

# Effect of chilling methods on the surface color and water retention of yellow-feathered chickens

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**ABSTRACT** This study was conducted to investigate the effects of air chilling (AC), water chilling (WC), combined chilling consisting of WC for 20 min and AC (CO<sub>20</sub>), and combined chilling consisting of WC for 30 min and AC (CO<sub>30</sub>) on the microbiological status, surface color, processing yield, and moisture content of yellow-feathered chicken carcasses. After chilling, the carcasses treated by AC exhibited the highest total viable counts (TVC) (4.7 cfu/cm<sup>2</sup>), followed by those treated by CO<sub>20</sub> and CO<sub>30</sub>, whereas the carcasses treated by WC showed the lowest ( $P < 0.05$ ) mean log TVC (4.2 cfu/cm<sup>2</sup>). Based on an instrumental color evaluation and photographs of carcass surfaces, the carcasses treated by AC showed a notable yellow color ( $P < 0.05$ ), whereas no significant difference ( $P > 0.05$ ) was found among the carcasses treated by CO<sub>20</sub>, CO<sub>30</sub>, and WC.

The skin samples of carcass parts treated by WC (breast, thighs, drumsticks, back, neck, and wings) exhibited higher moisture contents than the skin samples of the carcasses treated by AC ( $P < 0.05$ ), providing evidence that weight gain during WC is due to higher water absorption by the skin. The different parts of the broiler carcasses treated by AC had lower cooking losses than those of carcasses treated by combined chilling or WC ( $P < 0.05$ ), except for the thighs and claws. In breast and drumstick muscles, the moisture contents of the superficial parts from carcasses treated by WC were higher than those of the carcasses treated by AC, whereas the internal parts were not significantly affected by the chilling methods ( $P > 0.05$ ). The results of this work can be useful for understanding and improving the chilling process for yellow-feathered chickens.

**Key words:** yellow-feathered chickens, chilling, skin surface color, moisture content, water-holding capacity

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## INTRODUCTION

Yellow-feathered chickens, which are well known for their unique meat flavor, constitute one of the most popular local poultry breeds in Asia (Qi et al., 2017). In China, the production (head units) of live yellow-feathered chickens increased to 4.0 billion in 2016, which was comparable with the production of white-feathered broilers (Zheng et al., 2017). Traditionally, yellow-feathered chickens in China were sold as live chickens and were slaughtered in the wet market. As consumption increased, a new pattern emerged, as yellow-feathered chickens being “slaughtered in large-scale plants and sold with chilled meat” have been advocated nationwide

by the Chinese government (Wang et al., 2018). To meet this demand, innovative solutions may be required to optimize the slaughtering process and to improve the quality and shelf life of yellow-feathered chicken products in the poultry industry.

Carcass chilling is a critical step in poultry processing that influences the safety and quality of the final product. Water chilling (WC), air chilling (AC), and spray (evaporative) chilling are among the most common methods of chilling in the poultry industry (James et al., 2006). A number of research articles have compared different effects of chilling methods on the sensory attributes, bacterial contamination, and meat quality of broilers (Jeong et al., 2011a; Zhuang et al., 2013; Zhang et al., 2015). Further evidence has shown that broiler carcass chilling methods may influence the protein characteristics of the breast muscles and, consequently, lead to differences in meat quality (Bowker et al., 2014). However, there is no information available on yellow-feathered chickens.

The color of chicken carcasses has been considered to be one of the most critical attributes of quality by which consumers often base their quality assessment and

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product selection (Petracci and Fletcher, 2002). Different from white-feathered broilers, the deep yellow skin color of yellow-feathered chickens may be regarded as portraying meat from a healthy and high-quality bird, thereby producing a positive preference in the consumer. Broiler skin pigmentation is dependent on several factors, including genetics (Franco et al., 2012), concentration and dietary source of pigments (Pérez-Vendrell et al., 2001), health status of birds (Tyczkowski et al., 1991), and processing procedure (Suderman and Cunningham, 1980; Jeong et al., 2011b). It was revealed that increasing the scalding temperature removed the cuticle and resulted in a less-yellow skin color of the carcass (Suderman and Cunningham, 1980). Air chilling of carcasses produced a darker appearance, a yellower color, and more surface discoloration than water-chilled or evaporative air-chilled carcasses (Jeong et al., 2011b). Our previous investigation found that WC and AC resulted in obvious differences in the skin color of yellow-feathered broilers, especially with respect to yellowness, which is crucial for acceptance by the consumer (no publication). Therefore, considering the consumer's preference, more targeted studies will be needed to control for the parameters of the chilling process. Another concern with chilling systems is weight losses or gains during the chilling process. James et al. (2006) summarized that water losses of 1 to 1.5% in AC are common and can be up to 3%. Strong evidence of water absorption (4–8%) during the WC process has been shown in some studies (Zhuang et al., 2008; Perumalla et al., 2011). Afterward, the absorbed water is not normally retained after chilling, which results in drip loss (Huezo et al., 2007a). Jeong et al. (2011b) supported the view that most of the absorbed water was loosely held and trapped under the skin or between muscles and the skin absorbed the highest amount of water. However, there is a lack of information about the distribution of absorbed water in carcasses treated by WC.

Considering the very limited information that is available on the possible variation of quality attributions with respect to different chilling systems, the methods of AC and WC as well as the combined methods of using both water immersion and AC were investigated. The objective of this study was as follows: (i) to reveal the processing yield and quality attributes of yellow-feathered chickens in response to commercially available chilling systems, (ii) to explore the appropriate chilling conditions for processing, and (iii) to identify the water distribution of carcasses during processing. The findings of this study could provide new information for optimizing the slaughtering process for yellow-feathered chickens.

## MATERIALS AND METHODS

### Sampling

A total of 184 yellow-feathered broilers (male, approximately aged 75 D, 2 batches of 92 broilers each) were

obtained from a commercial chicken processing facility from October to November. Chickens were first manually exsanguinated using a knife, and then they were stunned with electricity (70 V for 8 s: alternating current) according to Islamic rules. Then, the carcasses were bled for 7 min, scalded at 60°C to 63°C for 120 s, and then defeathered mechanically, eviscerated manually, and washed. The average weight of the carcasses before chilling was  $2,147 \pm 32$  g. The sampling procedures were approved by the Animal Care and Use Committee of the Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences, and were performed in accordance with the animal welfare and ethical standards.

### Chilling Treatments

The tagged carcasses were assigned to 4 chilling treatments. For each treatment, 28 carcasses were subjected to AC or WC. Eighteen carcasses were subjected to a combination of WC for 20 min and AC (CO<sub>20</sub>) or combination of WC for 30 min and AC (CO<sub>30</sub>). For each treatment per batch, 3 carcasses were selected for continuous (10 min) monitoring of the internal breast temperature, which was monitored using a thermometer, until the temperature reached 4°C.

Treatment 1 (AC): Carcasses were chilled in a 180 m<sup>2</sup> refrigerated room (at 2°C, 85–90% relative humidity, and 2.93 m/s air velocity) for 40 min and were then transferred to a freezer room (at –18°C, 2.93 m/s of air velocities) for 80 min.

Treatment 2 (WC): Water chilling was conducted in a pilot-scale chiller tank that was filled with 120 L of a mixture of ice and tap water without agitation (0°C–4°C during chilling processing) for 80 min. The effective chlorine level in the water was 80 ppm (effective chlorine test paper, Oasis Bio-Chem, Guangdong, China). After chilling, the carcasses were hung to drain for 5 min and were weighed to obtain the post-chilling weight.

Treatment 3 (CO<sub>20</sub>): The carcasses were chilled in a water tank for 20 min, moved to a refrigerated room for 40 min, and then transferred to a freezer room for 20 min.

Treatment 4 (CO<sub>30</sub>): Carcasses were chilled in a water tank for 30 min, moved to a refrigerated room for 40 min, and then transferred to a freezer room for 20 min.

After chilling, the carcasses were divided into 2 groups. One group was analyzed immediately to determine the total viable counts (TVC), surface color, and moisture content. Another group was stored in the chilling room at 4°C for 24 h. The following day, the carcasses were reweighed to obtain the storage yield. Then, all the carcasses were divided into breast, thighs, drumsticks, scapulae, neck, wings, and claws, each of which was weighed, packed in a plastic bag, and kept on ice before cooking.

## Total Viable Counts

Microbiological sampling was performed by using the swabbing method. A pooled sample consisted of 6 cotton swabs corresponding to one sampling carcass area of 60 cm<sup>2</sup>, that is, 12 sampling sites (2 sites for each cotton swab) with one sampling area of 5 cm<sup>2</sup> (5 × 1 cm). The sampling sites of the skin on the carcass were selected according to Gill et al. (2006) with some modifications. The collection areas of the neck, butt, breast, back, wing, thigh, and drumstick were 5 cm<sup>2</sup>, 5 cm<sup>2</sup>, 10 cm<sup>2</sup>, 10 cm<sup>2</sup>, 10 cm<sup>2</sup>, and 10 cm<sup>2</sup>, respectively. At each sampling site, a sterile moistened (0.9% sodium chloride solution) swab was rubbed vertically, as delineated by a template. After swabbing, 6 tampon swabs from one carcass were placed into tubes with 60 mL of sterile 0.9% NaCl solution. The contents of the swabs were extracted into the diluent by agitating on a vortex-type mixer for 1 min. Then, the extracted content was serially diluted (1:10) in sterile 0.9% NaCl. Samples (1 mL) of serial dilutions were plated onto plate count agar and were incubated at 37 ± 1°C for 48 h to calculate the TVC. The measurement of TVC was carried out in triplicate per batch for each treatment.

## pH and Shear Force

pH and shear force measurements were performed in 5 replicates for the breast, thigh, and drumstick muscles. The muscle pH was measured using a pH meter with a spear-shaped probe (Testo 205, Testo AG, Lenzkirch, Germany). Samples (1.5-cm wide, 1.5-cm high, and 4.0-cm long) of raw meat were taken in parallel to the muscle fiber direction and were sheared perpendicularly to the longitudinal orientation of the muscle fiber by using a Warner-Bratzler probe (C-LM 3, Digital Meat Tenderness Meter, College of Engineering, Northeast Agricultural University, Harbin, China). The samples were cut from the superficial and center portion of the breast and thigh muscle. Owing to muscle variation and irregular alignment of the muscle fibers, muscles from drumsticks were collected from the same area so that the samples could be cut in dimensions of 1.5 × 1.5 × 4.0 cm. The test speed was 5 mm/s. The shear force value (N) was calculated as the maximum force recorded during the shear.

## Color and Photography

Commission International de l'Éclairage (CIE) lightness (L\*), redness (a\*), and yellowness (b\*) values were measured on the skin surfaces of the breast, thighs, drumsticks, neck, wings, scapulae, and belly using a Minolta Chroma Meter CR-400 colorimeter (Minolta, Osaka, Japan). Areas that were free of any obvious blood-related defects were selected. Three readings of CIE L\*, a\*, and b\* were averaged for each value. Photos of the chilled carcasses were taken using a smartphone camera (Galaxy A7 SM-7000, Samsung Electro-Mechanics, Tianjin, China).

## Weight Changes

Weight changes (%) (10 replicates per batch in each treatment) were measured as the weight differences among carcasses before and after chilling, after storage, and after cutting, which were expressed as a percentage of the initial weight of the carcasses before chilling:

$$\text{Weight change after chilling (\%)} = \frac{W_{chill2} - W_{chill1}}{W_{chill1}} \times 100\%$$

$$\text{Weight change after storage (\%)} = \frac{W_s - W_{chill1}}{W_{chill1}} \times 100\%$$

$$\text{Weight change after cutting (\%)} = \frac{W_{cut} - W_{chill1}}{W_{chill1}} \times 100\%$$

where  $W_{chill1}$ ,  $W_{chill2}$ ,  $W_s$ , and  $W_{cut}$  represent the weight (g) of the carcasses before chilling, after chilling, after 24-h postmortem storage, and after cutting (weight of total parts), respectively.

## Purge Loss, Cutting Loss, and Cooking Loss

The purge loss was calculated as the weight loss of the carcasses during storage and was expressed as a percentage of the carcass weight before storage (after chilling):

$$\text{Purge loss} = \frac{W_s - W_{chill2}}{W_{chill2}} \times 100\%$$

The cutting loss was calculated as the weight loss of the carcasses during cutting and was expressed as a percentage of the carcass weight before cutting (after storage):

$$\text{Cutting loss} = \frac{W_{cut} - W_s}{W_s} \times 100\%$$

After cutting, the cooked chicken samples of each cut were prepared by steaming for 20 min. The cooking loss was measured as the weight loss during cooking, which was expressed as a percentage of the initial weight of each raw cut:

$$\text{Cooking loss} = \frac{W_{cut0} - W_{cut1}}{W_{cut0}}$$

where  $W_{cut0}$  and  $W_{cut1}$  represent the weight (g) of each cut before and after cooking, respectively.

The measurements were carried out in 10 replicates per batch for each treatment.

## Moisture Content

The moisture contents of skin and meat from carcasses treated by AC and WC were determined after chilling, storage, and cooking. Six different parts of the skin,

**Table 1.** Means ( $\pm$ SEM<sup>1</sup>) of TVC,<sup>2</sup> pH,<sup>3</sup> and shear force<sup>4</sup> of yellow-feathered chickens chilled by different chilling methods.

Different parts	Chilling methods			
	AC <sup>5</sup>	CO <sub>20</sub> <sup>5</sup>	CO <sub>30</sub> <sup>5</sup>	WC <sup>5</sup>
TVC (lg [cfu/cm <sup>2</sup> ])	4.7 $\pm$ 0.1 <sup>a</sup>	4.6 $\pm$ 0.1 <sup>a,b</sup>	4.5 $\pm$ 0.1 <sup>b</sup>	4.2 $\pm$ 0.1 <sup>c</sup>
pH				
Breast	5.83 $\pm$ 0.03 <sup>a,b</sup>	5.93 $\pm$ 0.04 <sup>b</sup>	5.77 $\pm$ 0.06 <sup>a</sup>	5.90 $\pm$ 0.04 <sup>b</sup>
Thighs	6.47 $\pm$ 0.06 <sup>a</sup>	6.48 $\pm$ 0.04 <sup>a</sup>	6.46 $\pm$ 0.16 <sup>a</sup>	6.61 $\pm$ 0.05 <sup>a</sup>
Drumsticks	6.68 $\pm$ 0.04 <sup>a,b</sup>	6.63 $\pm$ 0.05 <sup>a,b</sup>	6.55 $\pm$ 0.18 <sup>a</sup>	6.70 $\pm$ 0.05 <sup>b</sup>
Shear force				
Breast	39.0 $\pm$ 2.3 <sup>a,d</sup>	40.4 $\pm$ 1.4 <sup>a</sup>	41.6 $\pm$ 1.4 <sup>a</sup>	42.8 $\pm$ 2.5 <sup>a</sup>
Thighs	57.1 $\pm$ 3.5 <sup>a</sup>	58.6 $\pm$ 3.2 <sup>a,b</sup>	67.1 $\pm$ 2.3 <sup>b</sup>	59.7 $\pm$ 2.8 <sup>a,b</sup>
Drumsticks	38.5 $\pm$ 1.7 <sup>a</sup>	42.8 $\pm$ 1.6 <sup>a</sup>	40.1 $\pm$ 2.2 <sup>a</sup>	43.1 $\pm$ 1.5 <sup>a</sup>

<sup>a-c</sup>Means within a row lacking a common superscript differ significantly ( $P < 0.05$ ).

Abbreviation: TVC, total viable count.

<sup>1</sup>SEM: standard error of the mean.

<sup>2</sup>Means with 6 replicates per treatment.

<sup>3</sup>Means with 10 replicates per treatment.

<sup>4</sup>Means with 10 replicates per treatment.

<sup>5</sup>AC: air chilling; WC: water chilling; CO<sub>20</sub>: combined method of WC for 20 min and AC; CO<sub>30</sub>: combined method of WC for 30 min and AC.

including breast, thighs, drumsticks, back, neck, and wing of yellow-feathered chickens, were excised without meat using a scalpel. Then, the meat samples from the breast, thigh, and drumstick were collected. The test was performed on both the superficial layer (from the surface of skinless carcass to  $\sim 0.5$  cm below) and the deep layer (from  $\sim 0.5$  cm below the surface to the internal bone) of meat considering 5 replicates per each batch. Approximately 2 g of minced skin or meat was put in a preweighed weighing disk, dried in an oven at

105  $\pm$  1°C for 12 h, cooled for 30 min, and then reweighed (AOAC 950.41B, 1991).

### Statistical Analysis

Two individual experimental trials were carried out. Data were analyzed using the general linear model procedures of the SPSS 19.0 software package (SPSS, Chicago, IL). Chilling methods were included as a fixed factor, and experimental trials were used as a random factor.

**Table 2.** Surface skin color ( $\pm$ SEM) of 7 different locations of yellow-feathered chickens chilled by different chilling methods (n = 26~30).

Different parts	Chilling methods			
	AC	CO <sub>20</sub>	CO <sub>30</sub>	WC
L*				
Breast	68.2 $\pm$ 0.7 <sup>a</sup>	76.6 $\pm$ 0.5 <sup>b</sup>	76.2 $\pm$ 0.3 <sup>b</sup>	76.2 $\pm$ 0.4 <sup>b</sup>
Thighs	67.8 $\pm$ 1.0 <sup>a</sup>	76.2 $\pm$ 0.5 <sup>b</sup>	75.3 $\pm$ 0.6 <sup>b,c</sup>	77.5 $\pm$ 0.5 <sup>d</sup>
Drumsticks	67.5 $\pm$ 0.7 <sup>a</sup>	73.6 $\pm$ 0.5 <sup>b,c</sup>	73.0 $\pm$ 0.5 <sup>b</sup>	74.8 $\pm$ 0.5 <sup>c</sup>
Back	70.2 $\pm$ 0.8 <sup>a</sup>	78.0 $\pm$ 0.3 <sup>b</sup>	77.5 $\pm$ 0.5 <sup>b</sup>	78.2 $\pm$ 0.4 <sup>b</sup>
Neck	73.8 $\pm$ 0.7 <sup>a</sup>	77.2 $\pm$ 0.5 <sup>b,c</sup>	78.0 $\pm$ 0.5 <sup>c</sup>	76.0 $\pm$ 0.5 <sup>b</sup>
Wings	72.0 $\pm$ 0.8 <sup>a</sup>	77.1 $\pm$ 0.3 <sup>b</sup>	77.0 $\pm$ 0.4 <sup>b</sup>	77.4 $\pm$ 0.4 <sup>b</sup>
Belly	68.8 $\pm$ 0.8 <sup>a</sup>	75.6 $\pm$ 0.4 <sup>b</sup>	75.6 $\pm$ 0.4 <sup>b</sup>	75.5 $\pm$ 0.5 <sup>b</sup>
a*				
Breast	4.9 $\pm$ 0.5 <sup>a</sup>	3.3 $\pm$ 0.5 <sup>b</sup>	2.4 $\pm$ 0.4 <sup>b</sup>	2.8 $\pm$ 0.3 <sup>b</sup>
Thighs	3.5 $\pm$ 0.3 <sup>a</sup>	2.3 $\pm$ 0.3 <sup>b</sup>	1.5 $\pm$ 0.2 <sup>b</sup>	1.6 $\pm$ 0.2 <sup>b</sup>
Drumsticks	2.8 $\pm$ 0.2 <sup>a</sup>	1.5 $\pm$ 0.2 <sup>b</sup>	2.3 $\pm$ 0.2 <sup>a</sup>	1.4 $\pm$ 0.2 <sup>b</sup>
Back	5.8 $\pm$ 0.3 <sup>a</sup>	3.7 $\pm$ 0.3 <sup>b</sup>	3.8 $\pm$ 0.3 <sup>b</sup>	3.3 $\pm$ 0.3 <sup>b</sup>
Neck	8.4 $\pm$ 0.5 <sup>a</sup>	6.3 $\pm$ 0.4 <sup>b</sup>	5.6 $\pm$ 0.3 <sup>b</sup>	5.7 $\pm$ 0.3 <sup>b</sup>
Wings	5.5 $\pm$ 0.4 <sup>a</sup>	3.3 $\pm$ 0.2 <sup>b</sup>	3.6 $\pm$ 0.2 <sup>b</sup>	3.2 $\pm$ 0.2 <sup>b</sup>
Belly	6.2 $\pm$ 0.7 <sup>a</sup>	4.1 $\pm$ 0.5 <sup>b</sup>	4.4 $\pm$ 0.5 <sup>b</sup>	3.5 $\pm$ 0.4 <sup>b</sup>
b*				
Breast	20.9 $\pm$ 1.0 <sup>a</sup>	13.5 $\pm$ 1.0 <sup>b</sup>	13.0 $\pm$ 0.7 <sup>b</sup>	10.5 $\pm$ 0.5 <sup>c</sup>
Thighs	20.8 $\pm$ 1.3 <sup>a</sup>	11.8 $\pm$ 0.7 <sup>b</sup>	10.4 $\pm$ 0.8 <sup>b</sup>	9.4 $\pm$ 0.4 <sup>b</sup>
Drumsticks	12.0 $\pm$ 1.0 <sup>a</sup>	6.5 $\pm$ 0.6 <sup>b</sup>	7.5 $\pm$ 0.9 <sup>b</sup>	6.0 $\pm$ 0.7 <sup>b</sup>
Back	26.3 $\pm$ 1.2 <sup>a</sup>	16.8 $\pm$ 0.6 <sup>b</sup>	16.5 $\pm$ 0.7 <sup>b</sup>	13.9 $\pm$ 0.5 <sup>c</sup>
Neck	20.7 $\pm$ 0.6 <sup>a</sup>	17.9 $\pm$ 0.9 <sup>b</sup>	17.4 $\pm$ 0.8 <sup>b</sup>	15.1 $\pm$ 0.7 <sup>c</sup>
Wings	17.2 $\pm$ 1.1 <sup>a</sup>	12.1 $\pm$ 0.4 <sup>b,c</sup>	14.4 $\pm$ 2.2 <sup>a,b</sup>	10.2 $\pm$ 0.5 <sup>c</sup>
Belly	22.7 $\pm$ 1.3 <sup>a</sup>	14.7 $\pm$ 0.8 <sup>b</sup>	15.4 $\pm$ 0.7 <sup>b</sup>	12.1 $\pm$ 0.9 <sup>c</sup>

<sup>a-c</sup>Means within a row lacking a common superscript differ significantly ( $P < 0.05$ ).

Abbreviations: a\*, redness; AC, air chilling; b\*, yellowness; CO<sub>20</sub>, combined method of WC for 20 min and AC; CO<sub>30</sub>, combined method of WC for 30 min and AC; L\*, lightness; SEM, standard error of the mean; WC, water chilling.

Tukey's Honestly Significant Difference (**HSD**) test was used to identify significant differences at  $P < 0.05$ . Data are presented as mean values  $\pm$  standard deviation.

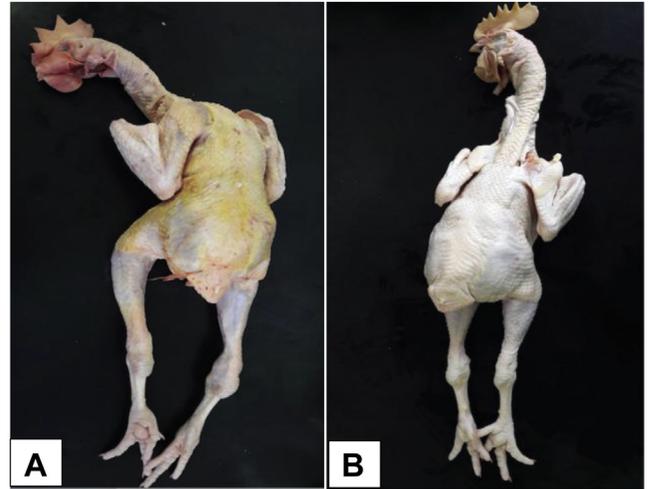
## RESULTS AND DISCUSSIONS

### TVC, pH, and Shear Force

The effect of different chilling systems on the bacterial load of chicken carcasses is of continuing concern (Berrang et al., 2008; Zhang et al., 2015). In the present study, carcasses treated by AC exhibited the highest TVC ( $4.7 \text{ cfu/cm}^2$ ), followed by those treated by combined chilling ( $\text{CO}_{20}$  and  $\text{CO}_{30}$ ), and carcasses treated by WC showed the lowest ( $P < 0.05$ ) mean log TVC ( $4.2 \text{ cfu/cm}^2$ ) (Table 1). These levels of bacterial counts are comparable with those reported in poultry processing (Demirok et al., 2013). The significant reduction in bacterial counts for carcasses treated by WC could be due to the washing effect and the chlorination of chilling water (Blood and Jarvis, 1974). This was in accordance with the study by Berrang et al. (2008) who found that the difference in counts attributable to the utilization of the chilling method was approximately  $0.5 \text{ log cfu/mL}$  of the half-carcass rinse. These authors also indicated that there was no clear microbiological reason to suggest one chilling method over the other. Breast meat had the lowest pH, with an average value of 5.86 compared with the values obtained for the thigh and drumstick meat ( $P < 0.05$ ). Compared with the  $\text{CO}_{30}$  treatment, the WC treatment resulted in an increase in the pH value of breast and drumstick meat (Table 1,  $P < 0.05$ ). None of these chilling treatments resulted in a significant difference ( $P > 0.05$ ) in the shear force of the chicken breast or drumstick meat (Table 1). This finding is consistent with a previous report that the shear force of breast fillets was similar between carcasses treated by AC and WC (Jeong et al., 2011a; Zhuang et al., 2013). Nevertheless, several studies indicated that breast fillets treated by WC exhibited higher shear force values than fillets treated by AC (Demirok et al., 2013; Bowker et al., 2014). It has been suggested that the differences among the age, genetic strain, deboning time, and rigor development may be a potential explanation for these variations (Demirok et al., 2013; Huezo et al., 2007a). However, only the shear force of raw meat was evaluated in the present study. Further investigations may be needed to assess the cooked meat quality.

### Color

Carotenoids and melanin are compounds that are responsible for skin color in chicken carcasses (Castaneda et al., 2005; Yu et al., 2018). Xanthophylls, which form a particular class of carotenoids, are the most prominent source of pigmentation in chicken feeds (Castaneda et al., 2005). Evidence has shown that the content of xanthophylls in broiler dietary grain sources affected the pigmentation of the skin of yellow-skinned



**Figure 1.** Representative photographs of yellow-feathered broiler carcass after air chilling (A) and water chilling (B).

chickens (Peng et al., 2017). During processing, scalding and chilling are important steps that may influence the surface color of carcass skin (Heath and Thomas, 1974; Jeong et al., 2011b). According to the results of the present study, carcasses treated by AC showed the lowest ( $P < 0.05$ ) CIE  $L^*$  values compared with those treated by the other 3 chilling methods (Table 2). For redness and yellowness, the CIE  $a^*$  and  $b^*$  values were the highest ( $P < 0.05$ ) for each of the 7 parts of carcasses treated by AC, and generally, no significant difference ( $P > 0.05$ ) was found among the carcasses treated by  $\text{CO}_{20}$ ,  $\text{CO}_{30}$ , and WC. These observations are consistent with the previous report that the breast skin of carcasses treated by WC was significantly lighter (higher  $L^*$ ), less red (lower  $a^*$ ), and less yellow (lower  $b^*$ ) than that of carcasses treated by AC (Huezo et al., 2007b). It is worth noting that the  $L^*$ ,  $a^*$ , and  $b^*$  values from the AC treatment in the present study were much higher than the values that were reported by Huezo et al. (2007b) ( $L^* = 68.2$ ,  $a^* = 4.9$ , and  $b^* = 20.9$  of breast vs.  $L^* = 57.1$ ,  $a^* = 2.0$ , and  $b^* = 5.1$  of breast, respectively). Especially, for the  $b^*$  values, our results for different parts of broiler carcasses (ranging from 6.0–26.3) were much higher than those that were observed by Jeong et al. (2011b), who obtained  $b^*$  values from white-feathered broilers (ranging from 0.9–7.0). These differences can be explained by the genetic strain effects (Lopez et al., 2011). It has been widely accepted that WC improves the appearance and color and AC causes discoloration of the surface of carcasses (Zhuang et al., 2013). However, in the present study, only AC led to the desirable and traditional yellow color of carcass surfaces when the yellow-feathered chickens were hard scalded. This information could be useful for producers.

The photographs in Figure 1 clearly reveal the visual differences between the surface colors of carcasses treated by AC and WC. The surfaces of yellow-feathered broiler carcasses treated by AC were yellower and heavier than carcasses treated by WC, confirming the CIE  $L^*$ ,  $a^*$ , and  $b^*$  values. It was suggested that the dried skin of

carcasses treated by AC becomes thin and translucent; thus, the underlying muscle increases the redness and yellowness (Huezo et al., 2007b). Moreover, the moisture content of skin treated by AC was significantly lower than that of skin treated by WC ( $P < 0.05$ , Figure 2), which may deepen the yellow appearance of surface skin. This appearance may occur because the carcasses treated by CO<sub>20</sub> and CO<sub>30</sub> showed a similar color pattern as that of carcasses treated by WC. In fact, broilers treated by CO<sub>20</sub> and CO<sub>30</sub> were immersed in a water tank for just 20 and 30 min, respectively, indicating that even a short immersion time could also result in a less-yellow skin surface of yellow-feathered broilers. Therefore, considering the preference of the consumer, it is important for manufacturers to control the immersion time or to avoid using a WC system.

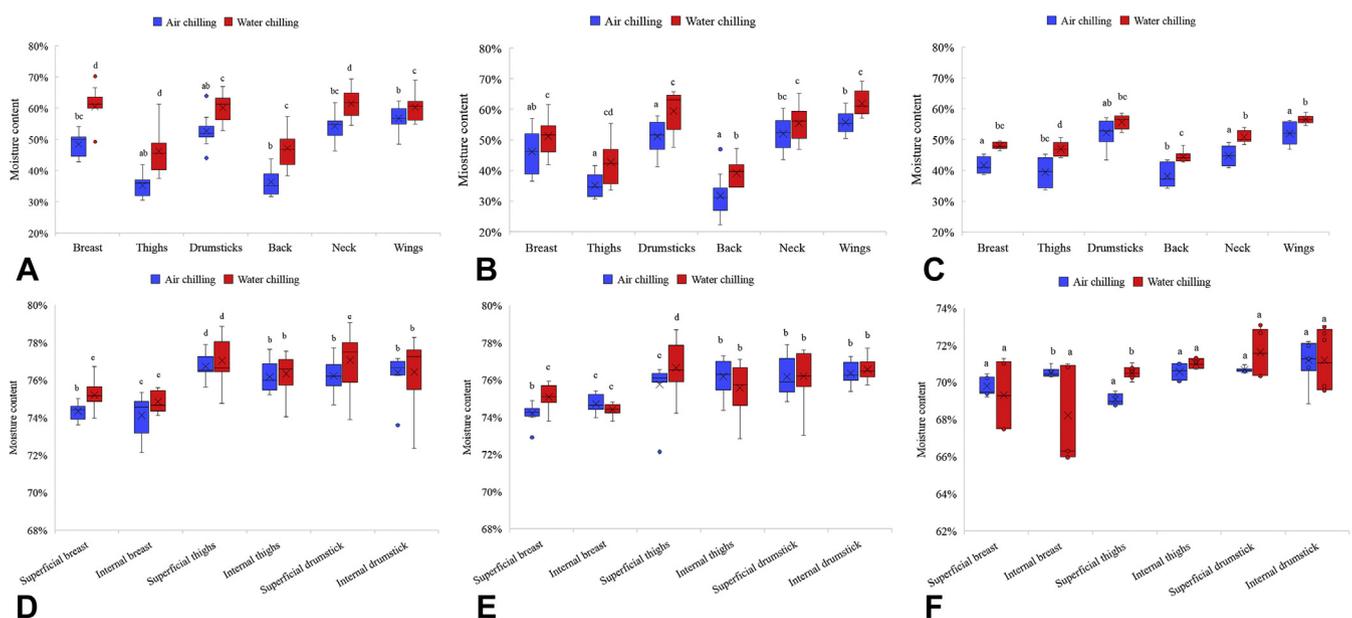
### Weight Change, Purge Loss, Cutting Loss, and Cooking Loss

It is generally accepted that carcasses will lose weight during AC but gain weight during the immersion process (James et al., 2006). When the weight change was calculated based on the prechilling weight, AC resulted in a 1.15% reduction in carcass weight, whereas CO<sub>20</sub>, CO<sub>30</sub>, and WC resulted in 1.89, 2.15, and 4.24% increase in carcass weight after chilling, respectively (Figure 3A). The water temperature, hydrostatic pressure, and water stirring conditions determine the amount of water that is absorbed by broiler carcasses during immersion chilling (Carciofi and Laurindo, 2007). In agreement with this finding, our results revealed that the longer immersion time led to a higher water uptake in carcasses. Similar results also have been observed in commercial white-

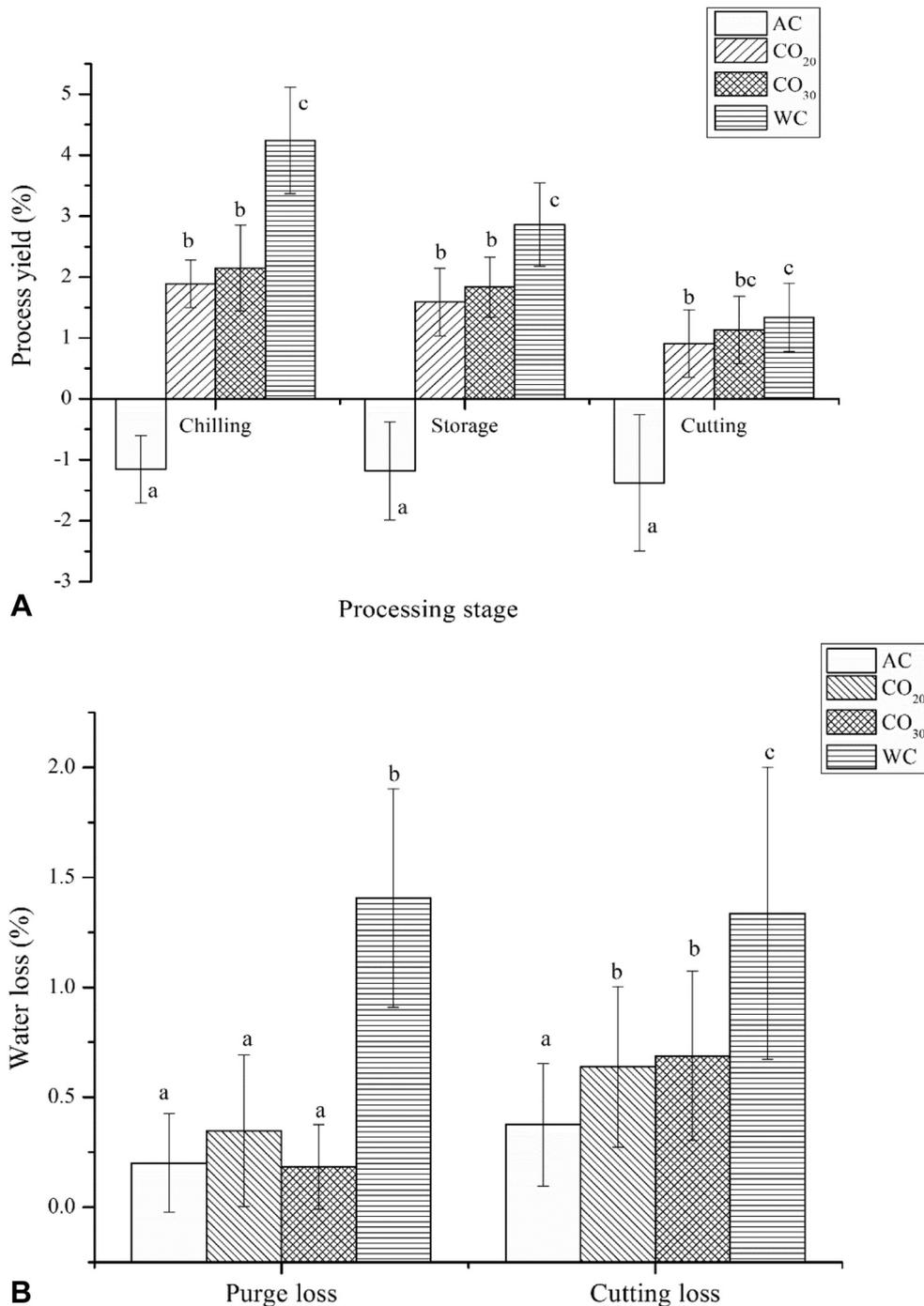
feathered broilers in response to AC and WC chilling systems. Jeong et al. (2011b) determined a 1.5% reduction in the weight of air-chilled broilers and a 4.6% increase in the weight of water-chilled broiler carcasses. Carcasses treated by WC had a significantly higher yield (+6.5%) than those treated with combined in-line AC (+1.98%) followed by AC (-1.10%) (Demirok et al., 2013).

Postmortem storage resulted in a loss of carcass weight (Figure 3B). The highest purge loss was observed ( $P < 0.05$ ) for carcasses treated by WC compared with that of other chilling groups. Moreover, the cutting loss of carcasses was the highest for those treated by WC, intermediate for those treated by CO<sub>20</sub> and CO<sub>30</sub>, and the lowest for those treated by AC ( $P < 0.05$ ). It is important to note that although WC resulted in the highest loss of moisture during the storage and cutting processes, the process yield (+1.3%) of carcasses treated by WC, calculated based on the prechilling weight, was still higher than that of carcasses treated by AC (-1.4%) after cutting (Figure 3A). Similar results have also been observed by Young and Smith (2004), who indicated that water-chilled carcasses absorbed an average of 11.7% moisture in the chillers but retained 6.0% moisture after cutting. The yield differences (water uptakes of 4.24% vs. 11.7%) between these 2 studies may have been due to the different carcass weights (2,147 g vs. 1,328 g), as the water uptake was higher in smaller carcasses than in larger ones (Essary and Dawson, 1965).

The different parts of chicken carcasses that were treated by AC had lower cooking losses than carcasses treated by combined chilling or WC ( $P < 0.05$ ), except for the thighs and claws (Figure 4). Generally, a clear trend of increased cooking loss was shown in breast,



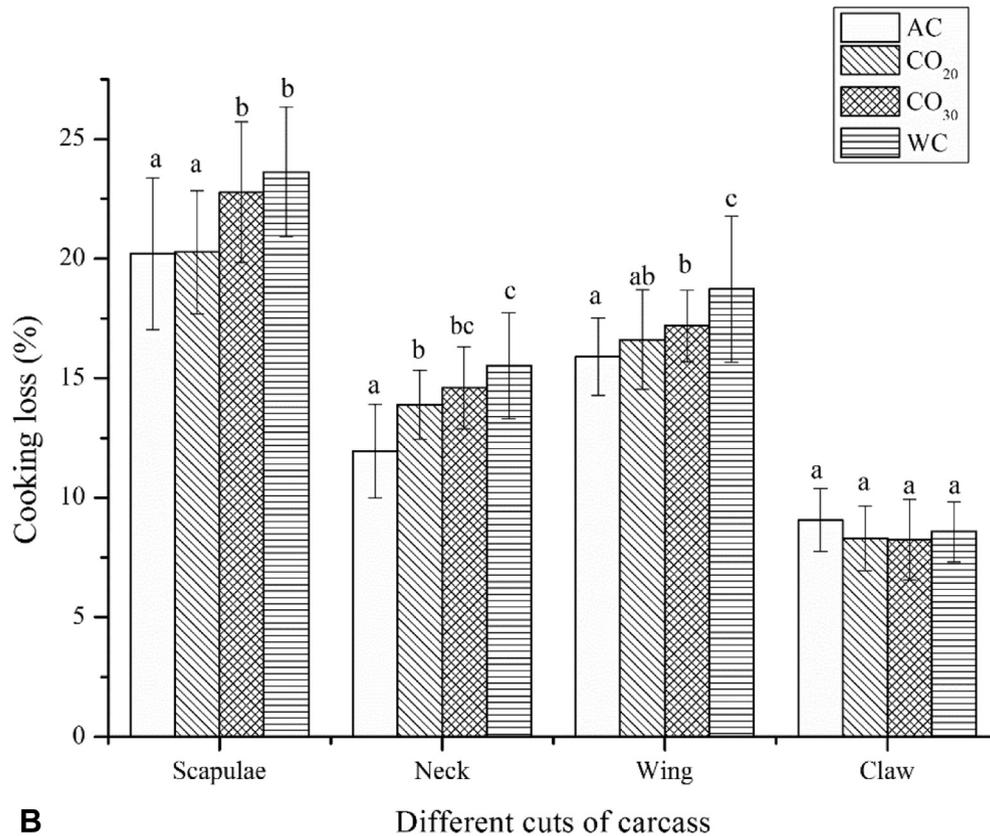
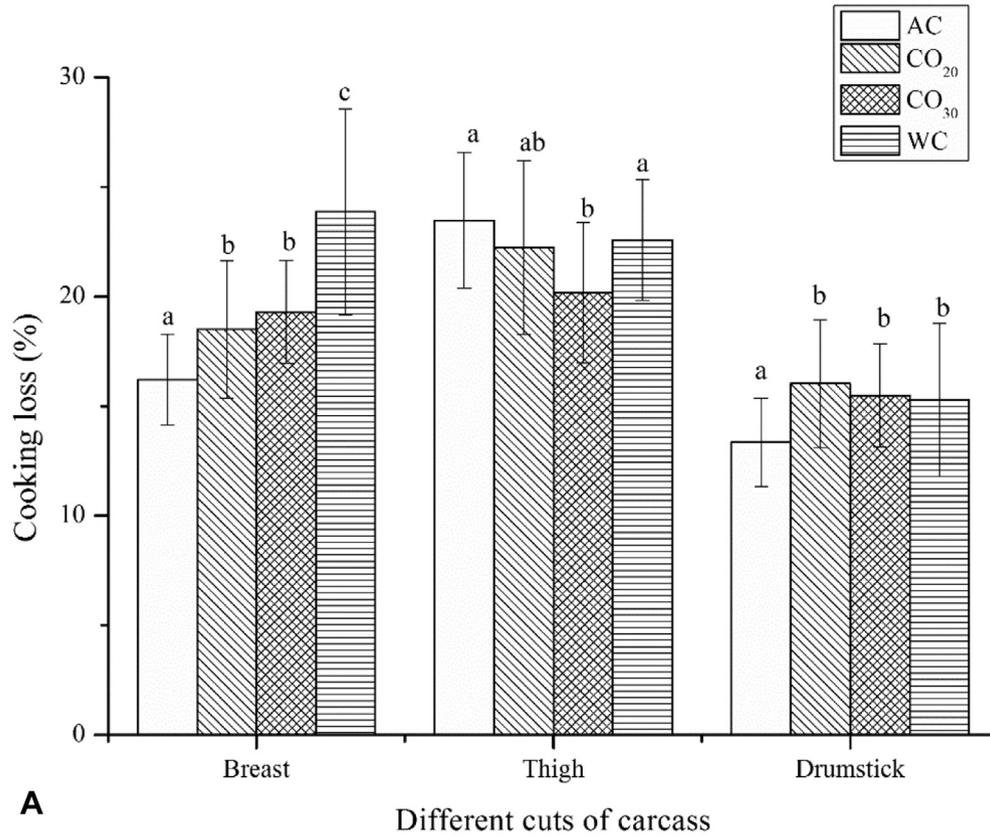
**Figure 2.** Box plot of moisture content of skin and meat in different parts of carcasses chilled by air chilling and water chilling. (A) Moisture content of skin after chilling; (B) moisture content of skin after storage; (C) moisture content of skin after cooking; (D) moisture content of meat after chilling; (E) moisture content of meat after storage; (F) moisture content of meat after cooking. Means with standard deviation ( $n = 8 \sim 10$ ) are shown. <sup>a-c</sup>Means within the same parts lacking a common superscript differ ( $P > 0.05$ ).



**Figure 3.** Chilling method effects on weight change of broiler carcasses during processing. (A) Weight change after chilling, postmortem storage, and cutting; (B) purge loss and cutting loss of carcasses. Means with standard deviation ( $n = 19-20$ ) are shown. <sup>a-c</sup>Means within a subfraction lacking a common superscript differ ( $P > 0.05$ ). AC, air chilling; CO<sub>20</sub>, combined method of WC for 20 min and AC; CO<sub>30</sub>, combined method of WC for 30 min and AC; WC, water chilling.

neck, and wings with an increased time of immersion. However, in previous studies performed by Jeong et al. (2011a) and Perumalla et al. (2011), none of the different chilling methods (WC and AC) resulted in a significant difference ( $P > 0.05$ ) in the cooking yields of chicken breast after 24 h of storage. It appeared that the absorbed water in carcasses treated by WC simply came out as drip loss during storage and did not affect the cooking yield (Jeong et al., 2011a). In the present study, one possible explanation could be that carcasses

treated by WC still retained 1.3% moisture uptake after storage. On the other hand, differences between drip loss and cooking loss were most likely due to changes in protein functionality. Drip loss and cook loss were significantly higher in carcasses that were chilled at 30°C than in those that were chilled at 0°C, 10°C, or 20°C (Alvarado and Sams, 2002). It was suggested that slow or inadequate chilling of carcasses resulted in pectoralis muscles with a decreased water-holding capacity (Alvarado and Sams, 2002).



**Figure 4.** Cooking loss of different parts of carcasses by different chilling methods. (A) Cooking loss of breast, thighs, and drumsticks; (B) Cooking loss of scapulae, necks, wings, and claws. Means with standard deviation ( $n = 20$ ) are shown. <sup>a-c</sup>Means within a subfraction lacking a common superscript differ ( $P > 0.05$ ). AC, air chilling; CO<sub>20</sub>, combined method of WC for 20 min and AC; CO<sub>30</sub>, combined method of WC for 30 min and AC; WC, water chilling.

## Moisture Content

In the present study, the moisture contents of skin and muscle from carcasses treated by WC and AC were further investigated. Generally, the skin of carcass parts treated by WC (breast, thighs, drumsticks, back, neck, and wings) exhibited higher moisture contents than the skin of carcass parts treated by AC ( $P < 0.05$ ) (Figure 2A and 2B), even after cooking (Figure 2C). In the breast and drumstick muscles, the moisture contents of the superficial parts from carcasses treated by WC after chilling were higher than those of carcasses treated by AC, whereas the internal parts were not significantly affected by the chilling methods ( $P > 0.05$ , Figure 2D–F). In addition, the moisture contents of skin for the samples treated by WC and AC differed by 3.4 to 12.0%, and this was higher than that of the muscle samples (<1%). Our study indicated that weight gain during WC occurred as a result of the highest water absorption on the skin, whereas muscles absorbed the least amount of water (Jeong et al., 2011b).

After 24 h of postmortem storage, the moisture content of skin from the breast, back, and neck of carcasses treated by WC decreased significantly (Figure 2B;  $P < 0.05$ ). However, for carcasses treated by AC, only the back skin showed reduced moisture content after storage ( $P < 0.05$ ). None of the superficial or internal muscle showed significant change (Figure 2E;  $P > 0.05$ ) in the moisture content after storage. Therefore, it appears that absorption of water in skin contributed more to a higher purge loss than did moisture in the muscle of broilers treated by WC (Figure 4B). Because the absorption of water by skin was crucial for water retention during storage, it was reasonable to reveal that skin on drumsticks treated by WC had the highest drip loss, whereas there was no significant difference ( $P > 0.05$ ) in the 24-h postmortem drip loss between skinless breast fillets treated by WC and those treated by AC (Demirok et al., 2013).

Cooking caused the highest decrease of moisture content in skin from breast, neck, and wings, regardless of the chilling method that was used, whereas skin from the back and thighs exhibited significant absorption of water (Figure 2B and 2C). Approximately 4 to 6% of moisture in both the superficial and internal muscles of breast, thighs, and drumsticks was lost during cooking (Figure 2F,  $P < 0.05$ ). On the other hand, the moisture content in the skin of carcasses treated by WC was higher after cooking, whereas most parts of the muscle from carcasses treated by AC and WC did not show a significant difference. However, there was no evidence that the skin of carcasses treated by WC lost more moisture during cooking than that of carcasses treated by AC. One theory to consider is that the dried surface skin of carcasses treated by AC was more likely to absorb the evaporation from the muscle during cooking; thus, the moisture in the muscle may have migrated to the surface skin of the carcasses treated by AC rather than being lost. With WC, the wet surface had less water absorption capacity, thus leading to the loss of evaporation from the muscle. Therefore, it is likely that the cut carcasses treated by AC

showed lower cooking losses than the carcasses treated by WC.

## CONCLUSION

Our results revealed that WC could reduce the initial microbial counts and improve the processing yield. However, water-chilled carcasses appeared to be less desirable because their surface skin lost their natural yellowness. Air chilling led to a desirable and traditional yellow carcass surface color, and air-chilled carcasses also exhibited the lowest purge loss and cooking loss. The moisture content of skin was suggested to play an important role in the improved water-holding capacity of air-chilled carcasses. These findings provided valuable information about the quality of yellow-feathered chickens in relation to different chilling systems during processing.

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## SUPPLEMENTARY DATA

Supplementary data associated with this article can be found in the online version at <https://doi.org/10.1016/j.psj.2019.11.020>.

## REFERENCES

- AOAC, Method 950.46B 1991. Official Methods of Analysis. Association of Official Analytical Chemist, Arlington, VA, USA.
- Alvarado, C. Z., and A. R. Sams. 2002. The role of carcass chilling rate in the development of pale, exudative Turkey pectoralis. *Poult. Sci.* 81:1365–1370.
- Berrang, M. E., R. J. Meinersmann, D. P. Smith, and H. Zhuang. 2008. The effect of chilling in cold air or ice water on the microbiological quality of broiler carcasses and the population of *Campylobacter*. *Poult. Sci.* 87:992–998.
- Blood, R. M., and B. Jarvis. 1974. Chilling of poultry: the effects of process parameters on the level of bacteria in spin-chiller waters. *J. Food Sci. Technol.* 9:157–169.
- Bowker, B. C., H. Zhuang, and R. J. Buhr. 2014. Impact of carcass scalding and chilling on muscle proteins and meat quality of broiler breast fillets. *LWT - Food Sci. Technol.* 59:156–162.
- Carciofi, B., and J. B. Laurindo. 2007. Water uptake by poultry carcasses during cooling by water immersion. *Chem. Eng. Process.* 46:444–450.
- Castaneda, M. P., E. M. Hirschler, and A. R. Sams. 2005. Skin pigmentation evaluation in broilers fed natural and synthetic pigments. *Poult. Sci.* 84:143–147.
- Demirok, E., G. Veluz, W. V. Stuyvenberg, M. P. Castaneda, A. Byrd, and C. Z. Alvarado. 2013. Quality and safety of broiler meat in various chilling systems. *Poult. Sci.* 92:1117–1126.
- 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.
- Franco, D., D. Rois, J. A. Vázquez, L. Purriños, R. González, and J. M. Lorenzo. 2012. Breed effect between Mos rooster (*Galician*

- indigenous* breed) and Sasso T-44 line and finishing feed effect of commercial fodder or corn. *Poult. Sci.* 91:487–498.
- Gill, C. O., L. F. Moza, M. Badoni, and S. Barbut. 2006. The effects on the microbiological condition of product of carcass dressing, cooling, and portioning processes at a poultry packing plant. *Int. J. Food Microbiol.* 110:187–193.
- Heath, J. L., and O. P. Thomas. 1974. The Effect of scalding conditions on the xanthophyll content and color of broiler skin. *Poult. Sci.* 53:1880–1885.
- 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.
- 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.
- Jeong, J. Y., K. K. Janardhanan, A. M. Booren, J. B. Harte, and I. Kang. 2011a. Breast meat quality and consumer sensory properties of broiler carcasses chilled by water, air, or evaporative air. *Poult. Sci.* 90:694–700.
- Jeong, J. Y., K. K. Janardhanan, A. M. Booren, D. M. Karcher, and I. Kang. 2011b. Moisture content, processing yield, and surface color of broiler carcasses chilled by water, air, or evaporative air. *Poult. Sci.* 90:687–693.
- Lopez, K. P., M. W. Schilling, and A. Corzo. 2011. Broiler genetic strain and sex effects on meat characteristics. *Poult. Sci.* 90:1105–1111.
- Pérez-Vendrell, A. M., J. M. Hernández, L. Llauradó, J. Schierle, and J. Brufau. 2001. Influence of source and ratio of xanthophyll pigments on broiler chicken pigmentation and performance. *Poult. Sci.* 80:20–326.
- Peng, Y., H. Tan, S. Liu, H. Li, Y. Chen, and J. Lin. 2017. Effects of different grain sources in both maternal and offspring diets on pigmentation and growth performance in yellow-skinned chickens. *J. Poult. Sci.* 54:228–235.
- Perumalla, A. V. S., A. Saha, Y. Lee, J. F. Meullenet, and C. M. Owens. 2011. Marination properties and sensory evaluation of breast fillets from air-chilled and immersion-chilled broiler carcasses. *Poult. Sci.* 90:671–679.
- Petracci, M., and D. L. Fletcher. 2002. Broiler skin and meat color changes during storage. *Poult. Sci.* 81:1589–1597.
- Qi, J., D. Y. Liu, G. H. Zhou, and X. L. Xu. 2017. Characteristic flavor of traditional soup made by stewing Chinese yellow-feather chickens. *J. Food Sci.* 82:2031–2040.
- Suderman, D. R., and F. E. Cunningham. 1980. Factor affecting the adhesion of coating to poultry skin. Effect of age, method of chilling, and scald temperature on poultry skin ultrastructure. *J. Food Sci.* 45:444–449.
- Tyczkowski, J. K., J. L. Schaeffer, and P. B. Hamilton. 1991. Measurement of malabsorption of carotenoids in chickens with pale-bird syndrome. *Poult. Sci.* 70:2275–2279.
- Wang, H., J. Qi, D. Duan, Y. Dong, X. Xu, and G. Zhou. 2018. Combination of a novel designed spray cabinet and electrolyzed water to reduce microorganisms on chicken carcasses. *Food Control* 86:200–206.
- 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.
- Yu, S., G. Wang, J. Liao, and M. Tang. 2018. Transcriptome profile analysis identifies candidate genes for the melanin pigmentation of breast muscle in muchuan black-boned chicken. *Poult. Sci.* 97:3446–3455.
- Zhang, L., J. Y. Jeong, K. K. Janardhanan, E. T. Ryser, and I. Kang. 2015. Microbiological quality of water immersion-chilled and air-chilled broilers. *J. Food Prot.* 74:1531–1535.
- Zheng, M., H. Li, H. Gao, W. Yao, J. Wen, and G. Gong. 2017. Monitoring report on the development of China's broiler industry 2016. *China Poult.* 39:69–72.
- Zhuang, H., B. C. Bowker, R. J. Buhr, D. V. Bourassa, and B. H. Kiepper. 2013. Effects of broiler carcass scalding and chilling methods on quality of early-deboned breast fillets. *Poult. Sci.* 92:1393–1399.
- 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.