The Relationship of Broiler Breast Meat Color and pH to Shelf-Life and Odor Development

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

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

ABSTRACT Experiments were conducted to compare the shelf-life of dark-colored and light-colored broiler breast meat. In each of three trials, 100 breast fillets were obtained from a commercial processing plant and subjectively categorized as "dark" or "light". The 100 fillets were then objectively evaluated for C.I.E. color values (lightness, redness, and yellowness). The fillets were separated into five storage groups, with each group containing 10 dark and 10 light fillets, and the fillets were held at 3 C for 0, 3, 6, 9, and 12 d. On each sampling day, fillets were evaluated in duplicate for psychrotrophic plate count (PPC), capacitance detection time (CDT), pH, and subjective odor evaluation. Dark fillets had significantly ($P < 0.05$) lower lightness values (L*), higher redness values (a*), lower yellowness values (b*), and higher pH values. Regression coefficients for odor scores resulted in darker fillets having significantly ($P < 0.05$) higher slopes than lighter-colored fillets even though intercept values were similar. Significant correlations existed between pH and color as well as odor, CDT, and PPC. These data suggest that darker broiler breast meat fillets have a shorter shelf-life than lighter breast fillets; the shorter shelf-life may be due to differences in pH.

(*Key words*: breast meat, spoilage, shelf-life, pseudomonads, meat color)

1997 Poultry Science 76:1042–1046

INTRODUCTION

Approximately 69% of all broiler chicken in the U.S. is sold fresh and 60% is marketed as cut-up parts (National Broiler Council, 1993). In a recent survey conducted by the National Broiler Council (1995), 47% of the families questioned preferred to serve fresh boneless-skinless breasts as opposed to other cuts of chicken. Because most chicken is sold fresh, it is essential to maintain the shelf-life of the product as long as possible. Spoilage of meat depends upon type of packaging, temperature of storage, final composition of the product (addition of antimicrobial substances, oxygen-reduction potential, pH, moisture content), and the number of initial spoilage bacteria (Johnston and Tompkin, 1992).

Barnes and Impey (1968) characterized bacterial isolates from spoiled poultry as pigmented and nonpigmented pseudomonads, *Acinetobacter*, and *Pseudomonas putrefaciens* (now *Shewanella putrefaciens*). Of these bacteria, *P. fluorescens* has been shown to be a primary spoiler of fresh poultry (Russell *et al*., 1995). *Pseudomonas* spp. reside on the exterior of the birds, equipment, walls, floors, and water supply of the processing plant. Psychrotrophic bacteria, such as the pseudomonads, grow well at refrigeration temperatures (3 C), and can multiply on the surface of poultry meat using glucose and other carbohydrates as energy sources. Once glucose has been depleted, bacteria grow by utilizing amino acids found in skin and muscle. Pooni and Mead (1984) reported that amino acid metabolism produces odorous end products, making food unacceptable to the consumer. Cox *et al.* (1975) and Thornley *et al.* (1960) observed that spoilage defects of poultry, such as putrid and ammonia-like odors, occur when spoilage bacterial populations reach 10^6 to 10^7 cells per square centimeter. Research in other meat systems indicates that pH plays an important role in rate of microbial spoilage (Rey *et al*., 1976). The ultimate pH of meat is highly dependent upon the amount of glycogen present in the muscle. This glycogen is depleted in the muscles of birds that have been exposed to stress prior to slaughter (Ngoka and Froning, 1982). Therefore, preslaughter stress may be related to muscle pH.

Fletcher (1995) reported considerable variations in the color of broiler breast meat fillets obtained from commercial processing plants. It was also reported that there was a significant correlation between muscle pH and extremes in color variation. Breast meat may appear darker due to high muscle pH (Livingston and Brown, 1981). These findings were confirmed by Yang and Chen (1993), who observed that ground chicken meat with high pH was darker, redder, and yellower in color than meat with low pH. Cornforth (1994) also stated that meat with a high pH has a higher water-binding capacity, hence making it appear darker.

Received for publication August 19, 1996.
Accepted for publication March 12, 1997.
[1]To whom correspondence should be addressed.

The bacteria associated with white and dark poultry meat have been reviewed (Barnes and Impey, 1968; Barnes, 1976; Lillard and Ang, 1989). It is important to note differences between the two types of meat such as moisture, protein, and fat (Xiong *et al*., 1993), amino acid profile (Hamm, 1981), and heme concentration (Saffle, 1973). However, differences in microbial spoilage of light and dark *Pectoralis major* muscles have not been reported.

This study was conducted to determine whether a relationship exists between broiler breast meat color, pH, and rate of microbial spoilage during storage. The hypothesis was that, if the pH of dark-colored meat is higher than the pH of light-colored meat, perhaps the growth of psychrotrophic bacteria on dark meat will be higher as well.

MATERIALS AND METHODS

In each of three trials, 50 dark and 50 light boneless-skinless *P. major* muscles were collected in a commercial processing plant, immediately following deboning of chilled broiler chicken carcasses. Samples were chosen according to a subjective visual assessment of color based on being either lighter or darker than the average fillet. Samples were collected, placed into sterile polyethylene bags, packed on ice, and transported to the laboratory. Upon arrival at the laboratory, samples were randomly sorted into five groups of 10 samples for each of the two color groups, assigned a storage time (0, 3, 6, 9, or 12 d), and placed into an incubator at 3 C.

Color measurements (L* = lightness, a* = redness, b* = yellowness) were determined in triplicate on all samples within 2 h of collection using a Minolta[2] colorimeter (C.I.E., 1978). Samples were held on ice during color evaluations. All samples were measured in polyethylene bags following calibration with a white reference tile (Y = 88.5, x = 0.310, y = 0.317) also enclosed within a polyethylene bag.

Following incubation at 3 C for 0, 3, 6, 9, or 12 d, 25 g of meat was aseptically removed from each breast sample, added to 225 g of sterile BactoPeptone,[3] and homogenized for 60 s. Psychrotrophic plate counts (PPC) were conducted in duplicate according to the procedure described by Russell (1996b) using Petrifilm®[4] Aerobic Count Plates and incubated at 10 C for 7 d.

Pseudomonas fluorescens were enumerated by determining capacitance measurements on the Bactometer Microbial Monitoring System M128,[5] using the procedure described by Russell (1996a,b). One milliliter of homogenized sample fluid was placed into 9 mL of Brain Heart Infusion (BHI) broth with *P. fluorescens* Selective Additive (PSA) (Russell, 1996b). After vortexing, 1 mL of the BHI-PSA mixture was placed into duplicate Bactometer module wells. Modules were incubated at 25 C for 48 h. Capacitance detection time (CDT) is dependent upon initial concentration of *P. fluorescens*, incubation temperature, and growth kinetics of *P. fluorescens* in BHI-PSA medium.

Subjective odor evaluations were conducted by a three-member panel. Odor scores were determined by opening a sample bag, sniffing the fillet, and recording a score. Scores of 1 to 5 were used according to the following descriptors: 1 = "fresh chicken" odor; 2 = no odor; 3 = slight odor development but still acceptable; 4 = definite off-odor indicative of spoiled chicken; 5 = very strong off-odor associated with spoiled chicken. Scores of 1 to 3 were considered indicative of acceptable meat; whereas, scores of 4 or 5 represented unacceptable and spoiled meat. The scores from the three panel members were averaged, and the mean was used as the score for that fillet.

All pH measurements were conducted on the anterior end of the breast. Two small incisions were made in the muscle, and pH was measured by inserting a probe directly into the fillet. The probe was equipped with an Ion Sensitive Field Effect Transistor sensor, reference electrode, and thermistor. The pH meter[6] was standardized by a two-point method against standard buffers of pH 4.0 and pH 7.0.

The experimental design was a $3 \times 2 \times 5$ factorial with replication, color, and storage day as dependent variables. A total of 300 fillets were used in the study. Data were analyzed using the statistical analyses and General Linear Models (GLM) procedures of SAS® (SAS Institute, 1988). Color values and pH were analyzed using the ANOVA procedure. Correlation coefficients for day, PPC, CDT, pH, odor, L*, a*, and b* were generated using the Pearson's Correlation Coefficient option of SAS® (SAS Institute, 1988). Subjective odor evaluation, PPC, and CDT were analyzed using linear regression models over time. Due to significant replication and color interactions, all data were analyzed by replication. Psychrotrophic plate counts were converted to $\log_{10}$ cfu / mL prior to statistical analyses. Significance levels are reported at the $P < 0.05$ level.

RESULTS AND DISCUSSION

The results of lightness (L*), redness (a*), and yellowness (b*) color values of the breast fillets by treatment and replication are presented in Table 1. Fillets subjectively selected as being "darker" than average had lower L* values (darker), higher a* values (redder), and lower b* values (less yellow) in all three replications than samples chosen as being "lighter" than average. However, for each replication, fillets were subjectively categorized as "light" or "dark" based upon comparison of their color to that of the average fillet processed on the day of selection. Because the color of

[2]Minolta Chroma Meter CR-100, Minolta Corp., Ramsey, NJ 07446.
[3]Difco Laboratories, Detroit, MI 48232.
[4]3M Microbiology Products, St. Paul, MN 55144.
[5]bioMérieux Vitek, Inc., Hazelwood, MO 63042.
[6]Sentron Model 2001, Sentron Inc., Federal Way, WA 98003.

TABLE 2. Correlation analysis of day, psychrotrophic plate count (PPC), capacitance detection time (CDT), pH, odor, lightness (L*), redness (a*), and yellowness (b*)

	Day	L*	a*	b*	pH	PPC	CDT
Odor	0.8709**	–0.2053**	0.2168**	–0.2208**	0.3647**	0.8459**	–0.7325**
CDT	0.7720**	0.1778**	–0.1861**	0.1148*	–0.2524**	–0.8382**	
PPC	0.9355**	–0.0905	0.1042	–0.0539	0.2710**		
pH	0.1703**	0.7465**	0.4377**	–0.4802**			

*$P < 0.05$.

**$P < 0.01$.

the average fillet varied with each replication, the differences in the L* values for fillets in the light and dark categories were not consistent. For the three replications, the difference in L* values between light and dark fillets were 7.9, 4.9, and 6.4, respectively (Table 1). For this reason, as well as the numerous replication by treatment interactions, the data were analyzed by replication and are presented in this manner.

Dark-colored fillets had significantly higher pH values than light-colored fillets for all three replications (Table 1). These findings agree with those reported previously (Livingston and Brown, 1981; Ahn and Maurer, 1990; Yang and Chen, 1993; Fletcher, 1995), in which dark-colored meat was found to have a high ultimate pH. When the pH of the meat is above the isoelectric point of the myofibrillar proteins in the meat, water molecules are tightly bound, causing more light to be absorbed by the muscle, and the meat appears darker in color (Kauffman and Marsh, 1987; Cornforth, 1994). In this study, correlation coefficients between C.I.E. color readings and pH of dark and light-colored breast fillets were highly significant (Table 2). Lightness (L*) and yellowness (b*) were found to correlate negatively to pH, whereas redness (a*) had a positive correlation. Thus, as the pH increased, the lightness and yellowness values decreased, but the redness values increased. Correlation of high pH meat with lower lightness values and higher redness values supports the observations of Yang and Chen (1993), who observed ground chicken meat adjusted to a high pH was darker and redder in color. However, Yang and Chen (1993) reported a positive correlation with pH and yellowness, which was not observed in this study. A positive correlation was noted between pH and day (Table 2), indicating an increase in the pH of fillets as storage time increased. These data supported previous research in which a significant increase in pH of ground chicken meat was observed with increased storage time (Yang and Chen, 1993).

Linear regression of odor scores showed no significant difference ($P > 0.05$) in the intercept values for dark and light samples for each replication (Table 3).

TABLE 3. Regression coefficients for odor score, $\log_{10}$ psychrotrophic plate count (PPC), and capacitance detection time (CDT) of broiler breast meat samples stored for 12 d at 3 C

			Regression coefficients[1]				
Variable	Replicate	Color	Intercept	SE[2]	Slope	SE[2]	R^2
Odor score	1	Dark	1.13	0.11	0.36[a]	0.01	0.92
		Light	1.03	0.07	0.27[b]	0.01	0.95
	2	Dark	1.04	0.13	0.28[a]	0.02	0.84
		Light	1.20	0.11	0.14[b]	0.01	0.66
	3	Dark	0.96	0.10	0.32[a]	0.01	0.92
		Light	1.13	0.10	0.22[a]	0.01	0.84
$\log_{10}$ PPC	1	Dark	3.55[a]	0.16	0.42	0.02	0.89
		Light	2.54[b]	0.17	0.45	0.02	0.89
	2	Dark	2.29	0.15	0.49	0.02	0.92
		Light	2.15	0.17	0.48	0.02	0.90
	3	Dark	2.96	0.14	0.48	0.02	0.93
		Light	3.09	0.14	0.44	0.02	0.92
CDT	1	Dark	20.84[b]	0.64	–1.18	0.09	0.79
		Light	22.87[a]	0.65	–1.23	0.09	0.80
	2	Dark	24.91	1.41	–1.37	0.19	0.52
		Light	25.29	1.16	–1.33	0.16	0.60
	3	Dark	19.35	0.80	–1.36	0.11	0.77
		Light	18.38	0.72	–1.09	0.10	0.72

[a,b]Means within columns and replication with no common superscript differ significantly ($P < 0.05$). n = 100.

[1]For example, odor for dark samples at first replicate = 0.36 (day, between 0 and 12 d) + 1.13.

[2]Standard error of the estimate.

TABLE 1. Lightness (L*), redness (a*), yellowness (b*), and pH values for dark and light[1] broiler breast meat for each replication

Replication	Color	L*	a*	b*	pH
1	Dark	43.7[b]	2.9[a]	0.9[b]	6.22[a]
	Light	51.6[a]	1.4[b]	2.4[a]	5.76[b]
2	Dark	48.5[b]	1.5[a]	3.2[b]	6.08[a]
	Light	53.4[a]	0.6[b]	4.9[a]	5.80[b]
3	Dark	43.2[b]	2.9[a]	1.8[b]	6.22[a]
	Light	49.6[a]	1.5[b]	3.4[a]	5.86[b]

[a,b]Means within columns and replication with no common superscript differ significantly ($P < 0.05$). n = 100.

[1]Dark and light designations were based on visual subjective evaluation during collection.

However, when slope values for odor were analyzed, dark-colored fillets had significantly higher slopes than the light-colored fillets. Therefore, initially, both dark and light fillets had the same odor scores, but dark fillets produced objectionable odors at a faster rate than light fillets. Odor scores for the fillets were found to correlate with both pH and C.I.E. color values (Table 2). This result was to be expected because pH and color values were previously found to be correlated.

Chicken spoilage off-odors can be attributed to the growth of psychrotrophic bacteria degrading amino acids found in the muscle (Pooni and Mead, 1984). Of these psychrotrophic bacteria, *Pseudomonas* spp. and *Shewanella* spp. had been previously identified as the primary bacteria producing sulfurous off-odors associated with spoiled poultry (Ayres *et al*., 1950; Russell *et al*., 1995). Cox *et al*. (1975) and Russell *et al*. (1995) have identified the pigmented and nonpigmented strains of *Pseudomonas* spp. and *S. putrefaciens* as the primary spoilage bacteria isolated from broiler carcasses. Elevated pH and low concentration of glucose substrates in dark meat result in spoilage odors developing at lower bacterial cell densities than under normal conditions (Newton and Gill, 1981). These authors further explain that some spoilage organisms, namely *Altermonas putrefaciens (now S. putrefaciens*), are inhibited by pH of normal meat but proliferate on high pH meat. This effect may explain why the dark-colored samples had more ammonia odor than light-colored samples even when both were considered to be spoiled.

The results for the linear regression of $\log_{10}$ PPC count are presented in Table 3. There was a significant difference in the intercept values of dark and light samples in the first replicate only. Slope values for the two color categories were not significantly different in any of the replications. There was a significant correlation between PPC and pH as well as PPC and odor score (Table 2). Newton and Gill (1981) reported that high pH (> 6.0) does not accelerate growth of spoilage organisms, rather, the lag phase time is reduced. Therefore, the high pH of darker meat shortened the lag phase time of psychrotrophic bacteria, which was confirmed by stronger off-odor production and higher PPC. It is important to note that PPC and C.I.E. color values were not significantly correlated. Results of PPC were therefore dependent upon pH, not the color of fillets directly.

Table 3 shows the results for the linear regression of capacitance detection time for broiler breast meat stored for 12 d at 3 C. Again, there was a significant difference observed in the intercept values for dark and light samples in Replication 1 only. Slope values for dark and light samples were not significantly different. A low CDT in Replication 1 indicates that the dark samples had a greater number of *P. fluorescens* at that particular time of storage. There was a significant negative correlation between CDT and PPC (Table 2). Thus, as PPC increased the CDT decreased. A correlation was also seen between CDT and C.I.E. color values, as well as odor scores. Fillets with a low CDT were seen to have a significantly darker and redder color, higher pH, increased off-odor production, and higher PPC than fillets with a high CDT.

The subjective off-odor evaluations were confirmed by corresponding high PPC and low CDT. Results from this study are similar to reports concerning the microbial growth on pale soft exudative (PSE) and dark, firm, and dry (DFD) pork. Rey *et al*. (1976) and Greer and Murray (1988) reported darker pork as having high pH and reported a significant correlation between bacterial counts and pH. Bacterial lag phase time was found to be shorter with dark-colored (high pH) pork. Growth of the total psychrotrophs and *Pseudomonas* spp. was also higher on dark meat, which affected off-odor production (Greer and Murray, 1988).

The results from this study indicate that variations in broiler breast meat color, due to pH, can be related to differences in the shelf-life of the product. High muscle pH produced conditions that make dark-colored fillets more susceptible to bacterial spoilage than light-colored fillets when held at the same refrigerated storage conditions. It may be advantageous for industry to separate broiler breast meat fillets according to color and to divert dark-colored fillets into further processed products where the shelf-life could be extended. However, it should be noted that during the cooking process, fillets that have a high muscle pH may result in a pink, undercooked appearance (Schmidt and Trout, 1984; Trout, 1989; Yang and Chen, 1993).

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., Hazelwood, MO 63042, for its support, which included the Bactometer Microbial Monitoring System, technical assistance, and supplies. The authors also thank Lynda Jones and Reg Smith for their technical assistance.

REFERENCES

Ahn, D. U., and A. J. Maurer, 1990. Poultry meat color: pH and the heme-complex forming reaction. Poultry Sci. 69: 2040–2050.

Ayres, J. C., W. S. Ogilvy, and G. F. Stewart, 1950. Post mortem changes in stored meats. I. Microorganisms associated with development of slime on eviscerated cut-up poultry. Food Technol. 4:199–205.

Barnes, E. M., 1976. Microbiological problems of poultry at refrigerator temperatures—a review. J. Sci. Food. Agric. 27:777–782.

Barnes, E. M., and C. S. Impey, 1968. Psychrophilic spoilage bacteria on poultry. J. Appl. Bacteriol. 31:97–107.

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

Cornforth, D. P., 1994. Color and Its Importance. Pages 34–78 *in*: Quality Attributes and Their Measurement in Meat, Poultry, and Fish Products. A. M. Pearson and T. R. Dutson, ed. Chapman and Hall, London, UK.

Cox, N. A., B. J. Juven, J. E. Thomson, A. J. Mercuri, and V. Chew, 1975. Spoilage odors in poultry meat produced by pigmented and nonpigmented *Pseudomonas.* Poultry Sci. 54:2001–2006.

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

Greer, G. G., and A. C. Murray, 1988. Effects of pork muscle quality on bacterial growth and retail case life. Meat Sci. 24:61–71.

Hamm, D., 1981. Amino acid composition of breast and thigh meat from broilers produced in four locations of the United States. J. Food Sci. 46:1122–1124.

Johnston, R. W., and R. B. Tompkin, 1992. Meat and Poultry Products. Page 822 *in*: Compendium of Methods for the Microbiological Examination of Foods. C. Vanderzant and D. F. Splittstoesser, ed. American Public Health Association, Washington, D.C.

Kauffman, R. G., and B. B. Marsh, 1987. Quality Characteristics of Muscle as Food. Pages 356–357 *in*: The Science of Meat and Meat Products. 3rd ed. J. F. Price and B. S. Schweigert, ed. Food and Nutrition Press, Inc., Westport, CT.

Lillard, H. S., and C.Y.W. Ang, 1989. Research note: Relationship of microbiological quality and oxidative stability of raw broiler meat during cold storage. Poultry Sci. 68: 1307–1309.

Livingston, D. J., and W. D. Brown, 1981. The chemistry of myoglobin and its reactions. Food Technol. 35:244–252.

National Broiler Council, 1993. Broiler Marketing Practices for Calendar Year 1993. Industry Survey Report. National Broiler Council, Washington, D.C.

National Broiler Council, 1995. Consumer Attitudes About and Usage of Chicken. Presented at the Food Editors' Seminar, 41st National Chicken Cooking Contest, Atlanta, GA.

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.

Pooni, G. S., and G. C. Mead, 1984. Prospective use of temperature function integration for predicting the shelf-life of non-frozen poultry-meat products. Food Microbiol. 1:67–78.

Rey, C. R., A. A. Kraft, D. G. Topel, F. C. Parrish, Jr., and D. K. Hotchkiss, 1976. Microbiology of pale, dark, and normal pork. J. Food Sci. 41:111–116.

Russell, S. M., 1996a. A rapid capacitance method for enumeration of *Pseudomonas fluorescens* and *Pseudomonas putida* from broiler chicken carcasses. J. Food Prot. (in press).

Russell, S. M., 1996b. 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, 1995. Spoilage bacteria of fresh broiler chicken carcasses. Poultry Sci. 74: 2041–2047.

Saffle, R. L., 1973. Quantitative determination of combined hemoglobin and myoglobin in various poultry meats. J. Food Sci. 38:968–970.

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

Schmidt, G., and G. Trout, 1984. pH and color. Meat Ind. 30 (8):33–34.

Thornley, M. J., M. Ingram, and E. M. Barnes, 1960. The effects of antibiotics and irradiation on the *Pseudomonas-Achromobacter* flora of chilled poultry. J. Appl. Bacteriol. 23:487–498.

Trout, G. R., 1989. Variation in myoglobin denaturation and color of cooked beef, pork, and turkey meat as influenced by pH, sodium chloride, sodium tripolyphosphate and cooking temperature. J. Food Sci. 54:536–544.

Xiong, Y. L., A. H. Cantor, A. J. Pescatore, S. P. Blanchard, and M. L. Straw, 1993. Variations in muscle chemical composition, pH, and protein extractability among eight different broiler crosses. Poultry Sci. 72:583–588.

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.