The Relationship of Broiler Breast Color to Meat Quality and Shelf-Life

C. D. ALLEN, D. L. FLETCHER,[1] J. K. NORTHCUTT, and S. M. RUSSELL

Department of Poultry Science, The University of Georgia, Athens, Georgia 30602-2772

ABSTRACT A total of three experiments were conducted to compare physical and microbiological properties of raw and marinated broiler breast fillets selected as being either lighter or darker than normal. Visibly light- and dark-colored breast fillets were divided into marinated and control groups, and vacuum-tumbled for 20 min at 4 C under 80 kPa pressure. Breast fillets from the four treatment groups were evaluated for shear values, raw and cooked meat pH, drip-loss, cook-loss, water-holding capacity, and 7 d psychrotrophic count. The light-colored fillets were significantly lighter, less red, and more yellow than the dark fillets. Lightness values increased when fillets were marinated. Moreover, the light fillets had a lower pH than dark fillets. The pH values of raw and cooked breast meat were related to meat color but not marination. Dark-colored fillets had significantly higher marination pick-up and a higher fraction of bound moisture and significantly lower drip and cook-loss. No differences were observed in shear values between color or marination treatments. There were no significant differences in psychrotrophic plate counts (PPC) or capacitance detection times (CDT) due to color or treatment at Day 1. After 7 d of storage at 4 C, PPC was significantly lower for marinated samples. No correlations were observed between pH and PPC, CDT, or odor. Based on these differences in physical and microbiological properties, further processors may consider separating breast fillets according to color.

(*Key words*: breast meat color, water-holding capacity, meat quality, marination, shelf-life)

1998 Poultry Science 77:361–366

INTRODUCTION

To the consumer, appearance is the major criterion for purchase selection and initial evaluation of meat quality. Other quality attributes, such as tenderness, juiciness, drip-loss, cook-loss, pH, and shelf-life are important to the consumer after purchasing the product, as well as to the processor when producing value-added meat products.

Differences in breast meat color have been attributed to the preslaughter condition and handling practices of poultry. Froning *et al.* (1978) and Ngoka and Froning (1982) reported darker-colored breast meat from birds that were allowed to struggle freely during slaughter when compared to breast meat from anesthetized birds. Struggling before slaughter depletes muscle glycogen and less lactic acid accumulates in the muscle during post-mortem glycolysis, resulting in higher ultimate meat pH (Wood and Richards, 1975).

Several researchers have demonstrated that a significant negative correlation exists between breast meat lightness color values and breast meat pH (Barbut, 1993; Fletcher, 1995; Allen *et al.*, 1997). Poultry meat with low pH has been associated with low water-holding capacity (WHC), which results in increased cook-loss and drip-loss (Froning *et al.*, 1978; Barbut, 1993; Northcutt *et al.*, 1994). Meat with low pH has also been reported to decrease tenderness (Froning *et al.*, 1978; Barbut, 1993) and increase shelf-life (Allen *et al.*, 1997).

The addition of polyphosphate to meat has been found to increase meat WHC by increasing pH (Froning, 1966; Young *et al.*, 1992; Yang and Chen, 1993). Combinations of sodium chloride and polyphosphate have been reported to synergistically improve moisture absorption and WHC while reducing drip-loss and cook-loss of poultry meat (Young *et al.*, 1987). Tumbling poultry in these solutions increased breast meat tenderness and the amount of soluble protein (Maki and Froning, 1987); thus enhancing the binding properties of poultry meat (Froning, 1966).

Contrasting results have been obtained concerning the antimicrobial properties of phosphates on the Gram-negative microflora of poultry. Earlier studies have demonstrated an increase in shelf-life of chicken carcasses chilled in phosphate solutions (Elliott *et al.*, 1964; Steinhauer and Banwart, 1964). Elliott *et al.* (1964)

Received for publication March 17, 1997.
Accepted for publication September 22, 1997.
[1]To whom correspondence should be addressed.

Abbreviation Key: CDT = capacitance detection times; GLM = General Linear Model; PPC = psychrotrophic plate counts; STPP = sodium tripolyphosphate; WHC = water-holding capacity.

attributed the inhibitory action of phosphates to the chelation of metal ions needed for microbial growth. More recent research, however, has been unsuccessful at establishing the relationship between the use of phosphates and reduction of Gram-negative bacteria on fresh meats (Zessin and Shelef, 1988; Harmayani *et al.*, 1991). Conditions, such as the type and amount of phosphate used, meat pH, ionic strength, other inhibitors, temperature, and presence of metal ions interact to influence bacterial growth rate (Tompkin, 1983).

Although previous research has been conducted to evaluate the relationship of breast meat color to certain meat qualities (Barbut, 1993; Fletcher, 1995; Allen *et al.*, 1997), no study has been done to examine the functional and microbiological properties of dark- and light-colored broiler breast fillets tumbled in a commercial marinade. The objective of this study was to determine whether breast muscle color was related to both physical properties and shelf-life of the meat, and whether these properties could be influenced by marination.

MATERIALS AND METHODS

Sample Collection and Treatment

A total of 760 light- and dark-colored boneless, skinless breast muscle filets (*Pectoralis major* only) were collected over a period of 12 d (replicates). Color measurements (CIE, 1978) were taken at the deboned breast packaging area of a commercial processing plant using a portable Minolta[2] colorimeter. Breast fillets chosen as being lighter than normal had lightness (L*) values greater than 50.0, whereas fillets being darker than normal had L* values less than 45.0. Color values were recorded in triplicate, and the average value was used. Samples were numbered, placed into sterile polyethylene bags, packed on ice, and transported to the laboratory.

One half of the light fillets and one half of the dark fillets were randomly selected, weighed, and vacuum tumbled for 20 min with 10% (wt / wt) of a prechilled (4 C) solution containing 3% sodium tripolyphosphate (STPP) and 7% NaCl as described by Young *et al.* (1996). The remaining half of the dark and light fillets were used as controls. Control fillets were weighed and vacuum-tumbled, but were not marinated. Samples were grouped according to the following treatments: 1) dark, unmarinated, 2) light, unmarinated, 3) dark, marinated, and 4) light, marinated. Groups were then placed in separate containers and held at 4 C for 18 h prior to determining post-tumble color values, cook-loss, cooked meat pH, shear determination, raw meat pH, WHC, and microbiological analyses. Four experimental groups, based on the measurements below, were replicated 3 times each, for the total 12 replications (sampling days).

Cook-Loss, Cooked Meat pH, and Shear Determination

From the four treatment groups, a total of 320 fillets were collected over 3 replicate d (120, 100, and 100, respectively) and analyzed for cook-loss. Fillets were placed on aluminum trays, cooked for 20 min at 95 C with steam, allowed to cool for 30 min, and reweighed to calculate cook-loss. From the 320 cooked fillets, 240 were selected for shear measurements, and the remaining 80 were used to determine cooked meat pH values. Shear values were determined using the Allo-Kramer shear cell on an Instron Universal Testing Machine,[3] as described by Papinaho and Fletcher (1996). Breast meat pH values were determined using the iodoacetate method as described by Jeacocke (1977) using a Sentron pH meter.[4]

Drip-Loss Analysis

A total of 120 samples, 40 from each replicate (10 per treatment), were used for drip-loss analysis. Immediately following post-tumble color and weight readings, fillets were suspended on hooks from the lid of an air-tight container as described by Northcutt *et al.* (1994). Containers were stored for 3 d at 4 C and the individual fillets reweighed to determine drip-loss. Drip-loss was calculated as (weight of drip loss / initial weight of fillet) × 100.

Raw Meat pH Value and WHC Determination

A total of 80 breast fillets (40, 20, and 20 for three replicates, respectively) from the four treatment groups were analyzed for raw meat pH according to the procedures described above for cooked pH determination. After pH determination, WHC measurements were made on each fillet by grinding[5] the fillet three times through a plate with 5-mm diameter holes, weighing 4 g of homogenate into 50-mL tubes in duplicate, and centrifuging[6] for 20 min at 60,000 × *g* (24,500 rpm) at 5 C. Immediately following centrifugation, expressed fluid was discarded, tubes were inverted for 10 min, and the meat removed from the tube and reweighed. Expressed juice was defined as the loss in weight after centrifuging and presented as a percentage of the initial weight of the uncooked sample (Bouton *et al.*, 1971). Total moisture content was determined in duplicate according to AOAC procedures (AOAC, 1984). The WHC was calculated as the fraction of water retained by the meat [1 – (expressible juice / total moisture content)].

Microbiological Analyses

A total of 240 samples, 80 from each replicate (20 per treatment), were used for microbiological determinations.

[2]Minolta Chroma Meter CR-100, Minolta Corp., Ramsey, NJ 07446.
[3]Instron Corp., Canton, MA 02021.
[4]Sentron Model 2001, Sentron Inc., Federal Way, WA 98003.
[5]Hobart Co., Troy, OH 45374.
[6]Sorvall Supraspeed Centrifuge RC-28S, Du Pont Co., Wilmington, DE 19880.

TABLE 1. Initial mean (± SEM) lightness (L*), redness (a*), and yellowness (b*) values of broiler breast fillets selected as "light" (L* > 50.0) or "dark" (L* < 45.0)

Color	L*	a*	b*
Light	51.13 ± 0.10[a]	2.32 ± 0.07[b]	3.71 ± 0.09[a]
Dark	43.07 ± 0.10[b]	4.61 ± 0.07[a]	2.07 ± 0.08[b]

[a,b]Means within columns with no common superscript differ significantly ($P < 0.05$). n = 760.

Following the tumbling treatment, samples were kept at 4 C for 18 h, and individually placed into sterile polyethylene bags. Half of the fillets were sampled at Day 1, and the remaining half were stored for 7 d at 4 C. For microbiological analyses, 25 g of meat was aseptically removed from each breast muscle, added to 225 mL of sterile BactoPeptone,[7] and homogenized for 60 s. Psychrotrophic plate counts (PPC) were conducted in duplicate using Petrifilm®[8] Aerobic Count Plates and incubating at 7 C for 10 d as described by Russell (1996). *Pseudomonas fluorescens* were enumerated using capacitance on the Bactometer Microbial Monitoring System M128[9] according to procedures described by Russell (1996).

Off-odor of each muscle was subjectively measured at Day 7 by a three-member panel. Each panel member opened the sample bag, sniffed the fillet, and recorded a score according to the following descriptors: 1 = "fresh chicken" or no detectable off-odor; 2 = slight odor development but still acceptable; 3 = definite off-odor indicative of spoiled chicken. The odor scores from the three panel members were averaged, and the mean was used as the score for that fillet. The pH value for each sample was determined in duplicate using the technique previously described.

The experimental design for physical measurements was a 2×2 factorial with color and marination treatment as dependent variables. Microbiological analysis was a $2 \times 2 \times 2$ factorial with color, marination treatment, and day as dependant variables. Data were analyzed using the statistical analyses and General Linear Models (GLM) procedures of SAS® (SAS Institute, 1988). Treatment effects were tested using residual error, or where significant by the treatment by replication interaction. Means were separated using the Duncan's multiple range test option of SAS® (SAS Institute, 1988). Correlation coefficients for color, pH, moisture pick-up, cook-loss, shear, WHC, PPC, capacitance detection time (CDT), and odor were generated using the Pearson's Correlation Coefficient option of SAS® (SAS Institute, 1988). The PPC were converted to $\log_{10}$ colony-forming units per milliliter prior to statistical analyses. Significance is reported at the $P < 0.05$ level.

[7]Difco Laboratories, Detroit, MI 48232.
[8]3M Microbiology Products, St. Paul, MN 55144.
[9]bioMèrieux Vitek, Inc., Hazelwood, MO 63042.

RESULTS AND DISCUSSION

The mean L*, a*, and b* values for the breast fillets selected as "light" (L* > 50.0) or "dark" (L* < 45.0) are presented in Table 1. The light fillets averaged L* = 51.13, a* = 2.32, and b* = 3.71, and the dark fillets L* = 43.07, a* = 4.61, and b* = 2.07, all significantly different ($P < 0.05$) from each other. The selection of the visually different "light" and "dark" fillets based on L* values resulted in a clear and consistent differentiation of the two color groups over time (replications). This was important, because in an earlier study arbitrary differences in light and dark fillets, selected only upon visual differences were not constant, especially between replications (Allen *et al.*, 1997).

After tumbling, L* values were significantly higher and both a* and b* values were significantly lower for both light and dark marinated fillets than the respective unmarinated control fillets (Table 2). These data conflicted with the findings of Yang and Chen (1993), in which lower lightness and higher redness values of broiler breast fillets were found after marination with 1 and 2% trisodium phosphate. Young *et al.* (1996) also reported no color changes in STPP marinated broiler breast fillets. However, Lyon and Magee (1984) reported an increase in the lightness of poultry meat presoaked in a polyphosphate solution. Poultry carcasses held in polyphosphate-treated chill water have also been described as acquiring a bluish-white appearance (Schermerhorn *et al.*, 1963).

Both marinated and control dark-colored fillets were found to have higher raw meat pH values than light-colored fillets (Table 2). Significant negative correlations existed between L* and raw meat pH (Table 3), which agreed with the findings of previous studies (Barbut, 1993; Yang and Chen, 1993; Fletcher, 1995; Allen *et al.*, 1997).

Because the pH of the marinade was 8.0, treated fillets were expected to be more alkaline than unmarinated fillets. However, no significant differences in pH were observed between treatments (Table 2). These results differ from the findings of Young *et al.* (1996), who reported an increase in breast muscle pH when marinated with the same concentrations of STPP and NaCl. This difference could be attributed to the time pH was measured after marination as well as the amount of marinade solution added to the fillets. Young *et al.* (1996) measured pH at approximately 1.5 h post-mortem and fillets were tumbled with a 20% solution compared to 18 h post-mortem and a 10% solution as used in this study.

As expected, marinated and tumbled fillets had higher percentages of moisture pick-up than unmarinated and tumbled fillets (Table 2). Unmarinated fillets actually lost moisture during the tumbling and holding process. Within each marination treatment, dark muscles, with the higher pH, picked up more moisture (marinated) or lost less moisture (unmarinated) than

TABLE 2. Mean (± SEM) lightness (L*), redness (a*), yellowness (b*), raw meat pH, moisture pick-up, drip-loss, water holding capacity, cooked meat pH, cook-loss, and shear values of breast fillets selected as light (L% > 50.0) or dark (L* < 45.0) and either marinated or unmarinated

	Unmarinated		Marinated		
Variable	Light	Dark	Light	Dark	n
L*	51.72 ± 0.13[b]	45.12 ± 0.23[d]	53.27 ± 0.16[a]	46.66 ± 0.20[c]	760
a*	2.21 ± 0.07[c]	3.82 ± 0.10[a]	1.81 ± 0.07[d]	3.50 ± 0.08[b]	760
b*	4.60 ± 0.15[a]	2.22 ± 0.14[c]	3.68 ± 0.13[b]	1.54 ± 0.13[d]	760
Raw meat pH	5.74 ± 0.02[b]	5.98 ± 0.05[a]	5.80 ± 0.03[b]	6.02 ± 0.03[a]	80
Moisture pick-up, %	–1.80 ± 0.12[d]	–0.28 ± 0.09[c]	6.00 ± 0.18[b]	7.67 ± 0.18[a]	520
Drip-loss, %	1.97 ± 0.15[b,c]	0.76 ± 0.05[c]	5.58 ± 0.28[a]	3.34 ± 0.21[b]	120
Water-holding capacity	0.71 ± 0.01[c]	0.79 ± 0.01[a]	0.66 ± 0.01[d]	0.74 ± 0.01[b]	80
Cooked meat pH	6.06 ± 0.02[c]	6.19 ± 0.02[a,b]	6.09 ± 0.02[b,c]	6.23 ± 0.03[a]	80
Cook-loss, %	29.43 ± 0.15[c]	27.37 ± 0.16[d]	34.38 ± 0.36[a]	32.90 ± 0.21[b]	320
Shear, kg	3.49 ± 0.08	3.19 ± 0.05	3.33 ± 0.10	3.27 ± 0.08	240

[a–d]Means in a row with no common superscript differ significantly ($P < 0.05$).

respective marinated or unmarinated light-colored muscles. Significant correlations were observed between percentage moisture pick-up and initial L*, and raw and cooked meat pH (Table 3). No correlation existed between percentage moisture pick-up and post-tumble L*.

Drip-loss, WHC, and cook-loss were measured to obtain an overall assessment of the water binding properties of meat. Because marinated fillets had a high percentage of moisture pick-up, these fillets also exhibited higher percentages of drip-loss and cook-loss (Table 2). Within the two treatments (marinated or unmarinated), light-colored samples had significantly higher percentages of drip-loss than dark-colored fillets. Cook-loss measurements also revealed that light-colored breast fillets lost more moisture than dark-colored samples.

Initial and tumbled L* values correlated positively with drip-loss and cook-loss (Table 3). These data agree with the findings of Barbut (1993), who observed a high correlation (0.70) between L* and cooking loss. In the present study, no correlation existed between raw meat pH and drip-loss or cook-loss. Other studies, however, have reported changes in drip-loss and cook-loss as being directly influenced by pH (Northcutt *et al.*, 1994).

Significant differences due to color and treatment were demonstrated with water-holding measurements (drip-loss and WHC) (Table 2). Because WHC measures the fraction of bound water retained in the muscle, samples with the lowest percentages of drip-loss and cook-loss exhibited the highest amount of WHC. Therefore, dark control fillets had the highest WHC followed by dark marinated fillets, light control fillets, and light marinated fillets, respectively. The WHC was found to be negatively correlated with initial and tumbled L* values (Table 3). A positive correlation was seen between WHC and raw meat pH. These correlations are in agreement with previous findings (Froning *et al.*, 1978; Barbut, 1993).

Cooked meat pH was similar to raw meat pH (Table 2). The increase in muscle pH after cooking has been attributed to changes of protein charge (Hamm and Deatherage, 1960). A correlation was observed between cooked meat pH and moisture pick-up, as well as L* values (Table 3). No correlation existed between cooked pH and percentage cook-loss. These data differ from that of Bouton *et al.* (1971), who reported a linear decrease in cook-loss as the cooked meat pH of mutton increased.

No significant differences in shear measurements were observed between color groups or treatments

TABLE 3. Correlation coefficients of initial lightness (L*), redness (a*), yellowness (b*), tumbled lightness (L*), redness (a*), yellowness (b*), raw meat pH (pH raw), cooked meat pH (pH cooked), moisture pick-up (pick-up), cook-loss, Allo-Kramer shear (A-K shear), water-holding capacity (WHC), and drip-loss measurements of light and dark colored breast fillets

Variable	A-K Shear	WHC	Drip-loss	Cook-loss	Pick-up	pH Cooked	pH Raw
L* initial	0.1768*	–0.7530**	0.4370**	0.2466**	–0.2409**	–0.6038**	–0.8055**
a* initial	–0.1209	0.4097**	–0.1298	–0.0564	0.2797**	0.4388**	0.5483**
b* initial	0.1068	–0.4517**	0.1455	–0.0082	–0.1981**	–0.1343	–0.5291**
L* tumbled	0.1412*	–0.7870**	0.5713**	0.4166**	–0.0026	–0.5808**	–0.7968**
a* tumbled	–0.0981	0.5825**	–0.2488**	–0.2969**	–0.0337	0.2483*	0.5464**
b* tumbled	–0.0302	–0.4444**	–0.0041	–0.1213*	–0.3785**	–0.0916	–0.5516**
pH raw	. . .	0.6291**	. . .	. . .	0.3737**		
pH cooked	. . .	. . .	. . .	0.0053	0.2615*		
Pick-up	–0.0266	–0.0660	0.6888**	0.6756**			
Cook-loss	0.1740**						

*$P < 0.05$.

**$P < 0.01$.

TABLE 4. Mean[1] (± SEM) pH, psychrotrophic plate count[2] (PPC), capacitance detection time (CDT), and odor[3] score of breast meat selected as light or dark, marinated or unmarinated, and stored for 1 or 7 d

	Unmarinated		Marinated	
Variable	Light	Dark	Light	Dark
Day 1				
pH	5.79 ± 0.01[b]	6.09 ± 0.03[a]	5.81 ± 0.02[b]	6.09 ± 0.03[a]
PPC	3.33 ± 0.18	3.16 ± 0.09	2.99 ± 0.06	3.01 ± 0.05
CDT	16.47 ± 0.84	15.58 ± 0.57	18.16 ± 0.37	17.92 ± 0.73
Day 7				
pH	5.82 ± 0.03[b]	6.16 ± 0.05[a]	5.84 ± 0.02[b]	6.10 ± 0.03[a]
PPC	6.99 ± 0.10[a,b]	7.11 ± 0.05[a]	6.80 ± 0.06[b]	6.85 ± 0.07[b]
CDT	7.98 ± 0.46	7.99 ± 0.38	7.83 ± 0.29	8.49 ± 0.34
Odor	1.30 ± 0.10[c]	1.80 ± 0.14[b]	1.67 ± 0.11[b]	2.17 ± 0.13[a]

[a–c]Means in a row with no common superscript differ significantly ($P < 0.05$).

[1]n = 240.

[2]PPC = $\log_{10}$ colony-forming units per milliliter.

[3]Odor scores categorized as: 1 = "fresh chicken" or no odor, 2 = slight odor development but still acceptable, 3 = definite off-odor indicative of spoiled chicken.

(Table 2). Results from this study agreed with Fletcher (1995), who found no significant differences in shear between breast muscles of various L*, a*, and pH values, and with Young *et al.* (1996), who stated that polyphosphate with NaCl had no significant effect on breast shear values. Allo-Kramer shear measurements were found to correlate positively with L* value (initial and tumbled) as well as cook-loss. Barbut (1993) also reported that L* value of poultry breast was positively correlated with cook-loss.

Microbiological properties of light and dark-colored breast meat at 1 and 7 d of storage are presented in Table 4. Results for muscle pH are similar to those reported in Table 2. For each treatment and day of storage, light-colored samples had significantly lower pH values than dark-colored fillets. These results were supported by a significant negative correlation between L* and pH (Table 5).

On Day 1, there were no significant differences in PPC or CDT measurements due to breast meat color or marination treatment (Table 4). These results were expected because the initial populations of psychrotrophs, specifically *P. fluorescens*, should be similar regardless of meat color and any antimicrobial activity of the marinade on microbial growth should not be detected.

After 7 d of storage, PPC were significantly higher for the dark unmarinated fillets than for marinated fillets (Table 4). Newton and Gill (1981) explained that high pH reduces the lag phase time or the time that the spoilage bacteria is preparing for growth. Other studies with poultry have demonstrated a significant correlation between psychrotrophic bacterial counts and pH, with higher counts being associated with higher muscle pH (Allen *et al.*, 1997). However, in this study, no correlation existed between PPC and pH (Table 5).

The CDT measurements were not significantly different for dark or light fillets or for marination treatment groups (Table 4). The CDT test enumerated only *P. fluorescens* spoilage bacteria based on previous research by Russell *et al.* (1996), who showed that *P. fluorescens* is a primary spoilage organism of fresh poultry. Elliott *et al.* (1964) found that nonfluorescent pseudomonads were more sensitive to the chelating process of polyphosphates than were the fluorescent pseudomonads. Because CDT analysis focused only on fluorescent species, this test may not have measured the growth rates of other *Pseudomonas* species.

Subjective odor analysis did not follow PPC growth trends. For each treatment, darker samples had higher odor scores than light-colored fillets. These data agreed with Allen *et al.* (1997), who reported that dark fillets

TABLE 5. Correlation coefficients of lightness (L*), redness (a*), yellowness (b*), pH, psychrotrophic plate count (PPC), capacitance detection time (CDT), and odor score of light and dark-colored breast fillets

	Day	Odor	CDT	PPC	pH
L*	–0.04178	–0.3361**	0.1081	–0.0747	–0.4875**
a*	0.2318**	0.3522**	–0.2918**	0.2323**	0.1101
b*	0.3691	–0.0308	–0.3403**	0.3630**	–0.6418**
pH	0.0776	0.1345	–0.0218	0.0787	
PPC	0.9661**	0.2201*	–0.9019**		
CDT	–0.8340**	–0.1434			

*$P < 0.05$.

**$P < 0.01$.

produced objectionable odors at a faster rate than light fillets. Marinated fillets were found to have higher odor scores than respective unmarinated samples. Odor scores may have been influenced by the marinade itself, because all three panelists noticed an off-odor from the STPP marinade.

Dark broiler breast fillets, whether marinated or not, were found to have lower L* values, higher muscle pH, higher percentages of marinade pick-up, higher amounts of retained moisture, lower percentages of drip-loss, and lower percentages of cook-loss than light broiler breast fillets. Tenderness values were not affected by color or marination treatment. These results indicate that variations in broiler breast muscle color can be related to differences in meat quality properties. Marination of the muscles did not reduce these differences. Therefore, it may be advantageous for processors to separate breast fillets according to color prior to further processing.

ACKNOWLEDGMENTS

This study was supported in part by state and Hatch funds allocated to the Georgia Agricultural Experiment Station. Appreciation is extended to bioMérieux Vitek, Inc., for its support, which included the Bactometer Microbial Monitoring System, technical assistance, and supplies. The authors also thank Gene Lyon and Louis Young for their advice and use of the facilities at USDA-ARS, Russell Research Center. The technical assistance from Gavin Poole, Lynda Jones, and Reg Smith was also appreciated.

REFERENCES

Allen, C. D., S. M. Russell, and D. L. Fletcher, 1997. The relationship of broiler breast meat color and pH to shelf-life and odor development. Poultry Sci. 76:1042–1046.

AOAC, 1984. Official Methods of Analysis. 14th ed. Association of Official Analytical Chemists, Washington, DC.

Barbut, S., 1993. Colour measurements for evaluating the pale soft exudative (PSE) occurrence in turkey meat. Food Res. Intl. 26:39–43.

Bouton, P. E., P. V. Harris, and W. R. Shorthose, 1971. Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. J. Food Sci. 36:435–439.

CIE, 1978. International Commission on Illumination, Recommendations on Uniform Color Spaces, Color Difference Equations, Psychometric Color Terms. Supplement No. 2 to CIE publication No. 15 (E-1.3.1) 1971/(TC-1.3) 1978. Bureau Central de la CIE, Paris, France.

Elliott, R. P., R. P. Straka, and J. A. Garibaldi, 1964. Polyphosphate inhibition of growth of pseudomonads from poultry meat. Appl. Micro. 12:517–522.

Fletcher, D. L., 1995. Relationship of breast meat color variation to muscle pH and texture. Poultry Sci. 74(Suppl 1):120. (Abstr.)

Froning. G. W., 1966. Effect of various additives on the binding properties of chicken meat. Poultry Sci. 45:185–188.

Froning, G. W., A. S. Babji, and F. B. Mather, 1978. The effect of preslaughter temperature, stress, struggle and anesthetization on color and textural characteristic of turkey muscle. Poultry Sci. 57:630–633.

Hamm, R., and F. E. Deatherage, 1960. Changes in hydration, solubility, and charges of muscle proteins during heating of meat. Food Res. 25:587–610.

Harmayani, E., J. N. Sofos, and G. R. Schmidt, 1991. Growth and aminopeptidase activity of *Pseudomonas fragi* in presence of phosphates. Lebensm.-Wiss. u.-Technol. 24: 350–354.

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

Lyon, B. G., and J. B. Magee, 1984. Effects of sodium chloride and polyphosphate pretreatments on fowl meat processed in flexible pouches. Poultry Sci. 63:1958–1963.

Maki, A. A., and G. W. Froning, 1987. Effect on the quality characteristics of turkey breast muscle of tumbling whole carcasses in the presence of salt and phosphate. Poultry Sci. 66:1180–1183.

Newton, K. G., and C. O. Gill, 1981. The microbiology of DFD fresh meats: A review. Meat Sci. 5:223–232.

Ngoka, D. A., and G. W. Froning, 1982. Effect of free struggle and preslaughter excitement on color of turkey breast muscles. Poultry Sci. 61:2291–2293.

Northcutt, J. K., E. A. Foegeding, and F. W. Edens, 1994. Water-holding properties of thermally preconditioned chicken breast and leg meat. Poultry Sci. 73:308–316.

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

Russell, S. M., 1996. A rapid method for predicting the potential shelf-life of fresh broiler chicken carcasses. J. Food Prot. 60:148–152.

Russell, S. M., D. L. Fletcher, and N. A. Cox, 1996. Spoilage bacteria of fresh broiler chicken carcasses. Poultry Sci. 75: 2041–2047.

SAS Institute, 1988. SAS®/STAT guide for personal computers. Version 6.03 edition. SAS Institute Inc. Cary, NC.

Schermerhorn, E. P., R. L. Adams, and W. J. Stadelman, 1963. Effects of polyphosphates on water uptake, moisture retention, and cooking loss in broilers. Poultry Sci. 42: 107–110.

Steinhauer, J. E., and G. J. Banwart, 1964. The effect of food grade polyphosphates on the microbial population of chicken meat. Poultry Sci. 43:618–625.

Tompkin, R. B., 1983. Indirect antimicrobial effects in foods: Phosphates. J. Food Safety 6:13–27.

Wood, D. F., and J. F. Richards, 1975. Effect of some antemortem stressors on postmortem aspects of chicken broiler *Pectoralis muscle.* Poultry Sci. 54:528–531.

Yang, C. C., and T. C. Chen, 1993. Effects of refrigerated storage, pH adjustment, and marinade on color of raw and microwave cooked chicken meat. Poultry Sci. 72:355–362.

Young, L. L., C. E. Lyon, G. K. Searcy, and R. L. Wilson, 1987. Influence of sodium tripolyphosphate and sodium chloride on moisture-retention and textural characteristics of chicken breast meat patties. J. Food Sci. 52:571–574.

Young, L. L., C. M. Papa, C. E. Lyon, and R. L. Wilson, 1992. Moisture retention and textural properties of ground chicken meat as affected by sodium tripolyphosphate, ionic strength, and pH. J. Food Sci. 57:1291–1293.

Young, L. L., J. K. Northcutt, and C. E. Lyon, 1996. Effect of stunning time and polyphosphates on quality of cooked chicken breast meat. Poultry Sci. 75:677–681.

Zessin, K. G., and L. A. Shelef, 1988. Sensitivity of *Pseudomonas* strains to polyphosphates in media systems. J. Food Sci. 53:669–670.