MOISTURE RETENTION AND VISUAL APPEARANCES OF BROILERS CHILLED BY WATER, AIR, OR EVAPORATIVE AIR

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***Abstract*—This study was conducted to evaluate the effects of three chilling methods (water, air, and evaporative air) on processing yields, moisture contents, surface color, and visual appearances of broiler carcasses. To subject to each chilling method, birds were submersed into ice slush for water chilling (WC), exposed to blowing air (1.0 m/sec at 0°C) for air chilling (AC), or evaporative air chilling (EAC) with a cold water (0.4°C) spraying every 5 min. During chilling, carcass temperature was most effectively reduced by WC, followed by EAC and AC. After the chilling, both WC and EAC picked up moisture by 4.6% and 1.5%, respectively while AC lost by 1.5%. Upon cutting and overnight storage, WC carcasses showed a higher moisture loss than those of EAC and AC which were no significantly different. In instrumental and visual color evaluations, AC resulted in darker, yellower color, and larger surface discoloration than WC and EAC.**

***Index Terms*— Air chilling, Broiler carcass, Evaporative air chilling, Water chilling.**

I. INTRODUCTION

Water chill (WC) has been a common chilling method in the United States (U.S.) due to its efficiency and no weight loss. Currently, air chill (AC) technology in U.S. is gaining in popularity for both consumers and processors especially after the revision of US federal regulation (USDA, 2001), restricting moisture retention on poultry carcass. Air chilling was reported to have a great potential for quality improvement (less cross-contamination and better taste), minimized water consumption, and reduced waste water management (McKee, 2001). In 2005, approximately 9 billion chickens in U.S. were processed and 63 billion gallons of water were subsequently consumed (Durham, 2008). In product safety, AC was reported to have lower risk of cross-contamination due to an individual chill than WC, having a communal water-bath (Sanchez, Fluckey, Brashears & McKee, 2002). During the chill, WC was shown to have a significant moisture gain (5.2%) while AC resulted in a weight loss (1.5 – 2%) (James, Vincent, de Andrade Lima & James, 2006; Mickelberry, Schwall & Stadelman, 1962). However, the trapped water during WC comes out throughout the further poultry processing and a retail display that could provide off-odors, undesirable appearance, and safety issues (Young & Smith, 2004; McKee, 2001). Evaporative air chill (EAC) picks up the moisture from zero to negligible amount (1 – 3%) depending on the frequency of water spraying (Thomson, Whitehead & Mercuri, 1974; Veerkamp, 1991). Different chilling methods significantly influence product safety, carcass appearance, and taste quality (James, Vincent, de Andrade Lima & James, 2006). However, limited research has been carried out, in the United States, especially for comparison of all of the three chilling technologies on carcass quality and appearance. Thus, the objective of this study was to evaluate the effects of three chilling methods on moisture gain/loss, visual appearance, and processing yield of broiler carcasses.

II. MATERIALS AND METHODS

A. Broiler carcass processing

A total of 99 male birds (approximately 46-d-old broiler; 33 birds/each replication) were obtained from a local broiler producer. After withdrawal from feed for 12 h, birds were transported to Michigan State University poultry processing facility. Following shackling, birds were electrically stunned (110 V, 1 A for 2 sec) and bled for 90 sec by severing the neck. Per replication, 11 birds were subjected to hard scalding (56.7 °C for 120 sec) for water chilling while an additional two groups of 11 birds received soft scalding (50°C for 220 sec) for either air or evaporative air chilling. The birds were defeathered in a rotary drum picker for 25 sec, manually eviscerated and washed. Each of the carcasses was then hung in shackle to drip for 5 min, weighed, and measured for an internal breast temperature. The resulting carcasses were individually tagged on the wing and assigned to one of 3 chilling treatments. Three separate replications were conducted in the same processing method.

B. Chilling treatments, deboning, and storage

Eleven carcasses from a hard scald were submersed for WC in ice-water slush (0.2 °C, 7.6 L/bird) and manually agitated every 5 min in a chilling tank located in a chilling room (1.7 ± 0.4 °C). At the end of chilling, each carcass was positioned to eliminate water from its internal cavity, hung in shackles to allow 5 min drip, and weighed for a post-chill weight change. For AC or EAC, each soft-scalded carcass was hung by the hocks and exposed to a continuous air flow (1.0 m/sec) in a chilling room. Two industrial-size fans (Model BF30DD, Ventamatic, Ltd., Mineral Wells, TX) were separately installed to blow cold air toward the carcasses of AC and EAC. For EAC, cold water (approximately 0.4 °C) was manually sprayed onto the carcasses (0.5 L/carcass) every 5 min during chilling. In each chilling, a digital thermometer/logger probe (Model 800024, Sper Scientific, Ltd., Scottsdale, AZ) was inserted into the breast center of an extra carcass to monitor the internal temperature every 5 min until it reached to 4 °C. In addition, the chilling room's temperature (1.7 ± 0.4 °C) and relative humidity (RH, 88 ± 4%; Model 4410 traceable digital humidity/thermometer, Friendswood, TX) were recorded every 15 min. Each carcass was removed from the shackle and weighed for a post-chill weight upon chilling completion. Surface skin color was measured on both sides of breast, wing, thigh, drumstick, and scapula. All carcasses were then individually inserted into a freezer bag (S.C. Johnson & Son Inc., Racine, WI) and held in the same chilling room prior to conducting a visual evaluation approximately 20 min later. Following 5 h aging including the time of visual evaluation, carcasses were cut into 5 parts: breast, wing, thigh, drumstick, and backbone. Each part was immediately weighed, individually placed in a freaer bag, and stored on an ice covering for 24 h. All parts were re-weighed the following day for a 24 h post-cut purge, vacuum-packaged, and frozen for a later evaluation of moisture content.

C. Carcass processing yield, visual evaluation, and statistical analysis

Both processing yield and purge loss were calculated from 10 birds per treatment as follows; Chilling yield = [post-chill carcass weight/prior-to-chill carcass weight] × 100. Overall cutting yield = [immediate-cut weight of total parts/post-chill carcass weight] × 100. Overall purge loss = [(immediate-cut weight of total parts – 24 h post-cut weight of total parts)/(immediate-cut weight of total parts)] × 100. Purge loss = [(immediate-cut weight of each part – 24 h post-cut weight of each part)/(immediate-cut weight of each part)] × 100. CIE $L^*a^*b^*$ values were measured on surface skins of breast, wing, thigh, drumstick, and scapula of post-chill carcasses using a chroma meter (CR-400, 8 mm aperture, illuminant C; Konika Minolta Sensing, Inc., Osaka, Japan) calibrated with a white plate (L^* 97.28, a^* -0.23, b^* 2.43). Six readings from each part (3 readings/each side) were obtained from each replication. Moisture contents were determined in duplicate following the method of AOAC (2002). For a carcass visual evaluation, surface color on each of 10 chilled carcasses per treatment was determined by 10 to 12 trained panel members. All carcasses were coded with random numbers, placed on a white enamel plate, and presented to each of panelists. The carcasses were evaluated on a 9-point scale for intensity of yellowness (9 = most yellow, 1 = less yellow), intensity of whiteness (9 = most white, 1 = less white), degree of dark-color defects (9 = extremely defected, 1 = none), degree of bleach-like defects (9 = extremely defected, 1 = none), and degree of dryness or wetness (9 = extremely wet, 1 = extremely dry).

All experiments were replicated three times. Data were statistically analyzed using the general linear model (GLM) procedure of the statistical analysis system (SAS, 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. Visual carcass evaluation data were pooled across panelists and were analyzed as previously described.

III. RESULTS AND DISCUSSION

The internal temperature of eviscerated carcasses averaged 39.9 °C and decreased below 4 °C during chilling in 55, 155, and 120 min for WC, AC, EAC, respectively (Fig. 1). After chilling, WC resulted in the highest ($p < 0.05$) weight gain (4.64%) while AC carcasses lost by 1.49% and EAC maintained as close as the prior-to-chill weight (Table 1). After cutting, carcasses from WC released the highest amount of water and had the lowest ($p < 0.05$) cutting yield among the three chilling (Table 1). In a similar pattern, overall purge loss after 24 h storage was greater ($p < 0.05$) for WC carcasses (1.28%) than those of AC (0.47%) and EAC (0.49%), which were no significantly different (Table 1).

When moisture contents of 24 h-aged carcass parts (breast, wing, thing, drumsticks, and scapula) were measured, no significant difference was found on each of 5 parts among the chilling methods (date not shown). CIE L^* values (lightness) on the surface skins of breast, wing, thigh, drumstick, and scapula were higher ($p < 0.05$) in WC than those of AC or EAC with a few exceptions (Table 2). The results indicated that the loss of *stratum corneum* (outer skin layer) from hard scalding and absorbed water during WC might collaboratively affect the light scattering and increase the intensity of lightness (Huezo, Smith, Northcutt & Fletcher, 2007). CIE a^* values were always higher (more red; $p < 0.05$) for the five parts of WC followed by AC and EAC (Table 2). The chilling methods had influenced on CIE b^*

(yellowness) values of carcass surface (Table 2). Air chilled carcasses resulted in the most yellow color (highest CIE b^*; $p < 0.05$) while WC and EAC had the least and medium, respectively, major carcass parts except the breast portion.

Table 3 shows visual appearances that were scored by trained panelists on broiler carcasses at the end of each chilling. Panelists indicated a similar pattern to the instrumental measurement with significant differences ($p < 0.05$) in yellowness, darkness, and wetness/dryness among the carcasses chilled differently. More specifically, AC carcasses showed the highest scores for yellowness, dryness and appearance-defect than other two treatments. For the intensity of whiteness and appearance defects, AC and WC had the least white and lowest bleach-like defect scores, respectively, than the other chilling methods. The trends of more yellow and darker appearance in AC samples are probably due to the retaining of yellow-pigmented layer (*stratum corneum*) from soft scalding (Sams, 2001) and surface dehydration during the chilling. In bleach-like defects, WC carcasses received a lower score ($p < 0.05$) than AC and EAC carcasses which were similar ($p > 0.05$) to each other.

IV. CONCLUSION

Different chilling methods differently affected broiler carcasses for moisture contents, processing yields and visual appearances. Compare to air-mediated chilling, water chilling resulted in a higher moisture pick-up at the end of chilling, and higher moisture loss during further processing and storage. The moisture gain and loss is expected from the loosely trapped water during the chilling. Considering dryness and no purge, air-mediated chilling appears to be more efficient than the moisture-in and moisture-out WC. In addition, the purge from water chilled carcasses were suggested to induce more cross-contamination and faster spoilage. More importantly, air chill could save from a half to one gallon of water per bird and subsequent waste water. Water chill appears to be effective and economical up to the chilling step, but air chill could provide more advantages thereafter including less water consumption, reduced waste management, no purge, and improved shelf life.

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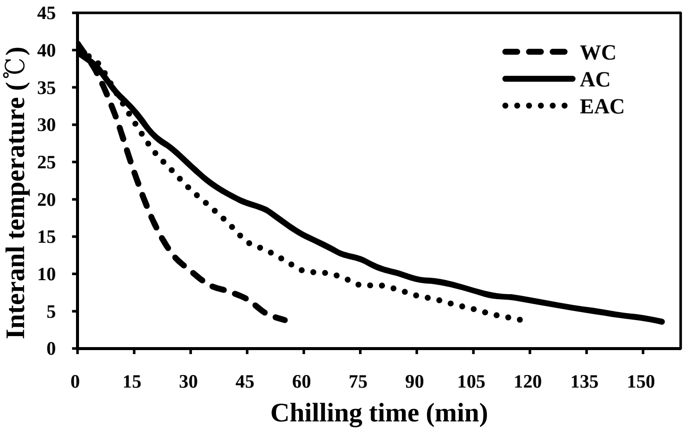

Fig. 1. Temperature change profiles of broiler carcasses fillets during water chilling (WC), air chilling (AC), and evaporative air chilling (EAC).

Table 1. Effects of chilling methods on chilling yield, cutting yield, and 24 h purge loss of broiler carcasses chilled by WC, AC, or EAC

Chilling[1]	Chilling yield (%)[2]	Cutting yield (%)[3]	Purge loss (%)[4]					
			Breast	Wing	Thigh	Drumstick	Backbone	Overall mean
WC	104.64^{a} ± 0.31	98.06^{b} ± 0.19	1.49^{a} ± 0.17	1.07^{a} ± 0.09	1.26^{a} ± 0.19	0.69^{a} ± 0.13	1.42^{a} ± 0.13	1.28^{a} ± 0.19
AC	98.51^{c} ± 0.12	99.72^{a} ± 0.16	0.81^{b} ± 0.09	0.44^{b} ± 0.05	0.23^{b} ± 0.03	0.24^{b} ± 0.03	0.32^{b} ± 0.05	0.47^{b} ± 0.04
EAC	100.98^{b} ± 0.19	99.58^{a} ± 0.18	0.76^{b} ± 0.06	0.54^{b} ± 0.04	0.23^{b} ± 0.03	0.32^{b} ± 0.04	0.35^{b} ± 0.04	0.49^{b} ± 0.04

All values are mean ± standard error of three replicates: n= 30 obervations per means.

[1] Chilling treatments: WC (water chilling), AC (air chilling), EAC (evaporative air chilling).

[2] Carcass weight difference before/after chilling.

[3] Carcass/parts weight difference before/after cutting of 5 h-aged carcass.

[4] Part weight difference before/after 24 h-storage after cutting of the parts.

$^{a-c}$ Means within a columm with unlike superscript letters are different ($p < 0.05$).

Table 2. Effects of chilling methods on surface skin color for five different parts of broiler carcasses

Chilling[1]	Traits	Breast	Wing	Thigh	Drumstick	Scapula
	CIE *L**					
WC		64.94^{a} ± 0.25	68.89^{a} ± 0.16	68.49^{a} ± 0.22	61.46^{a} ± 0.21	70.87^{a} ± 0.16
AC		63.14^{b} ± 0.23	67.18^{b} ± 0.19	66.98^{b} ± 0.32	59.61^{b} ± 0.24	68.90^{c} ± 0.24
EAC		63.32^{b} ± 0.22	69.27^{a} ± 0.23	67.11^{b} ± 0.33	61.13^{a} ± 0.24	70.17^{b} ± 0.22
	CIE *a**					
WC		3.24^{a} ± 0.13	4.14^{a} ± 0.12	3.38^{a} ± 0.10	4.03^{a} ± 0.12	4.62^{a} ± 0.15
AC		2.07^{b} ± 0.09	3.18^{b} ± 0.13	2.70^{b} ± 0.13	3.08^{b} ± 0.10	3.31^{b} ± 0.12
EAC		1.79^{b} ± 0.09	2.71^{c} ± 0.13	2.19^{c} ± 0.12	2.72^{c} ± 0.09	2.80^{c} ± 0.12
	CIE *b**					
WC		4.72^{a} ± 0.17	4.63^{c} ± 0.16	2.82^{c} ± 0.22	0.90^{c} ± 0.20	4.74^{c} ± 0.22
AC		4.32^{ab} ± 0.20	7.00^{a} ± 0.19	6.78^{a} ± 0.30	2.14^{a} ± 0.20	7.65^{a} ± 0.32
EAC		3.75^{b} ± 0.25	5.95^{b} ± 0.23	4.95^{b} ± 0.38	1.47^{b} ± 0.29	6.50^{b} ± 0.36

All values are mean ± standard error of three replicates: n= 180 obervations per means.

[1] Chilling treatments: WC (water chilling), AC (air chilling), EAC (evaporative air chilling).

$^{a-c}$ Means within a columm with unlike superscript letters are different ($p < 0.05$).

Table 3. Effects of three chilling methods on visual appearance of broiler carcasses

Chilling[1]	Intensity of yellow color	Intensity of white color	Appearance defect (dark-spot)	Appearance defect (bleaching)	Degree of dryness/wetness
WC	1.74^{c} ± 0.06	4.00^{ab} ± 0.14	1.57^{c} ± 0.05	1.93^{b} ± 0.09	7.41^{a} ± 0.10
AC	3.84^{a} ± 0.12	3.77^{b} ± 0.11	4.15^{a} ± 0.13	3.78^{a} ± 0.13	2.35^{c} ± 0.12
EAC	3.10^{b} ± 0.11	4.33^{a} ± 0.12	1.90^{b} ± 0.09	3.97^{a} ± 0.15	5.49^{b} ± 0.12

All values are mean ± standard error of three replicates: n= 310 obervations per means.

[1] Chilling treatments: WC (water chilling), AC (air chilling), EAC (evaporative air chilling).

$^{a-c}$ Means within a columm with unlike superscript letters are different ($p < 0.05$).