maintained at 0°C by adding ice or warm water when required. The ice-cold used in this study was kept rotating during for 6h daily in day time. Carcasses were hung by both legs on a shackle rack and placed in the ice-cold room. Immediately after the 4 h cooling period, the Pectoralis major and minor muscles were harvested from the carcasses as described by Hamm (1981) and Thompson *et al*. (1987). Carcasses where on a deboning cone, the breast skin was removed, and both muscles removed by severing the humeral-scapular joints and pulling downward on the wings to strip the meat from the carcass. The P. minor muscles were harvested by first separating the muscle from the keel bone with a knife and then pulling the muscle downward to remove the meat from the bone. Immediately after deboning, both muscles were weighed and the right-side muscles reserved for colour, temperature, and pH evaluation. Following the 6 h measurements, the meat samples were individually bagged and stored in a cooler at 5^{o}C until 24 h PM. Meat quality measurements were repeated at 24 h and the right-side muscles were vacuum packed and stored at -0.20°C, and later analysed for water holding capacity and expressible moisture.

Measurements

Muscle pH and Temperature

Temperature and pH were measured at various PM times on the Pectoralis major and minor muscles using a spear-tipped glass pH probe and a temperature probe attached to a portable pH meter. After evisceration, a small cut was made on the cranial end of the right-side breast, the probes were inserted approximately 1 cm into the muscle, and pH and temperature were recorded after a steady reading was obtained for 10 s. Subsequent measurements were made at the same location in every carcass. The P. major pH and temperature were measured at 0.30 h (pre-cooled), 6 h (post-cooled and after deboned), and 24 h (following storage in a cooler for 20 h) PM. The P. minor pH and temperature was recorded at 6 h and 24 h PM at the cranial end of the muscle.

Meat Colour

Colour measurements of the skinless muscle surfaces were determined using colour meter for both colour and luminance measures surface colours of the meat which read the difference in colour in L d*a*b*, L*C*H* and Delta E*ab according to requirements. The colour meter was programmed to calculate the average of three separate colour readings (L* = 97.91, a* = -0.68, b* =2.45). Immediately after colour evaluation, the right fillet was placed in zip-loc plastic bags and kept frozen at –20°C until used. In preparation for colour measurements, the muscle surfaces were pat-dried to minimize and standardize surface gloss. Three readings were taken using 8 mm aperture held at a right angle to the muscle surfaces, at an area free of any noticeable colour defects such as bruises or broken blood vessels. Colour of the P. major and minor muscles was evaluated at 6 h and 24 h PM at the same location in which pH and temperature were recorded. P. major colour readings were taken at the cranial end of the dorsal (skin side) and ventral (bone side) surfaces of the muscle.

Water Holding Capacity and Expressible Moisture

The water binding properties of the P. major and minor muscles were estimated by measuring the amount of water released from the muscle proteins by the application of force (expressible juice) and by measuring the ability of muscle proteins to retain water present in excess and under the influence of external force (Water holding capacity). In preparation for analyses, the cranial ends of both Pectoralis muscles were cut from frozen samples, placed in labelled plastic bags, and allowed to thaw for 10 h in a cooler at 4°C. Samples were then cut into smaller pieces and ground in a food processor for 1 min to achieve the necessary particle size. During the preparation process, any visible fat, connective, and bone tissues were removed from the samples. The ground meat samples were placed in test tubes and held at 4°C for

analyses Expressible moisture was determined using the method described by Jauregui *et al.* (1981) and modified by Earl *et al.* (1996) as follows.

Three pieces of Whatman filter paper, 5.5 cm in diameter, and one piece of Whatman 7.0 cm in diameter, were folded into a thimble shape over the outside of an inverted 16 x 150 mm test tube with the filter paper as the internal surface of the thimble. The filter paper was weighed before and after the addition of a 1.5 ± 0.5 g sample of ground muscle fold wrapped in a 15 cm2 piece of white tulle netting (0.1 mm mesh). The sample in the thimble was centrifuged in a 50 ml polycarbonate tube at 30,900 x g for 15 min in a refrigerated centrifuge at 2°C. After centrifugation, the filter paper and meat sample were removed from the tube by tweezers, the meat-netting package discarded, and the filter paper reweighed. The amount of moisture released from the sample and absorbed by the filter papers was used to calculate the percentage of expressible moisture as follows: % Expressible Moisture = (weight of moisture expressed /original weight of sample) x 100. Samples were run in duplicates and the expressible moisture reported as the percent of weight lost from the original sample. Water holding capacity was determined by the procedure described by Wardlaw *et al.,* (1973). Five-gram samples of ground meat were weighed inside a 35 ml polycarbonate centrifuge tube and combined with 8.0 ml of 0.6 M NaCl solution. The contents were mixed thoroughly for 30 s, held at 4° C for 30 min, and then centrifuged for 15 min in a refrigerated centrifuge at 2° C using a force of 7,000 x g. Subsequent to centrifugation, the volume of the NaCl solution not retained by the meat pellet was measured with a 10 ml volumetric cylinder calibrated in 0.1 ml increments. Samples were run in duplicates and the water holding capacity was calculated as (volume of NaCl solution added – volume of NaCl solution held by the meat) / (volume of NaCl solution added). Results are expressed as the proportion of added NaCl solution retained by the meat and are reported as a percentage.

Statistical analyses

The effects of broiler strain, chilling method and their interaction on performance and meat quality traits were analysed using the analysis of variance option of the general linear models (GLM) procedures of SAS (SAS Institute, 1988). Means differing significantly were separated using the Tukey's procedure option of SAS and a probability of $P \leq 0.05$ was accepted as indicative of statistical significance.

Results and Discussion

Body weight and Carcass Traits

The effects of strain and cooling method on body weight, carcass weight, and the weights of the P. major, P. minor, and total breast muscle are presented in Table 1. There was a significant main effect on body weight after the time of slaughter due to strains. Live BW of broilers of strains A, B, D are similar but significantly heavier than those of strains C and E. The BW of broilers of strain E was the lowest with difference of 171g, 87g, 2g, 36g for strains A, B, C, D birds, respectively for refrigerated. The body weight for fanned after some time was lowest in specie C with 18g, 57g, 12g, 5g for strains A, B, D, E, respectively. The CWT did not differ among species, despite significant differences in BW for refrigerated and ice-cooled water. The BW and CWT did not differ for the main effect of CM and the specie by CM interaction.

The weights of the P. major, P. minor, and total breast muscle did not differ among strains. However, the individual and combined weight of the Pectoralis muscles tended to be heavier in specie A broiler when compared to the other strains. The CM treatments had a significant effect on the weight of the two major breast muscles and total breast muscle weight. The refrigerated of carcasses significantly increased the P. major, P. minor, and total breast muscle weights. The P. major were 31g, 9g, 6g, 17g, 8g heavier for refrigerated than fanned for P. major in A, B, C, D, E, respectively. The P. minor were heavier for refrigerated than fanned by 12g, 1.9g. 0.8g, 34g, 4.7g, respectively. While the and total breast muscle weights were heavier in refrigerated than ice-cooled water by 25g, 4g, 8g, 16g, 7g, respectively in strains A, B, C, D, D, respectively.

These results suggest that the breast muscles of strain A broilers appeared to have a higher water holding capacity than the breast muscles from strains B, C, D and E. The increase in weight of the muscle in

carcasses freezing in cool-water can be attributed to swelling and hydration of the muscle as the result of water uptake by muscle proteins. Furthermore, it has been reported that WHC is usually highly correlated with the swelling capacity of muscle tissues (Hamm, 1960).

Strain and cooling method

The effects of strains, CM and their interaction on the P. major, P. minor, and total breast muscle yields are presented in Table 2. The percentage yield of breast muscle based on body weight following feed and water deprivation for 12 h for the five strains for freezing method ranged from 13.01 to 13.87 and ice - cold ranges 12.47 to 12.74 for the P. major, refrigerated 2.54 to 2.67while ice - cold ranges 2.74 to 2.89 for the P. minor, and freezing ranges14.65 to 15.86 and ice - cold 15.14 to 16.11 for total breast meat. The strains differences in yield were only significant for the P. major and total breast muscle. The yield of the P. major muscle of birds from strain A was significantly higher than for those from strains B, C, D and E. However, no significant differences ($p>0.05$) in yield of the P. minor were observed between strains.

Table 1. Effect of strain and cooling methods (CM) on body weight (BW), carcass weight (CWT), Pectoralis major, Pectoralis minor, and total breast meat weight of broilers

Strain	CM	BW	CWT	P. major	P. minor	Breast meat
	Freezing :		(g)			
A		2353^{a}	1653^{a}	325^{a}	76.5^{a}	389^{a}
B		2269^{b}	1647^{b}	302^{b}	72.1^{c}	372^{c}
C		2184^{d}	1623^{c}	302^{b}	69.8^{d}	372^{c}
D		2218^{c}	1601^{d}	310^{b}	71.2^{c}	379^{b}
E		2182^{d}	1597^{d}	301^{b}	75.7^{b}	371^{c}
	Ice – cold:		(g)			
A		2232^{b}	1638^{a}	294^{b}	64.6^{b}	364^{b}
B		2271^{a}	1626^{b}	293^{b}	70.2^{a}	368^{a}
C		2214^{d}	1608^{d}	296^{a}	69.0^{a}	364^{b}
D		2226^{b}	1618^{c}	298^{a}	68.1^{a}	363^{b}
E		2219^{c}	1620^{c}	293^{b}	71.0^{a}	371^{a}
SEM		16.1	11.4	7.8	2.4	10.8
Main effect means						
A		2301^{a}	1613^{a}	316^{a}	70.8^{a}	382^{a}
B		2271^{b}	1607^{b}	298^{c}	71.7^{a}	368^{c}
C		2201^{d}	1473^{c}	301^{b}	70.1^{a}	374^{b}
D		2223^{c}	1501^{b}	315^{a}	70.2^{a}	352^{d}
E		2202^{d}	1502^{b}	304^{b}	71.0^{a}	360^{c}
SEM		26.14	20.41	5.93	2.01	5.22
	Freezing	2268	15.10	301	68.1	383
	Ice – cold	2241	14.63	296	68.9	364
	SEM	11.96	13.65	4.02	1.4	5.02
Source of variation		Probability				
Strain		0.03	0.30	0.09	0.62	0.23
CM		0.04	0.62	0.03	0.005	0.009
Strain x CM		0.06	0.23	0.06	0.004	0.04

^{a,b,c,d}: Means in a column within an effect with no common superscript differ significantly ($P<0.05$); SEM: Standard error of mean; CM-cooling methods; A: Abor acres++; B: Ross 308; C: Cobb 500; D: Marshall; E: Hubbard

Total breast muscle yield was significantly higher in strain C birds for freezing and ice-cold when compared to the yield of strains A, B, D and E broilers. The main effect means Body percentage for freezing and ice - cold for P. major, P. minor and breast meat shows that there was significant difference between for P. major and breast meat except P. minor. These results indicate that these commercial genotypes differed significantly in performance and carcass traits. These differences are of particular importance because as birds are genetically designed in certain traits of economic importance, the ability to respond to other demands can be altered affecting the expression of other traits. In the pork industry,

intensive selection for muscle development and against fat deposition has resulted in breeds and lines with increased stress susceptibility resulting in the development of PSE meat (Oliver *et al,* 1991).

pH and Temperature on the Pectoralis major muscle

The effects of strains and cooling method on pH and temperature of the P. major muscle at various times PM are shown in Table 3. As expected, irrespective of strain and method used to cool the carcasses, the pH of the P. major muscle declined over time. Significant differences ($p<0.05$) in pH of the P. major muscle at all sampling time periods were detected among strains. At 30 min post-mortem (PM), birds from strain C exhibited significantly lower pH values than those of strains A, B, D and E. However, the pH from strains A, B, D and E broilers did not differ in pH. The same relationship was observed among strains by 6 h PM. By 24 h PM, the pH values of strains B, C and D were similar but significantly lower than that of strains A and E broiler. In general, broilers from strains A and E exhibited significantly higher pH values at all PM sampling times than birds from strains A, B, D and E broilers which consistently exhibited lower pH values through 24 h., that is the values decrease in each of the strains A, B, C, D and E with increased with time 0.30h, 6h and 24h.

Table 2. Effect of strain and cooling method on Pectoralis major, Pectoralis minor, and total breast meat

Strain	Cooling Method	P. major	P. minor	Breast meat
		Individual means		
	Freezing	% of BW		
A		13.34^{c}	2.67^{a}	15.85^{a}
B		13.87^{a}	2.58^{a}	14.65^{c}
C		13.04^{d}	2.59^{a}	15.86^{a}
D		13.61^{b}	2.62^{a}	14.79^{b}
E		13.01^{d}	2.54^{a}	15.62^{c}
Ice – cold				
A		12.56^{b}	2.75^{b}	15.47^{bc}
B		12.74^{a}	2.89^{a}	15.64^{b}
C		12.68^{b}	2.86^{a}	16.11^{a}
D		12.63^{bc}	2.74^{b}	15.21^{cd}
E		12.47	2.82^{ab}	15.14
SEM		0.19	0.03	0.32
Main effect means				
A		10.68^{ab}	2.21^{c}	15.05^{d}
B		12.26^{cd}	2.36^{a}	15.52^{a}
C		12.73^{a}	2.24^{ab}	15.31^{b}
D		12.31^{d}	2.22^{c}	15.10^{c}
E		12.47^{c}	2.23^{c}	15.09c^{d}
SEM		0.61	0.05	0.22
	Freezing	12.64	2.26	16.28
	Ice – cold	12.42	2.21	14.79
	SEM	0.23	0.06	0.21
Source of variation		Probability		
Strain		0.002	0.47	0.009
CM		0.006	0.005	0.002
Strain x CM		0.31	0.01	0.008

^{a,b,c,d}: Means in a column within an effect with no common superscript differ significantly ($P<0.05$); SEM: Standard error of mean; CM-cooling methods; A: Abor acres++; B: Ross 308; C: Cobb 500; D: Marshall; E: Hubbard

Table 3. Effect of strain and cooling method (CM) on pH and temperature (°C) of the Pectoralis major and minor muscles recorded at various times post-mortem

Variable	Time post-mortem (h)					
	30 min		6 h		24 h	
Strain	pH	T	pH	T	pH	T
A	6.07[a]	39.46[a]	5.92[a]	12.71[b]	5.87[a]	13.12[a]
B	5.87[b]	38.57[b]	5.81[b]	13.15[a]	5.68[c]	12.58[c]
C	6.07[a]	39.21[ab]	5.78[c]	12.62[c]	5.69[c]	12.84[b]
D	6.07[a]	38.50[c]	5.82[b]	12.72[b]	5.76[b]	12.29[d]
E	6.07[a]	38.50[c]	5.78[c]	12.21[d]	5.82[ab]	12.72[bc]
SEM	0.03	0.11	0.03	0.24	0.03	0.62
Cooling Method:						
Freezing	6.02	38.76	5.86	13.65	5.75	12.46
Ice – cold	6.04	38.54	5.79	11.75	5.68	12.68
SEM	0.03	0.17	0.03	0.20	0.04	0.46
Source of variation	Probabilities					
Strain	0.01	0.03	<0.0001	0.36	0.0006	0.71
C M	0.21	0.31	0.06	<0.0001	0.03	0.38
Strain x CM	0.48	0.001	0.10	0.03	0.68	0.71

[a,b,c,d]: Means in a column within an effect with no common superscript differ significantly (P<0.05); SEM: Standard error of mean; CM-cooling methods; A: Abor acres++; B: Ross 308; C: Cobb 500; D: Marshall; E: Hubbard

There was no significant difference between Freezing and ice cold at 0.30h, 6h and 24h Broilers. Studies in pork indicate that a carcass pH less than 6.00 at 45 min PM is an indicator of early PM metabolism and is considered as the critical pH below which PSE meat characteristics develops. It has been suggested that pH values at 15 min PM below 5.7 in broilers (Kijowski and Niewiarowick, 1978) and below 5.85 in turkeys (Vanderstoep and Richards, 1974) are indicative of a rapid rate of glycolysis often resulting in meat with PSE like characteristics. In the current study, strain B broilers exhibited an average pH at 0.30 h PM of 5.87, 6h PM of 5.81 and 24 h PM 5.76.

A genetic influence in poultry muscle PM metabolism has been suggested in many similar studies. Genetic selection for rapid growth in chickens has been shown to influence the rate and extent of pH decline in the muscle (Dransfield and Sosnicki, 1999). 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). In contrast, Berri *et al.* (2001) reported that the rate and extent of pH decline in the P. major muscle was higher in unselected experimental and commercial control lines than in their selected birds. Xiong *et al.* (1993) reported significant differences in the ultimate pH and other biochemical variables among breast muscles of different genetic crosses. Gardzielewska *et al.* (1995) reported that the rate of pH decline at 15 min PM varied among broiler genetic lines and between individual birds. Among the commercial genotypes evaluated, one commercial line exhibited a higher incidence of accelerated early PM metabolism with 6% of breast muscles having a pH < 5.7 at 15 min PM. The CM treatments had no significant effect on the P. major muscle pH at 0.30h PM. This was expected since the pH was recorded not quite long before the carcasses cooling processes continue. However, at 6 and 24 h PM, cooling conditions influenced the pH of the P. major. The pH was significantly higher on carcasses cooled in freezing when compared to ice-cold carcasses. The rate of carcass cooling is known to be considerably faster in freezing than in ice-cold systems (Dunn *et al.*, 1995). Broiler carcasses chilled in water immersion freezing systems achieve temperatures below 4° C within 1.5 h of the time of death while ice-cold carcasses reach an equal temperature at 2.5 h following death (Sams, 1999). Therefore, in this study the slightly higher P. major pH values at 6 and 24 h PM exhibited by carcasses cooled in freezing could be attributed to a reduction in the rate of PM glycolysis due to lower early PM temperatures.

Pearson and Young (1989) showed that the rate of anaerobic metabolic processes and the subsequent accumulation of lactate leading to a pH fall in the muscles after death was dependent on muscle temperature. Bendall (1973) reported that the reduction in metabolic/enzymatic activity in muscle cells was caused by a reduction in glycogen concentration, falling pH, and temperature. However, among those factors, chilling rates and muscle temperature appeared to be more influential in the rate and extent of PM muscle pH decline. Maribo *et al.* (1998) reported that pig carcasses cooled soon after death by showering with cold water (10°-12° C) experienced a significantly reduced rate and extent of pH decline in the muscle. The 1° -2° C reduction of temperature in the cooled carcasses resulted in a lower rate of the pH fall and a pH 0.1 to 0.2 units higher at all sampling times. In avian species, PM temperatures of 27°, 17° and 7° C compared to elevated PM temperatures of 37° and 43° C have been previously reported to reduce the decline of muscle pH and to delay glycolysis (Marsh, 1954). Poultry carcasses chilled in ice-water maintained at different temperatures have been shown to influence both the rate and the extent of pH decline. McKee and Sams (1998) reported that the pH of the P. major muscle of turkey carcasses held in ice-water at 0° C exhibited a lower rate and extent of pH decline when compared to carcasses held at 20° and 40° C.

There was a significant effect on P. major temperature at 0.30 h PM due to strain. The temperature of the P. major at 0.30 h PM was slightly but significantly higher in birds of strain A than in those of broilers of strains B, C, D and E. This could possibly be due to the significantly higher BW and relatively heavier carcass and P. major weights exhibited by strain A birds. These factors could have contributed to less dissipation of heat in particular at the cranial end of the P. major muscle where temperature measurements were taken. The significant specie by CM interaction in temperature at 0.30 h PM was caused by the higher carcass temperature exhibited in birds of strain A. The P. major temperatures at 6 and 24 h are not indicative of carcass temperature after cooling since these temperatures were recorded at the time of pH measurements after the muscle was excised from the carcass

Pectoralis major Colour Attributes

Poultry meat colour is an important quality attribute affected by ante mortem and PM factors. The L* value measures lightness of colour, is often used to predict the mechanical properties of muscle tissues, and is suggested to be a good predictor of PSE meat. The effects of strain and CM on the L*, a* and b* values measured at the dorsal and ventral surfaces of the P. major muscle at 6 and 24 h PM are presented in Tables 4 and 5. Regardless of species and CM, meat lightness increased after storage for 20 h on both surfaces of the P. major. However, the dorsal surface was considerably lighter than the ventral surface. On average, L* values at 6 h for species A, B, C, D and E ranges between 53.87 to 54.76 and 24h were54.68 to 57.62 units higher on the dorsal than on the ventral surface of the breast, respectively. The increased L* values at 24 h can be associated to the observed pH decline after 6 h. The decrease in pH results in denaturation of sarcoplasmic proteins increasing light scattering and meat paleness (Bendall, 1973).

McCurdy (1996) reported that L* values in turkey breast increased consistently from 3 to 24 h PM. Bendall and Swatland (1988) observed the same trend in increasing L* values over time and indicated that the best predictor for PSE in pork is obtained at 24 h PM. Meat yellowness increased consistently on both surfaces of the breast after storage for 20 h, and b* values were higher on the ventral than on the dorsal surface of the breast at both PM times. Colour a* values were higher on the ventral than on the dorsal surface of the breast. Meat redness on the ventral surface was considerably reduced after storage but remained stable at the dorsal surface. These results suggest that considerable changes in colour occur after breast harvesting and storage.

Table 4. Effect of strain and cooling method on colour parameters of lightness (L*), redness (a*), and yellowness (b*), recorded at 6 and 24 h post-mortem on the dorsal surface of the Pectoralis major muscle of broilers

Variable	Time post-mortem (h)					
	6			24		
Strain	L*	a*	b*	L*	a*	b*
A	53.87^{d}	0.84^{c}	0.75^{a}	54.68^{c}	0.78^{c}	0.94^{d}
B	54.48b^{c}	1.26^{a}	0.32^{b}	57.26^{a}	1.31^{a}	1.92^{a}
C	54.76^{a}	0.79^{d}	0.10^{d}	56.85^{b}	0.96^{b}	1.75^{c}
D	54.63^{ab}	0.92^{b}	0.34^{b}	54.58^{c}	0.79^{c}	0.98^{cd}
E	54.01^{cd}	0.84^{c}	0.21^{c}	57.62^{a}	0.95^{b}	1.89^{b}
SEM	0.52	0.15	0.18	0.43	0.15	0.31
Cooling Method:						
Freezing	53.19	0.86	0.47	58.43	1.17	1.75
Ice – cold	54.53	0.94	0.33	57.06	0.86	1.41
SEM	0.51	0.21	0.17	0.38	0.13	0.20
Source of variation	Probability					
Strain	0.51	0.03	0.04	0.06	0.16	0.005
C M	0.52	0.95	0.52	0.17	0.14	0.16
Strain x CM	0.81	0.75	0.62	0.08	0.65	0.41

^{a,b,c,d}: Means in a column within an effect with no common superscript differ significantly ($p<0.05$). SEM-Standard error mean, CM-cooling methods

The use of colour measurements, in particular L* values, has been suggested as a fast and efficient method to sort out meat with PSE characteristics at the processing plant. However, minimal attention has been given to the time and location at which such measurements should be performed. The results indicate that the location and the time at which colour measurements are performed can influence significantly all colour values in particular L* values. These results agree with those of Wilkins *et al*. (2000) and Sandusky and Heath (1996) who reported that the position along the length of the pieces of the meat significantly influenced all colour attributes. In those studies, the posterior portion of the meat was lighter than the cranial portion. Authors concluded that the thinness of the muscle in the posterior portion might cause greater reflectance of light and influence all three colour attributes. Therefore, measuring factors should be better identified and controlled in order to obtain better estimates of colour and meat quality. Significant differences in L* values among species were observed at 6 h PM but only at the ventral surface of the breast. At 24 h, L * values were significantly different among species on CM-cooling methods both surfaces and despite their increase after storage were still significantly different by species.

The negative association between muscle pH and L* values was observed in the present study at both sampling time periods and among species. The P. major muscle of specie A birds exhibited lower L* values at all PM times and surfaces when compared to those of strains B, C, D and E for both refrigerated and fanned. The lower L* values of the P. major muscle were consistent with the higher pH values exhibited by specie A birds. There were no significant differences in L* values between dorsal vs ventral surfaces of the breast at 6 h due to CM, despite that significant differences in pH were observed. At 24 h, significant differences due to CM were observed only on L* values measured at the ventral surface of the P. major. The L* values of carcasses cooled in refrigerated were significantly higher than for those cooled by fanned.

Table 5. Effect of strain and cooling method (CM) on colour parameters of lightness (L*), redness (a*), and yellowness (b*), recorded at 6 and 24 h post-mortem on the ventral surface of the Pectoralis major muscle of broilers

Variable		Time post-mortem (h)					
		6			24		
		L*	a*	b*	L*	a*	b*
Strain	CM	Individual means					
A	Freezing	49.69^{c}	1.76^{c}	3.61^{c}	54.62^{b}	1.69^{bc}	4.27^{d}
B		51.17^{a}	2.14^{a}	3.28^{d}	54.84^{a}	2.18^{a}	4.53^{c}
C		50.68^{b}	1.74^{c}	4.02^{a}	53.62^{c}	1.52^{d}	5.02^{a}
D		51.01^{ab}	1.83^{b}	3.74b^{c}	54.66^{ab}	1.75^{b}	4.62^{b}
E		51.02^{ab}	1.66d^{a}	3.77^{b}	52.74^{d}	1.68b^{c}	4.67^{b}
A	Ice – cold	49.67^{d}	2.21^{ab}	3.23d^{a}	52.04^{c}	1.86^{a}	3.72^{c}
B		52.26^{a}	2.26^{a}	3.56^{c}	51.42^{b}	1.83^{a}	4.22a
C		51.53^{bc}	2.05^{c}	3.69^{a}	53.39^{a}	1.59^{c}	3.66^{d}
D		51.62^{b}	2.27^{a}	3.61^{ab}	52.41^{b}	1.82^{a}	3.74^{c}
E		51.27^{c}	2.26^{a}	3.62^{ab}	51.31^{bc}	1.81^{a}	3.82^{a}
SEM		0.72	0.18	0.26	0.52	0.21	0.42
Main effect means							
A		51.02^{d}	1.84^{b}	3.33^{d}	53.32^{d}	1.75^{b}	3.72^{d}
B		51.28^{a}	2.03^{a}	3.56^{c}	54.17^{ab}	2.11^{a}	4.43^{ab}
C		51.12^{c}	1.79^{c}	3.72^{a}	54.02^{c}	1.72^{b}	4.46^{a}
D		51.16^{b}	1.36^{d}	3.35^{cd}	54.22^{a}	1.76^{b}	4.48^{a}
E		51.17^{b}	1.52^{cd}	3.62^{b}	54.32^{a}	1.77^{b}	4.47^{a}
	SEM	o.52	0.23	0.15	0.54	0.15	0.23
Cooling Method							
Freezing		51.64	1.84	3.53	54.64	1.90	4.62
Ice – cold		51.16	2.21	3.48	53.08	1.83	3.36
SEM		0.48	0.14	0.13	0.76	0.22	0.25
Source of variation:		Probability					
Strain		0.05	0.27	0.12	0.05	0.05	0.10
C M		0.47	0.22	0.54	0.004	0.97	0.004
Strain x CM		0.51	0.76	0.05	0.75	0.51	0.43

a-d Means in a column within an effect with no common superscript differ significantly ($P < 0.05$). SEM-Standard error mean.

However, the breast pH was significantly lower at 4 and 24 h in the breast muscles of carcasses cooled in refrigerator compared to those ice-cooled water. The differences observed were very small; pH and L* values of the P. major muscle differed only by 0.48 and 1.56 units between CM, respectively. Reasons for these changes in meat lightness due to CM treatments are unclear and difficult to explain. A negative correlation between L* and a* values and a positive correlation between a* and total pigment concentration have been reported in the literature (Fleming *et al.*, 1991; Boulianne and King, 1995).

Therefore, it is possible that in this study the higher L* values of muscles from refrigerated carcasses could be caused by a reduction in a* values by dilution of heme pigments as a result of hydration. An opposite effect could be envisaged in muscles from carcasses cooled by air. However, as no significant differences due to CM in a* values were detected in this study regardless of sampling time and location, this factor cannot account for the higher breast L* values observed in ice-water cooled carcasses. Meat colour b* values were only significantly different at 24 h on measurements taken at the ventral surface of the breast. The b* values were higher on the breast muscle of carcasses cooled in refrigerator when compared to those cooled by fanned. Fleming *et al.* (1991) reported no differences in breast meat colour L*, a*, and b* values and haem pigment concentration between ice-slush chilled and air-chilled broiler carcasses.

pH and Colour Attributes on the Pectoralis Minor Muscles

The effect of specie and CM on the P. minor muscle pH and colour attributes recorded at 6 h and 24 h are presented in Table 6. There were significant differences ($p<0.05$) in pH of the P. minor muscle due to strain at 6 and 24 h PM. The pH of strains E, A and C broilers slightly similar but significantly higher pH values at 6 h than to those of strains B and D. At 24 h, broilers from strain B exhibited lower pH values than those of strains A, C, D and E. The pH values of the P. minor muscle were considerable higher than the pH values of the corresponding P. major muscle at 6 and 24 h. However, a similar pattern in the rate and extent of pH decline among the P. major and P. minor muscles was observed within a strain. There were no differences ($p>0.05$) between CM in pH values of the P. minor muscle at either sampling time. It is possible that effects of CM on temperature and the subsequent effect in pH decline early after death were prevented by the inherent location of the P. minor in the carcass. At 6 h PM, the L* and b* values of the P. minor muscles cooled in refrigerated were

Table 6. Effect of strain and cooling method on the Pectoralis minor muscle pH and colour parameters of lightness (L*), redness (a*), and yellowness (b*), recorded at 6 and 24 h post-mortem

Variable	Time post-mortem (h)							
Strain	6				24			
	pH	L*	a*	b*	pH	L*	a*	b*
A	6.16^{ab}	50.10^{c}	2.53^{a}	3.64^{b}	6.23^{b}	53.05^{a}	2.22^{a}	3.72^{d}
B	6.11^{d}	51.13^{c}	3.12^{c}	3.64^{b}	5.68^{a}	52.73^{b}	2.22^{a}	4.23^{cd}
C	6.14^{c}	53.31^{a}	2.16^{b}	4.06^{a}	6.20^{bc}	53.06^{a}	2.14^{b}	4.61^{a}
D	6.12^{d}	50.12^{c}	2.15^{b}	3.62^{bc}	6.24^{b}	52.75^{b}	2.16^{bc}	4.34^{b}
E	6.21^{a}	52.13^{b}	2.16^{b}	3.64^{b}	6.22^{b}	53.04^{a}	2.23^{a}	4.28^{c}
SEM	0.01	0.02	0.04	0.02	0.01	0.02	0.02	0.03
Cooling Method:								
Freezing	6.21	50.02	2.63	3.42	6.04	52.31	2.51	4.39
Ice – cold	6.23	51.23	2.51	4.15	6.04	52.14	2.53	4.16
SEM	0.02	0.32	0.21	2.14	0.02	0.35	0.15	0.23
Source of variation	Probability							
Strain	0.0002	0.004	0.006	0.34	0.0001	0.0001	0.003	0.02
C M	0.64	0.001	0.62	0.004	0.52	0.42	0.86	0.18
Strain x CM	0.15	0.62	0.81	0.72	0.13	0.52	0.51	0.53

^{a,b,c,d}: Means in a column within an effect with no common superscript differ significantly ($P < 0.05$). SEM-Standard error mean.

CM-cooling methods significantly lower than those cooled by fanned, with no differences in a* values observed. However, at 24 h PM these differences were no longer significant. The negative association between pH and L* values was also observed in the P. minor muscle. The P. minor muscle L* values were significantly lower in species A and D birds when compared to those of species B, C and E at 6 h, corresponding to the higher pH values observed by species A, C and D birds at 24 h PM. Overall, the P. minor muscles were considerably darker than the P. major muscles as evidenced by the lower L* values achieved in those muscles. There was no significant difference ($p>0.05$) between Freezing and ice- cold carcass meat at 6 and 24 h except yellowness (b*) at 24 h.

Water Holding Capacity and Expressible Moisture

Expressible moisture and WHC were measured to obtain an overall assessment of the water binding properties of the pectoralis muscles. The effects of specie and CM on WHC and expressible moisture of the pectoralis muscles are presented in Table 7. There were significant differences ($p<0.05$) on WHC of both pectoralis muscles due to strain. The P. major and minor

Table 7. The effects of strain and cooling method on the Pectoralis major and minor muscles water holding capacity (WHC) and expressible moisture (EM) of broilers

Variable	Time post-mortem (24 h)			
	WHC		EM	
Strain	P. major	P. minor	P. major	P. minor
A	20.67[a]	38.17[a]	41.42[c]	42.31[bc]
B	13.90[d]	23.48[d]	41.53[ab]	43.24[a]
C	18.47[b]	32.62[c]	42.27[cd]	42.65[b]
D	16.48[c]	37.02[ab]	42.62[a]	42.31[bc]
E	18.72[bc]	31.07[c]	41.72[d]	43.31[a]
SEM	1.04	3.10	0.71	0.79
Cooling Method				
Freezing	16.95	27.86	41.24	42.27
Ice – cold	18.27	34.62	42.18	43.05
SEM	0.92	1.73	0.32	0.62
Source of variation			Probability	
Strain	<0.0001	<0.0001	0.52	0.73
C M	0.31	0.05	0.31	0.36
Strain x CM	0.17	<0.0001	0.21	0.82

[a,b,c,d]: Means in a column within an effect with no common superscript differ significantly ($P < 0.05$).
WHC-water holding capacity, CM-cooling methods EM- expressible moisture (EM)

Muscles of strains A, C and E broilers exhibited similar but significantly higher WHC than muscles of strain B and D birds. The higher WHC observed in the pectoralis muscles of strains A, C and E broilers can be directly related to the significantly higher pH and lower L* values exhibited by those muscles at 24 h. The inferior water holding properties exhibited in both pectoralis muscles of species B and D broilers can be attributed to the accelerated rate of PM glycolysis that characterized the birds from this strains. The combination of a low pH at elevated temperatures early PM is likely to have resulted in protein denaturation affecting protein functionality for water holding properties in these muscles. These results agree with previous reports indicating that ultimate pH influences several mechanical properties of meat (Fernandez *et al.* (1994) but that the most important factor affecting colour and water binding properties is the protein denaturation caused by a rapid decline in pH early PM when carcass temperatures are still high (Warris and Brown, 1987; Briskey, 1964). Warris and Brown (1987) reported that WHC, measured as drip loss, appeared to be related to the extent of protein denaturation, but that it was more likely to be determined by a combined effect of the pH at which rigor occurs and the final pH attained.

No significant differences ($p>0.05$) in expressible moisture were observed between strains or CM. This was not expected, in particular among strains, because expressible moisture has been found to be correlated with ultimate pH and L* values and to follow a similar trend to changes observed in other WHC assessment methods such as drip and cook loss. It is possible that in this study the majority of the expressible moisture present in the muscles was lost to drip during handling and storage of muscle samples. These results agree with those of Froning *et al.* (1960) who reported that moisture content of broiler breast meat was not influenced by chilling, because most of the additional moisture was lost through the drip. Significant differences in WHC due to CM were observed only in the P. minor muscles. The P. minor muscles from fanned carcasses had a higher WHC than those cooled in refrigerated. Although not significant, the WHC of the P. major muscles tended to be higher in fanned carcasses as well. It appears that the water uptake of muscles during freezing cooling conditions inhibited the further capacity of muscle proteins to retain additional water.

Conclusion

Freezing and ice - cold water Cooling method affects carcass quality. Body weight of broilers strains A, B, D are similar but significantly heavier than those of strains C and E. **T**he pH of the P. major muscle declined over time. Regardless of strain and CM, meat lightness increased after storage for 20 h on both

surfaces of the P. major. However, the dorsal surface was considerably lighter than the ventral surface. The rate and extent of pH decline among the P. major and P. minor muscles was observed within a strain. There were significant differences on WHC of both pectoralis muscles due to strain. The variation and measurable differences in all meat quality parameters observed in the strains indicate that these traits can be used in breeding schemes at the primary level to improve meat quality of commercial genotypes. However, further research is necessary to clarify the causes of these variations in muscle quality of the broiler strains.

Acknowledgement

I wish to appreciate the cooperation of my students and technical staff of the Department of Animal Production, University of Jos and many others for financial assistance during the research.

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