

Moisture content, processing yield, and surface color of broiler carcasses chilled by water, air, or evaporative air

J. Y. Jeong,* K. K. Janardhanan,* A. M. Booren,*† D. M. Karcher,* and I. Kang*†¹

**Department of Animal Science, and †Department of Food Science and Human Nutrition, College of Agriculture and Natural Resources, Michigan State University, East Lansing 48824*

ABSTRACT This study was conducted to investigate the effects of water chilling (WC), air chilling (AC), and evaporative air chilling (EAC) on the moisture content, processing yield, surface color, and visual appearance of broiler carcasses. For the WC treatment, 1 group of birds was hard scalded and submersed into ice slush, whereas for AC, 1 group of birds was soft scalded and exposed to blowing air (1.0 m/s at 0°C) and for EAC, or 1 group of birds was soft scalded and exposed to blowing air and a cold water spray (every 5 min). During chilling, carcass temperature was reduced most effectively by WC (55 min), followed by EAC (120 min) and AC (155 min). After chilling, both WC and EAC

carcasses picked up moisture at 4.6 and 1.0% of their weights, respectively, whereas AC carcasses lost 1.5% of their weight. On cutting at 5 h postmortem, WC carcasses showed the highest (2.5%), EAC showed the second highest (0.4%), and AC showed the least (0.3%) moisture loss. After 24 h of storage, almost 83% of the absorbed water in the WC carcass parts was released as purge, whereas EAC and AC carcasses maintained weights close to the prechilled weights. In an instrumental color evaluation and a visual evaluation by panelists, AC carcasses showed a darker appearance, a more yellow color, and more surface discoloration compared with WC or EAC carcasses.

Key words: water chilling, air chilling, evaporative air chilling, broiler carcass

2011 Poultry Science 90:687–693
doi:10.3382/ps.2010-00980

INTRODUCTION

The 3 most common methods of poultry chilling in industry are air (AC), water (WC), and evaporative air chilling (EAC; Sams, 2001). Previous research has shown that each of the chilling methods results in a different quality of finished products, such as microbial contamination, moisture content, flavor, appearance, and meat texture (Petra et al., 1999; McKee, 2001; James et al., 2006). Chilling of poultry carcasses is necessary to prevent microbial growth, and the United States federal regulations require that the carcass temperature must reach 4.4°C or less within 4 to 8 h, depending on the postslaughter carcass weights (USDA, 2009). Of the 3 methods, WC has traditionally been used in the United States, whereas AC has been commercialized for more than 35 yr in Europe.

Recently, however, AC is gaining in popularity in the United States from both consumers and processors, especially after the revision of the US federal regulations (USDA, 2001) restricting moisture retention on poul-

try carcasses. In AC, cold air is blown into both the abdominal cavity and the exterior of the thick parts (e.g., breast, legs) of the carcass to improve the efficacy and uniformity of chilling (Barbut, 2002). Air chilling, although inferior to WC in chilling efficiency, offers great potential for quality improvement (less cross-contamination and a better taste), minimizes water consumption, reduces waste water management, and is labor saving during or after chilling (Pederson, 1979; Veerkamp, 1989; McKee, 2001).

Air chilling induces a dried carcass appearance compared with WC carcasses, reflecting both moisture and heat loss during the chill (Veerkamp, 1989; Sams, 2001). Weight loss of AC carcasses varies from 0.8 to 2.5% (Veerkamp, 1986; Huezo et al., 2007b), whereas WC carcasses have a significant moisture gain of up to 11.7% (Young and Smith, 2004). The moisture gained in WC, however, is lost throughout further processing and retail display, causing problems such as yield loss, off-odors, an undesirable color, and microbial safety issues (McKee, 2001; Young and Smith, 2004).

Evaporative air chilling, a mixed type of AC and WC, was developed to combine the advantages of both methods. During EAC, cold water is sprayed onto carcasses at periodic intervals while they are moving on the shackle line in an AC room. As a result, EAC can

©2011 Poultry Science Association Inc.
Received June 29, 2010.
Accepted November 12, 2010.
¹Corresponding author: kang@msu.edu

improve heat transfer, minimize weight loss, and reduce skin discoloration compared with AC (Veerkamp, 1989; Barbut, 2002; International Commission on Microbiological Specifications of Foods, 2005). In moisture pick-up, EAC was reported to have from zero change to a minimal change ($\pm 1\%$), depending on the frequency of water spraying and the velocity of cold air (Thomson et al., 1974; Evans et al., 1988; Veerkamp, 1989, 1991).

In scalding, AC requires a soft scald to prevent skin discoloration caused by the loss of the epidermis during picking, whereas the color of WC carcasses is maintained if a hard scald is used (Veerkamp, 1991; Sams, 2001). Evaporative air chilling was initially designed for a hard scald but could also be used with a soft scald (Veerkamp, 1985). It is generally recognized that both chilling methods and scalding types can influence carcass skin color (yellowness or whiteness), swelling, shrinkage, and the finished carcass weight (Veerkamp, 1981, 1986, 1991). Mielnik et al. (1999) found that chicken chilled by EAC had a lighter and less intense yellow color than those chilled by AC because the sprayed water prevented the surface from dehydrating and maintained a lighter skin color. Northcutt (1997) reported that both carcass color and visual appearance are important because consumers receive their first impressions visually, and based on this impression, they often decide whether to buy the product.

Recently, several researchers have evaluated case-by-case effects of either AC and WC, or AC and EAC on fresh broiler meats for quality improvement, chilling yield, and shelf life extension (Mielnik et al., 1999; Young and Smith, 2004; Huezo et al., 2007a,b; Carroll and Alvarado, 2008). However, not much research has been conducted on the effects of the 3 chilling methods (WC, AC, or EAC) on broiler carcass appearance, moisture, and processing yield, especially in the United States. Adapting a new technology with a sizable investment is not an easy decision, especially for poultry plants that already have a WC system. Without practical and scientific information on broiler products chilled by different methods, consumers lack sufficient information to make a purchasing decision. Therefore, the objective of this study was to evaluate the effects of the 3 different chilling methods (WC, AC, and EAC) on broiler carcass quality, including the surface color, visual appearance, and status of moisture change (gain or loss) after chilling and during further processing.

MATERIALS AND METHODS

Broiler Carcass Processing

A total of 99 male birds (Ross 708, approximately 46-d-old broilers; 3 replicates of 33 birds each) were obtained from a local broiler producer. After birds were withdrawn from feed for 12 h and cooped in plastic cages, the birds were transported to the Michigan State

University poultry processing laboratory. On arrival, the birds were shackled, electrically stunned for 3 s (40 mA, 60 Hz, 110 V), and bled for 90 s by severing both the carotid artery and jugular vein on one side of the neck. In each replication, a group of 11 birds was subjected to hard scalding (56.7°C for 120 s) for WC, whereas 2 groups of 11 birds received soft scalding (50°C for 220 s) for either AC or EAC. The birds were defeathered in a rotary drum picker (SP38SS Automatic Pickers, Brower Equipment, Houghton, IA) for 25 s, manually eviscerated, and washed. Carcasses were hung on a shackle, allowed to drain for 5 min, weighed to obtain a prechill weight, and tagged on the wing. The tagged carcasses were assigned to 1 of 3 chilling treatments. Three separate replications from different flocks were conducted using the same procedure on 3 different days.

Chilling Treatments, Deboning, and Storage

In each replication, for the WC treatment, 11 hard-scalded carcasses were submersed in ice slurry (approximately 0.2°C, 7.6 L/bird), with a 30-s agitation every 5 min for the entire chilling period. After chilling, carcasses were hung on shackles, allowed to drain for 5 min, and weighed to obtain a postchill weight. For both AC and EAC, 2 industrial-size fans (BF30DD portable air circulator, Ventamatic Ltd., Mineral Wells, TX) were installed separately to blow cold air toward the carcasses. Two sets of 11 soft-scalded carcasses were randomly hung by the hocks on a stainless steel bar to expose them to either a continuous air flow (1.0 m/s) for AC or both the air flow and 0.4°C water spraying (0.5 L/carcass) by a manual sprayer (RL Pro sprayer 997P, Root-Lowell Manufacturing Co., Lowell, MI) for EAC every 5 min during the chilling. In addition, both temperature ($1.7 \pm 0.4^\circ\text{C}$) and RH ($88 \pm 4\%$; 4410 traceable digital humidity/thermometer, Control Company, Friendswood, TX) of the chilling room were monitored every 15 min. After AC and EAC, the carcasses were removed from the shackles and weighed (postchill weight). For each chilling method, 1 carcass (a medium weight) was used for monitoring the internal breast temperature every 5 min with a digital thermometer/logger (800024, Sper Scientific Ltd., Scottsdale, AZ) until a temperature of 4°C was reached.

Immediately after chilling, each carcass was weighed and the surface skin color was measured instrumentally on both sides of 5 carcass areas (breast, wings, thighs, drumsticks, and scapulae). Carcasses were then individually packaged in freezer bags (S. C. Johnson & Son Inc., Racine, WI) and held on ice in the same chilling room before conducting a visual evaluation approximately 1 h after chilling. Following the evaluation and at 5 h postmortem, all carcasses were fabricated into breast, thighs, drumsticks, and back, each of which was weighed immediately after fabrication, individually placed in a freezer bag, and stored on ice for 24 h.

The following day, all the parts were reweighed to obtain 24-h postfabrication weights. The parts were then deboned, deskinning, vacuum-packaged, and frozen for subsequent moisture determination.

Chilling Yield, Fabrication Yield, and Purge Loss

Four measurements (chilling yield, fabrication yield, purge loss of parts, and total purge loss) were made from 10 carcasses per chilling method as follows:

$$\text{percentage chilling yield} = (\text{postchill carcass weight} / \text{prechill carcass weight}) \times 100\%,$$

$$\text{fabrication yield} = (\text{immediate postfabrication weight of total parts} / \text{prechill carcass weight}) \times 100\%,$$

$$\text{purge loss of each part} = [(\text{immediate postfabrication weight of each part} - \text{24-h postfabrication weight of each part}) / (\text{immediate postfabrication weight of each part})] \times 100\%, \text{ and}$$

$$\text{total percentage purge loss (average)} = [(\text{immediate postfabrication weight of total parts} - \text{24-h postfabrication weight of total parts}) / (\text{immediate postfabrication weight of total parts})] \times 100\%.$$

Color Measurements and Moisture Content Determination

Moisture content of the boneless, skinless meat and the skin color were determined on 10 carcasses per chilling method. Commission Internationale de l'Éclairage (CIE) L^* , a^* , and b^* values (where L^* refers to lightness, a^* refers to redness, and b^* refers to yellowness) were measured on the surface skin of the breast, wings, thighs, drumsticks, and scapulae after chilling, using a chromameter (8-mm aperture, illuminant C; CR-400, Konika Minolta Sensing Inc., Osaka, Japan) that was calibrated with a white plate (L^* , 97.28; a^* , -0.23; b^* , 2.43). Areas were selected that were free of any obvious blood-related defects, such as bruises, hemorrhages, or full blood vessels (Fletcher et al., 2000). Six readings of CIE L^* , a^* , and b^* were obtained for each part (3 readings/side) of the breast, wings, thighs, drumsticks, and scapulae. Moisture content was determined in duplicate on both sides (boneless and skinless) of the 5 carcass parts by the weight loss after 16 to 18 h of drying in a dry oven (Yamato DX 400, Yamato Scientific Co. Ltd., Tokyo, Japan) at 102°C (method 950.46B, AOAC, 2000).

Visual Carcass Evaluations

The visual appearance of 10 carcasses/chilling treatment was assessed by a 10- to 12-member trained panel under fluorescent light (34 W Warm White light; F40/Spec./RS/EW/Alto, Philips Lighting Company, Somerset, Versailles, KY). Panelists consisted of students, staff, and faculty members from Michigan State University. After opening the bags, all carcasses were coded with a 3-digit random number, arranged on white enamel plates, and then sequentially presented to the panelists in a random order. All panelists received the carcasses in the same order. Prior to the evaluation, 3 training sessions were conducted with corresponding photographs, which were prepared from preliminary tests. Through the training, all panelists were trained on responses to obtain a consistent evaluation with the following 9-point scale: intensity of yellow color (9 = extremely yellow, 1 = not yellow), intensity of white color (9 = extremely white, 1 = not white), appearance defects 1 (dark spots; 9 = extreme defects; 1 = no defects), appearance defects 2 (bleached-looking spots; 9 = extremely defects, 1 = no defects), and surface moisture (dryness or wetness; 9 = extremely wet, 1 = extremely dry). The evaluations were performed at the poultry processing facility in the meat laboratory at Michigan State University and were replicated 3 times throughout this study.

Statistical Analysis

All experiments were replicated 3 times. Data were statistically analyzed using the GLM procedure of SAS (SAS Institute, 2002) as a randomized block design. If significance was determined ($P < 0.05$) in the model, dependent variable means were separated using the least significant difference procedure of SAS (SAS Institute, 2002). Visual carcass evaluation data were pooled across panelists and were analyzed as described previously.

RESULTS AND DISCUSSION

The internal carcass temperature was 39.9°C at the beginning and decreased to 4°C, with average chilling times of 55, 155, and 120 min for WC, AC, and EAC, respectively (Figure 1). It is commonly known that immersion carcass chilling in water (45 to 50 min) is more efficient and faster than chilling in air (130 to 150 min; Zhuang et al., 2009; Huezo et al., 2007a,b). Zhuang et al. (2009) reported that the average of initial carcass temperature, when carcasses were commercially obtained and transported to their laboratory, was 32.1°C and reached 4°C in 45 min for WC and in 130 min for AC. In the current study, we noticed slightly longer times (55 and 155 min) for the WC and AC treatments, probably because of the high initial carcass temperature (39.9°C) upon processing on-site, different processing

factors (e.g., water-to-ice ratio, velocity, or air temperature), and different carcass weights. James et al. (2006) showed that the chilling time of poultry carcasses was affected by various factors, such as the carcass weight, water-ice mixture, starting temperature, air velocities, hanging conditions, temperature and humidity of the chilling room, and chilling method.

Evaporative air chilling exhibited a chilling rate between the WC and the AC, probably because the sprayed water improved the evaporative heat loss more than the air, as noted previously (Mielnik et al., 1999; James et al., 2006). Mielnik et al. (1999) reported, based on both temperature differences and known carcass weights, that carcasses subjected to a 50-min EAC lost 1.8 kcal/kg more than carcasses subjected to AC during the same time period. James et al. (2006) summarized results from 3 chilling systems in a review paper and showed that the chilling rate in a water immersion system was far faster than the chilling rate in air, whereas EAC was between the 2.

After chilling, WC carcasses had the highest chilling yield (104.6%), whereas EAC and AC carcasses showed an intermediate yield (101.0%) and the least yield (98.5%), respectively. These results are consistent with previous findings on moisture retention in the order of WC > EAC > AC (Veerkamp, 1981, 1986; Mielnik et al., 1999; ICMSF, 2005; James et al., 2006; Huezio et al., 2007b; Zhuang et al., 2008). Recently, Zhuang et al. (2008) reported that AC carcasses lost 2.4% of their weight after 150 min of chilling, whereas WC carcasses gained 4.6% of their weight after 50 min. Veerkamp (1991) also indicated a weight gain (1.0%) in subscaled broilers when the weight change is carried out by weighing carcasses just prior to the carcass weight equipment and after chilling.

Water-chilled carcasses, after fabrication at 5 h postmortem, resulted in the most weight loss, from 104.6 to 102.1% (2.5%), whereas EAC carcasses had an intermediate decrease, from 101.0 to 100.5% (0.5%), and AC carcasses had the least decrease, from 98.5 to 98.2% (0.3%; Table 1). Young and Smith (2004) compared the moisture retention of WC and AC carcasses after cutting at 24 h postmortem and reported that WC carcasses lost 5.7% of the moisture gained (11.7%) after fabrication, whereas AC carcasses had no loss at all. These results were similar to the results of the cur-

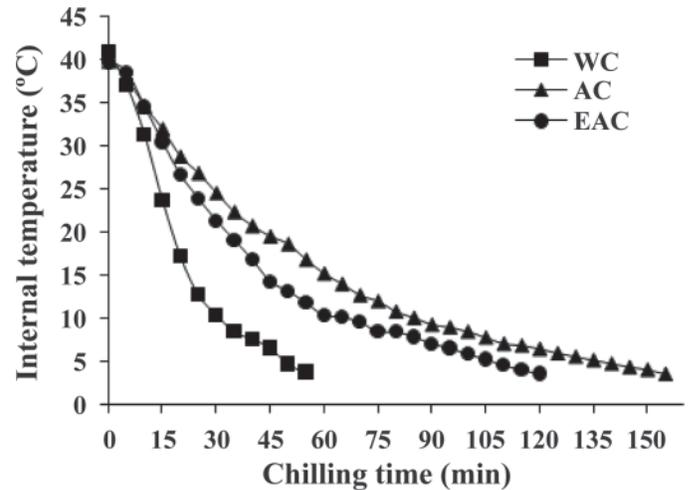


Figure 1. Temperature change profiles of broiler breast fillets during water chilling (WC; ■), air chilling (AC; ▲), or evaporative air chilling (EAC; ●).

rent study, although their timing (24 h postmortem) of carcass fabrication was different from ours (5 h postmortem). The yield difference between the 2 studies could have resulted from different water uptakes (4.6 vs. 11.7%) after chilling and different carcass weights (1,824 vs. 1,328 g) before chilling. Essary and Dawson (1965) showed that the percentage of water uptake was greater in smaller carcasses than in larger ones.

The total purge of the 5 carcass parts (breast, wings, thighs, drumsticks, and back), after cutting up and overnight storage, was significantly greater for WC carcasses (1.3%) compared with AC (0.5%) or EAC carcasses (0.5%; Table 1). This demonstrated that WC carcasses were likely releasing more of the absorbed water than EAC carcasses during cutting and extended storage. Similarly, Young and Smith (2004) reported that WC carcasses had a greater purge than AC carcasses when fore- and hindquarters were stored for 24 h.

Moisture content of the breast and thighs was not significantly affected by the 3 chilling methods, whereas other muscles (wings, drumsticks, and scapulae) showed some variation ($P > 0.05$; Table 2). Similarly, no moisture difference was reported for breast and leg muscles when they were chilled by AC and EAC (Mielnik et al., 1999) or by WC and AC (Zhuang et al., 2008).

Table 1. Chilling yield, fabrication yield, and 24-h purge loss (\pm SEM) of broiler carcasses chilled by 1 of 3 chilling methods

Chilling method	Chilling yield ¹ (%)	Fabrication yield ² (%)	Purge loss of each part (%) ³					Average
			Breast	Wings	Thighs	Drumsticks	Back	
Water	104.6 \pm 0.31 ^a	102.1 \pm 0.22 ^a	1.5 \pm 0.17 ^a	1.1 \pm 0.09 ^a	1.3 \pm 0.19 ^a	0.7 \pm 0.13 ^a	1.4 \pm 0.13 ^a	1.3 \pm 0.19 ^a
Air	98.5 \pm 0.12 ^c	98.2 \pm 0.14 ^c	0.8 \pm 0.09 ^b	0.4 \pm 0.05 ^b	0.2 \pm 0.03 ^b	0.2 \pm 0.03 ^b	0.3 \pm 0.05 ^b	0.5 \pm 0.04 ^b
Evaporative air	101.0 \pm 0.19 ^b	100.5 \pm 0.13 ^b	0.8 \pm 0.06 ^b	0.5 \pm 0.04 ^b	0.2 \pm 0.03 ^b	0.3 \pm 0.04 ^b	0.4 \pm 0.04 ^b	0.5 \pm 0.04 ^b

^{a-c}Means within a column with unlike superscripts are different ($P < 0.05$).

¹Measured immediately after chilling (number of observations in each chilling, $n = 30$).

²Measured after cutting at 5 h postmortem (number of observations in each chilling, $n = 30$).

³Measured after overnight storage (number of observations in each chilling, $n = 30$).

Table 2. Moisture content¹ (\pm SEM) after 24-h storage in 5 different parts² of broiler carcasses chilled by 1 of 3 chilling methods

Chilling method	Breast (%)	Wings (%)	Thighs (%)	Drumsticks (%)	Scapulae (%)
Water	75.7 \pm 0.09 ^a	76.1 \pm 0.14 ^a	76.0 \pm 0.15 ^a	77.6 \pm 0.09 ^b	76.5 \pm 0.13 ^a
Air	75.5 \pm 0.18 ^a	76.1 \pm 0.18 ^a	76.2 \pm 0.14 ^a	77.3 \pm 0.09 ^b	75.9 \pm 0.16 ^b
Evaporative air	75.7 \pm 0.13 ^a	75.5 \pm 0.21 ^b	76.0 \pm 0.13 ^a	77.0 \pm 0.10 ^c	75.1 \pm 0.28 ^c

^{a-c}Means within a column with unlike superscripts are different ($P < 0.05$).

¹Number of observations in each chilling for each part, n = 90.

²Deboned and deskinned.

In the drumsticks and scapulae, moisture content was the highest ($P < 0.05$) for WC samples, followed by AC and EAC samples. Nevertheless, the ranges of moisture content in both drumsticks (77.0 to 77.6%) and scapulae (75.1 to 76.5%) were less than 1.5% across the 3 chilling methods, indicating that moisture changes inside the meat were relatively small, regardless of the chilling method. These results support the view that most absorbed water was loosely held and trapped under the skin or between muscles so that the muscle absorbed the least amount of water, whereas the skin absorbed the greatest (Lentz and Rooke, 1958; Klose et al., 1960).

Chilling methods affected color values (CIE L^* , a^* , and b^*) on the carcass surface (Table 3). The CIE L^* values (lightness) on the skin surface were higher ($P < 0.05$) in WC carcasses for all 5 areas (breast, wings, thighs, drumsticks, and scapulae) than in AC or EAC carcasses, except for the wings and drumsticks in EAC carcasses. Generally, WC carcasses exhibited a lighter surface color for the 5 different locations. It seems that the loss of stratum corneum (the outer layer) from hard scalding and water absorption during WC were responsible for the light scattering and intense lightness (Graf and Stewart, 1953; Sams, 2001; Huezo et al., 2007b). Huezo et al. (2007b) reported that one reason for the significantly lighter (higher L^*) skin in WC than AC carcasses might be the loss of some epidermis during agitation, washing, and carcass-to-carcass contact. On the other hand, AC carcasses always had a darker (lower CIE L^* values; $P < 0.05$) surface than did WC and EAC carcasses for all 5 locations, except for the breast

and thighs in EAC carcasses (Table 3). It was suggested that the skin on AC carcasses dried during cooling, became more translucent, and was darker because the underlying muscle was visible through the skin (Huezo et al., 2007b). Unlike the lighter and darker comparison between WC and AC carcasses, EAC produced mixed outcomes: lower CIE L^* values (darker) in 3 locations (breast, thighs, and scapulae) compared with WC carcasses but higher CIE L^* values (lighter) in 3 locations (wings, drumsticks, and scapulae) compared with AC carcasses. These results can be explained by the exposure of the carcasses to both air and water. Mielnik et al. (1999) and Huezo et al. (2007b) reported that surface dehydration in AC reduced lightness on the carcasses, which could be prevented by water spraying during EAC.

The CIE a^* value for WC carcasses was always the highest (more red; $P < 0.05$) on the 5 carcass parts except the breast, followed by AC and EAC. In contrast, Huezo et al. (2007b) pointed out that the breast skin of WC carcass was significantly less red (lower a^* values) than that of AC carcasses after chilling. These conflicting results might be related to differences in the scalding temperature. In fact, the WC carcasses in this study were hard scalded, whereas soft scalding was used in their study. Nevertheless, Huezo et al. (2007b) observed 2.0 CIE a^* units on the breast skin of soft-scalded AC carcasses after chilling, which was similar to the result in the present study (CIE a^* of 2.1). Evaporative air-chilled carcasses had the lowest ($P < 0.05$) CIE a^* values in all locations except the breast, showing no significant difference (less redness) from AC

Table 3. Surface skin color¹ (\pm SEM) in 5 different locations of broiler carcasses chilled by 1 of 3 chilling methods

Trait and chilling method	Breast	Wings	Thighs	Drumsticks	Scapulae
CIE L^*					
Water	64.9 \pm 0.25 ^a	68.9 \pm 0.16 ^a	68.5 \pm 0.22 ^a	61.5 \pm 0.21 ^a	70.9 \pm 0.16 ^a
Air	63.1 \pm 0.23 ^b	67.2 \pm 0.19 ^b	67.0 \pm 0.32 ^b	59.6 \pm 0.24 ^b	68.9 \pm 0.24 ^c
Evaporative air	63.3 \pm 0.22 ^b	69.3 \pm 0.23 ^a	67.1 \pm 0.33 ^b	61.1 \pm 0.24 ^a	70.2 \pm 0.22 ^b
CIE a^*					
Water	3.2 \pm 0.13 ^a	4.1 \pm 0.12 ^a	3.4 \pm 0.10 ^a	4.0 \pm 0.12 ^a	4.6 \pm 0.15 ^a
Air	2.1 \pm 0.09 ^b	3.2 \pm 0.13 ^b	2.7 \pm 0.13 ^b	3.1 \pm 0.10 ^b	3.3 \pm 0.12 ^b
Evaporative air	1.8 \pm 0.09 ^b	2.7 \pm 0.13 ^c	2.2 \pm 0.12 ^c	2.7 \pm 0.09 ^c	2.8 \pm 0.12 ^c
CIE b^*					
Water	4.7 \pm 0.17 ^a	4.6 \pm 0.16 ^c	2.8 \pm 0.22 ^c	0.9 \pm 0.20 ^c	4.7 \pm 0.22 ^c
Air	4.3 \pm 0.20 ^{ab}	7.0 \pm 0.19 ^a	6.8 \pm 0.30 ^a	2.1 \pm 0.20 ^a	7.7 \pm 0.32 ^a
Evaporative air	3.8 \pm 0.25 ^b	6.0 \pm 0.23 ^b	5.0 \pm 0.38 ^b	1.5 \pm 0.29 ^b	6.5 \pm 0.36 ^b

^{a-c}Means within a color trait and column with unlike superscripts are different ($P < 0.05$).

¹Number of observations in each chilling for each part and color trait, n = 180. CIE = Commission Internationale de l'Éclairage.

Table 4. Mean values¹ (\pm SEM) assigned by trained panelists for the visual appearance of broiler carcasses chilled by 1 of 3 chilling methods

Chilling method	Intensity of yellow color	Intensity of white color	Appearance defects 1 (dark spots)	Appearance defects 2 (bleached-looking spot)	Surface moisture (dryness-wetness)
Water	1.7 \pm 0.06 ^c	4.0 \pm 0.14 ^{ab}	1.6 \pm 0.05 ^c	1.9 \pm 0.09 ^b	7.4 \pm 0.10 ^a
Air	3.8 \pm 0.12 ^a	3.8 \pm 0.11 ^b	4.2 \pm 0.13 ^a	3.8 \pm 0.13 ^a	2.4 \pm 0.12 ^c
Evaporative air	3.1 \pm 0.11 ^b	4.3 \pm 0.12 ^a	1.9 \pm 0.09 ^b	4.0 \pm 0.15 ^a	5.5 \pm 0.12 ^b

^{a-c}Means within a column with unlike superscripts are different ($P < 0.05$).

¹Number of observations in each chilling method for each attribute, $n = 360$; based on a 9-point scale (9 = extremely yellow, extremely white, extreme defects, and extremely wet; 1 = not yellow, not white, no defects, and extremely dry).

carcasses. In a comparison of EAC and AC, Mielnik et al. (1999) reported no significant difference in a^* values on the breast skin, although no additional observations were reported for other locations.

The chilling methods also resulted in different CIE b^* values for carcasses. Water-chilled carcasses were the least yellow (lowest CIE b^* ; $P < 0.05$) among the 3 treatments for the 5 locations, again except for the breast, for which EAC was intermediate between WC (the least) and AC (the most; $P < 0.05$), as in previous results (WC < AC; Huezo et al., 2007b).

Both carcass color and visual appearance are very important because they have a substantial effect on sales appeal. James et al. (2006) reported that different chilling methods can influence product quality and visual appearance. In the present study, the effects of the 3 chilling methods on broiler carcasses were evaluated by trained panelists for 5 visual attributes: 1) intensity of yellow color, 2) intensity of white color, 3) appearance defects 1 (dark spots), 4) appearance defects 2 (bleached-looking spots), and 5) surface moisture (dryness-wetness; Table 4). The yellowness skin score was the highest in AC carcasses, followed by EAC and WC carcasses, which were similar to the instrumental values (CIE b^* ; Table 3 and 4). The intensity of yellowness in AC carcasses has been explained by the retention of epidermal tissue (i.e., stratum corneum; Graf and Stewart, 1953; Thomas et al., 1987; Sams, 2001) and surface dehydration (Mielnik et al., 1999; Huezo et al., 2007b), whereas the least yellowness in WC carcasses has been explained by the removal of the tissue (Thomas and McMeekin, 1980; Thomas et al., 1987, James et al., 2006). Water-chilled carcasses were not different ($P > 0.05$) from AC or EAC carcasses in the intensity of the white color. However, AC carcasses were less white than EAC carcasses (Table 4).

Regarding appearance defects 1 (dark spot), the highest score ($P < 0.05$) was given to AC carcasses, whereas the lowest score ($P < 0.05$) was given to WC carcasses. In carcass surface moisture (dryness vs. wetness), WC carcasses received the highest ($P < 0.05$) wetness score (7.4), AC carcasses received the highest ($P < 0.05$) dryness score (2.4), and EAC carcasses received an intermediate score (5.5). In appearance defects 2 (bleached-looking spots), WC carcasses received

a lower score ($P < 0.05$) than AC and EAC carcasses, which were similar ($P > 0.05$) to each other. These results suggest that the darker color of and dark spots on AC carcasses were related to the combination of the outer skin loss (even though soft scalded) and surface dehydration during AC, which were reduced with water spraying in EAC. Previous research has indicated that AC can cause the carcass skin to have an unattractive appearance because of the drying effect (Veerkamp, 1981; Sams, 2001). However, the visual defects would be of less importance (Corry et al., 2007) as the proportions of cut-up parts (sometimes without skin) and value-added products increase. In 2007, 89% of 9 billion broiler carcasses were sold as cut-up parts or further processed products, and the remainder (11%) were sold as whole carcasses (National Chicken Council, 2009). In addition, the dried skin can rehydrate after packaging, offsetting the defects in appearance (Sams, 2001).

In conclusion, the 3 chilling methods (WC, AC, and EAC) tested in this study affected both carcass appearance and product quality, such as moisture pickup, water retention, and surface color. Water-chilled carcasses resulted in a higher moisture pickup at the end of chilling, but a greater moisture loss occurred during further processing and extended storage. The purge from WC carcasses would induce more microbial contamination and faster spoilage of the final products. However, both AC and EAC showed relatively less moisture gain after chilling and almost no purge during further processing. Although AC carcasses showed darker and more frequent visual defects (dark and bleached-looking spots), the discoloration can be reduced by EAC or is less of a concern as increasing portions of carcasses are processed further. Water chilling appears to be more effective in reducing the temperature during chilling, but AC could provide more advantages after chilling, such as less water consumption, a reduced amount of wastewater, no purge, and a potentially improved shelf life.

ACKNOWLEDGMENTS

The authors thank the Midwest Poultry Consortium (St. Paul, MN) and Michigan Agricultural Experiment Station (East Lansing) for funding for this research.

REFERENCES

- AOAC. 2000. Official Methods of Analysis of AOAC International. 17th ed. AOAC Int., Gaithersburg, MD.
- Barbut, S. 2002. Primary processing of poultry. Pages 81–107 in *Poultry Products Processing: An Industry Guide*. S. Barbut, ed. CRC Press LLC, Boca Raton, FL.
- Carroll, C. D., and C. Z. Alvarado. 2008. Comparison of air and immersion chilling on meat quality and shelf life of marinated broiler breast filets. *Poult. Sci.* 87:368–372.
- Corry, J. E. L., S. J. James, G. Purnell, C. S. Barbedo-Pinto, Y. Chochois, M. Howell, and C. James. 2007. Surface pasteurization of chicken carcasses using hot water. *J. Food Eng.* 79:913–919.
- Essary, E. O., and L. E. Dawson. 1965. Quality of fryer carcasses as related to protein and fat levels in the diet. 1. Fat deposition and moisture pick-up during chilling. *Poult. Sci.* 44:7–15.
- Evans, J. A., D. B. MacDougall, T. C. Grey, and A. J. Gigiel. 1988. Preliminary design data on turkey chilling. Institute of Food Research—Bristol Laboratory: Chemical Engineering Group Industrial Report. Food Refrigeration and Process Engineering Research Centre, University of Bristol, Bristol, UK.
- Fletcher, D. L., M. Qiao, and D. P. Smith. 2000. The relationship of raw broiler breast meat color and pH to cooked meat color and pH. *Poult. Sci.* 79:784–788.
- Graf, R. L., and G. F. Stewart. 1953. Slack vs. sub-scald for broilers. *Poult. Proc. Mark.* 59:12.
- Huezo, R., J. K. Northcutt, D. P. Smith, and D. L. Fletcher. 2007a. Effect of chilling method and deboning time on broiler breast fillet quality. *J. Appl. Poult. Res.* 16:537–545.
- Huezo, R., D. P. Smith, J. K. Northcutt, and D. L. Fletcher. 2007b. Effect of immersion or dry air chilling on broiler carcass moisture retention and breast fillet functionality. *J. Appl. Poult. Res.* 16:438–447.
- International Commission on Microbiological Specifications of Foods. 2005. Poultry products. Pages 108–173 in *Microorganisms in Foods 6: Microbial Ecology of Food Commodities*. 2nd ed. International Commission on Microbiological Specifications of Foods, ed. Kluwer Academic/Plenum Publishers, New York, NY.
- James, C., C. Vincent, T. I. de Andrade Lima, and S. J. James. 2006. The primary chilling of poultry carcasses—A review. *Int. J. Refrig.* 29:847–862.
- Klose, A. A., M. E. Pool, D. De Fremery, A. A. Campbell, and H. L. Hanson. 1960. Effect of lab scale agitation chilling of poultry on quality. *Poult. Sci.* 39:1193–1198.
- Lentz, C. P., and E. A. Rooke. 1958. What changes occur in eviscerating poultry during immersion cooling and drainage. *Food Canada* 18:24–27.
- McKee, S. 2001. Chilling difference. *Watt Poult. USA* 12:18–24.
- Mielnik, M. B., R. H. Dainty, F. Lundby, and J. Mielnik. 1999. The effect of evaporative air chilling and storage temperature on quality and shelf life of fresh chicken carcasses. *Poult. Sci.* 78:1065–1073.
- National Chicken Council. 2009. Statistics & research: How broilers are marketed. Accessed June 2010. http://www.nationalchicken-council.com/statistics/stat_detail.cfm?id=7.
- Northcutt, J. K. 1997. Factors affecting poultry meat quality. *Coop. Ext. Serv. Bull.* 1157. University of Georgia, Athens. Accessed April 2010. <http://pubs.caes.uga.edu/caespubs/pubcd/B1157/B1157.htm>.
- Pederson, R. 1979. Advantages and disadvantages of various methods for the chilling of poultry. Rep. No. 189. Landbrugsministeriets Slakteri-og Konserverlaboratorium, Copenhagen, Denmark.
- Petrak, T., Z. Kalodera, P. Novakovic, and L. Gumhalter Karolyi. 1999. Bacteriological comparison of parallel and counter flow water chilling of poultry meat. *Meat Sci.* 53:269–271.
- Sams, A. R. 2001. First processing: Slaughter through chilling. Pages 19–34 in *Poultry Meat Processing*. A. R. Sams, ed. CRC Press LLC, Boca Raton, FL.
- SAS Institute. 2002. SAS User's Guide. SAS Inst. Inc., Cary, NC.
- Thomas, C. J., and T. A. McMeekin. 1980. Contamination of broiler carcass skin during commercial processing procedures: An electron microscopic study. *Appl. Environ. Microbiol.* 40:133–144.
- Thomas, C. J., T. A. McMeekin, and D. McCall. 1987. Soft scald induced damage of chicken skin. *Br. Poult. Sci.* 28:659–662.
- Thomson, J. E., W. K. Whitehead, and A. J. Mercuri. 1974. Chilling poultry meat—A literature review. *Poult. Sci.* 53:1268–1281.
- USDA. 2001. Performance standards for on-line antimicrobial reprocessing of pre-chill poultry carcasses. Docket No. 98-062P. Food Safety and Inspection Service, USDA, Washington, DC.
- USDA. 2009. Temperatures and chilling and freezing procedures. 9CFR Part 381.66b. Office of Federal Register, National Archives and Records Administration, Washington, DC.
- Veerkamp, C. H. 1981. Evaporative air chilling of sub-scald poultry. *Poult. Int.* 20:16, 18, 20.
- Veerkamp, C. H. 1985. Developments in poultry chilling. *Poult. Int.* 24:68–70.
- Veerkamp, C. H. 1986. Control of weight loss by evaporative air chilling. Recent advances and development in the refrigeration of meat by chilling. Pages 101–105 in *Proceedings of the Meat Chilling Conference*. International Institute of Refrigeration, Langford Institute of Food Research, Bristol, UK.
- Veerkamp, C. H. 1989. Chilling, freezing, and thawing. Pages 103–125 in *Processing of Poultry*. G. C. Mead, ed. Elsevier Applied Science, New York, NY.
- Veerkamp, C. H. 1991. Can evaporative air-chilling control weight loss in cooling? *Misset World Poult.* 7:37–39.
- Young, L. L., and D. P. Smith. 2004. Moisture retention by water- and air-chilled chicken broilers during processing and cutup operations. *Poult. Sci.* 83:119–122.
- Zhuang, H., E. M. Savage, D. P. Smith, and M. E. Berrang. 2008. Effect of dry-air chilling on Warner-Bratzler shear force and water-holding capacity of broiler breast meat deboned four hours postmortem. *Int. J. Poult. Sci.* 7:743–748.
- Zhuang, H., E. M. Savage, D. P. Smith, and M. E. Berrang. 2009. Effect of dry-air chilling on sensory descriptive profiles of cooked broiler breast meat deboned four hours after the initiation of chilling. *Poult. Sci.* 88:1282–1291.