Effect of dry-air chilling on sensory descriptive profiles of cooked broiler breast meat deboned four hours after the initiation of chilling[1]

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ABSTRACT The objective of this study was to evaluate the effect of a dry air-chilling (AC) method on sensory texture and flavor descriptive profiles of broiler pectoralis major (fillet) and pectoralis minor (tender). The profiles of the muscles immersion-chilled and deboned at the same postmortem time and the profiles of the muscles hot-boned (or no chill) were used for the comparison. A total of 108 eviscerated carcasses (6-wk-old broilers) were obtained from a commercial processing line before the chillers. Carcasses were transported to a laboratory facility where they were either i) chilled by a dry AC method (0.7°C, 150 min in a cold room), ii) chilled by immersion chilling (IC; 0.3°C, 50 min in a chiller), or iii) not chilled (9 birds per treatment per replication). Both IC and AC fillets and tenders were removed from the bone at 4 h after the initiation of chilling (approximately 4.75 h postmortem) in a processing area (18°C). The no-chill muscles were removed immediately upon arrival. The sensory properties (21 attributes) of cooked broiler breast meat were evaluated by trained panelists using 0- to 15-point universal intensity scales. The average intensity scores of the 9 flavor attributes analyzed ranged from 0.9 to 4.0. Regardless of breast muscle type, there were no significant differences in sensory flavor descriptive profiles between the 3 treatments. The average intensity scores of the 12 texture attributes ranged from 1.5 to 7.5 and there were no significant differences between the AC and IC samples. The average intensity scores of the texture attributes, cohesiveness, hardness, cohesiveness of mass, rate of breakdown, and chewiness of the no chill fillets and tenders were significantly higher than those of either of the chilled samples. These results demonstrate that chicken breast meat from AC retains sensory flavor profile characteristics but AC results in sensory texture profile differences when compared with no-chill meat. Sensory flavor and texture profiles of AC broiler breast meat do not differ from those of IC samples when the muscles are deboned at the same time after the initiation of chilling.

Key words: broiler, breast muscle, air chilling, immersion chilling, sensory flavor and texture

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INTRODUCTION

In the United States, ice-water immersion chilling (**IC**) has been the primary chilling method used to lower chicken carcass temperature to meet the USDA safety requirement that carcasses have to be chilled to 4.4°C or lower in less than 8 h (Code of Federal Regulations, 2003; Crews, 2006). However, air chilling (**AC**) has gained popularity in recent years (Crews, 2006). Since 1998, there have been 7 plants in the United States using AC to chill chicken carcasses, and several others have made arrangements to install AC equipment in the near future (Durham, 2008). Air-chilling methods use forced cold air circulation (usually 0 to 1.7°C) to chill chicken carcasses in a tunnel-room for 90 to 150 min to an end carcass temperature of less than 4.4°C. Air-chilling methods can be classified into dry AC and wet AC (complemented with chilled water spray). The dry AC methods can be further divided into the following: down-flow AC, in which carcasses are conveyed through a chilled room on an overhead conveyor with chilled air being blown over the products from above; cross-flow AC, in which products are chilled by cold air from the side of the carcasses; infrachill, in which the inside of the products, its abdominal cavity, and those portions with a thicker layer of meat such as the breast are chilled with a directed flow of air; and maturation chilling, which consists of 2 phases: during the first phase of approximately 30 min, very cold air is blown onto the carcasses at high velocities and during the second phase, which lasts approximately 2 h, carcasses are chilled further by relatively low-velocity air at 0°C (Barker et al., 2004; Anonymous, 2008). Air-chilling

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methods have been used for over 35 yr in Western Europe and have been codified as the only way to chill during processing for domestic consumption (Thomas, 1977; James et al., 2006).

Air chilling has been claimed to be the safest chilling technology and delivers a much higher-quality, better-tasting, and more tender chicken (Gazdziak, 2006). Several studies showed that AC resulted in reduced shear force values of chicken breast fillets when compared with IC methods and that there might be differences in sensory quality between AC and IC boneless, skinless chicken breast products obtained from retail markets. Bauermeister et al. (2001) found that the average Allo-Kramer shear value of 2-h deboned, air-chilled fillets was 7.40 kg/g compared with 10.15 kg/g of a retail immersion-chilled product. Huezo et al. (2007b) reported that the shear value of air-chilled fillets deboned 0 h postchill (about 2.5 h postmortem) was nearly 2 kg/g lower than immersion-chilled fillets deboned 1.67 h postchill (about 2.5 h postmortem). In quality surveys of boneless, skinless chicken breast obtained from local retail markets without knowing the processing practice details, Zhuang et al. (2007) and Lee et al. (2008) both noticed that, overall, air-chilled products seemed consistently more tender than the no-additive, immersion-chilled products. However, there is very limited published research comparing the side-by-side effects of AC and IC on sensory flavor and texture quality of deboned chicken breast meat (James et al., 2006). A few studies were conducted more than 25 yr ago. At that time, the AC method used was either significantly different from current practice or was not well documented (Scholtyssek et al., 1970; Hale et al., 1973; Grey et al., 1982). Meat samples were from whole carcasses rather than cut-up or boneless, skinless products (Hale et al., 1973; Grey et al., 1982) and were usually stored for a few days up to several months before sensory testing was conducted (Scholtyssek et al., 1970; Knoop et al., 1971; Hale et al., 1973; Ristic, 1982).

Since 1980, boneless, skinless broiler breast meat has become the primary raw poultry meat product in the marketplace (Fletcher, 2004). The sensory texture quality of boneless breast meat can be significantly affected by postmortem deboning time (Sams, 1999). The standard practice of the deboning time for the IC products is 4 to 6 h postmortem in the United States (Lee et al., 2008). There appears to be a need for an updated validation of the effects of AC on sensory quality of chicken meat processed with modern postharvest chicken operation practices using deboned chicken breast meat for both academic and industry purposes. Descriptive analysis is a powerful sensory evaluation tool that can provide information about both specific qualitative and quantitative sensory aspects of a product. The objective of this study was to evaluate the effect of a dry-air, cross-flow AC method on sensory descriptive profiles of chicken breast meat, both pectoralis major (fillet) and pectoralis minor (tender) deboned at 4 h after the initiation of chilling compared with the sensory profiles of the muscles that were deboned at the same postmortem time after ice-water IC or muscles that were hot-boned (no chill).

MATERIALS AND METHODS

Broiler Carcasses

During each of 4 replications, 27 soft-scalded, eviscerated broiler (42 d old) carcasses were obtained from a local processing plant (Athens, GA) before chilling. Carcasses were placed, in bulk, in 2 36-L coolers (Igloo, Shelton, CT, internal dimension 52 × 30 × 35 cm) and transported to the laboratory within 20 min (average carcass temperatures were 32°C on arrival) where they were randomly selected from the coolers, tagged with numbered wing tags, weighed, and assigned to 1 of 3 treatments: dry AC, ice water IC, and no chill.

Chilling Treatments

In each replication, 9 carcasses for IC were submersed in 151 L of a mixture of ice and tap water (0.3 ± 0.1°C and 0.5 mg/kg of chlorine) in a pilot-scale, paddle-type agitated chill tank (fabricated on site) in a processing area (18°C). The paddles in the chiller were operated at 1.6 rpm for the duration of the 50-min chill. The ice water and carcass (breast) temperatures (1 to 3 carcasses) were measured every 5 min during chilling using a Digi-Sense hand-held digital thermometer (Cole Parmer Instrument Co., Vernon Hills, IL) fitted with a Physitemp hypodermic needle microprobe (Physitemp, Clifton NJ). After IC, carcasses were hung in shackles and allowed to drip for 15 min before being weighed and sealed in 1-gallon (3,785 mL) Ziploc freezer bags (SC Johnson & Son Inc., Racine, WI). Bagged carcasses were held in a cold room (0.7°C) for another 175 min before deboning at 4 h or 240 min after the initiation of chilling (approximately 4.75 h postmortem).

Carcasses for AC were cooled for 150 min using a cross-flow method in a refrigerated room (0.7 ± 0.4°C) with the RH of 86 ± 3% that was measured every 15 min (Cox Recorders, Belmont, NC) during AC. Nine carcasses were hung from shackles and chilled by 3 circulation fans 5.3 m away. The fans were in constant operation resulting in air moving past the carcasses at an average of 76.2 m per min as measured with a velometer (Alnor Products TSI Inc., Shoreview, MN). Time-temperature profiles were collected at 3 different depths in the thickest part of a chicken breast of the heaviest bird, which were i) halfway from skin to the center of chicken breast (1/4 depth from skin to ribs), ii) the center (1/2 depth), and iii) halfway from the center to the ribs (3/4 depth), by using a 12-channel Digi-Sense scanning thermometer model 92000-00 (Barnant Co., Barrington, IL) and Physitemp hypodermic needle microprobes. After AC, the carcasses were

weighed, placed in 1-gallon Ziploc freezer bags (1 bird/bag), and held in the same cold room (0.7°C) as the IC samples for 90 min before deboning at 4 h after the initiation of chilling.

Deboning, Color, pH, Weights, and Packaging

For each chilling treatment of total 9 carcasses per replication, deboning, measuring color and pH, weighing, and packaging were completed in less than 10 min using an assembly line approach with 1 to 2 individuals completing each task. The fillets and tenders were manually deboned. Color and pH were measured on each left fillet according to the method of Zhuang and Savage (2008b). Breast fillets and tenders were individually weighed, vacuum-packed (508 mmHg) in cooking bags (Seal-a-Meal bag, The Holmes Group, El Paso, TX), and stored overnight in a refrigerator (average 1.3°C) before cooking. Breast muscles of the no-chill samples were removed from carcasses within 15 to 25 min of arrival at the laboratory (between 30 to 45 min postmortem).

Cooking and Sampling for Sensory Evaluation

The fillets vacuum-bagged and stored overnight in a refrigerator were cooked and sampled by following the same procedures reported by this laboratory (Zhuang and Savage, 2008a).

The tenders were cooked 10 to 13 min to an internal temperature of 78 to 80°C. Samples were allowed to rest 3 min before slicing for sensory testing. The tendon end of each tender was removed by making a cut perpendicular to the tendon. The narrow end of a 1.9 × 3.8 cm template was aligned at the first cut and a 1.9 × 3.8 cm strip was removed. The 3.8 cm length was further cut into two 1.9-cm pieces for sensory evaluation.

Sensory Evaluation

Sensory profiles of samples were determined by a 7- to 9-member trained panel as described in our previous publication (Zhuang and Savage, 2008a). All panelists had been trained a minimum of 100 h in flavor and texture profiling and had extensive experience with chicken fillet descriptive analysis using a spectrum-like method (Meilgaard et al., 1999). Before the beginning of the study, the attributes, phases of evaluation, definitions, line scale anchors, and references (Table 1) were reviewed and applicability to both fillets and tenders was verified (Meilgaard et al., 1999; Rutledge, 2004; our laboratory).

The sensory testing involved 4 replications and a randomized design. A total of 33 fillets and 33 tenders per treatment were tested.

Statistics

Data were analyzed using SAS software for chilling method, muscle type, and chilling method by muscle type effects and mean separations by using the least-squared means option of the GLM procedure (SAS version 9.1, SAS Institute Inc., Cary, NC). The null hypothesis implied no difference in the measurement means between chilling methods, between types of muscles, and between chilling method and muscle type interactions. The statistical significance selected for type I or α error (rejection of the null hypothesis) was $P < 0.05$. Principal component analysis (**PCA**) for sensory texture mapping of pectoralis major data was carried out using Senstools version 3.1.6 software (OP&P Product Research BV, Utrecht, the Netherlands) under the Multivariate Analysis selection.

RESULTS AND DISCUSSION

Carcass Time-Temperature Profiles, Carcass Weight, and Fillet Color and pH

Figurea 1A and 1B show the time-temperature profiles of broiler carcasses and cooling chambers during the chilling processes. The average initial internal carcass temperature before chilling was 32.1 ± 0.76°C (±SD), measured in the thickest part of the breast. Under our experimental conditions, the average time to reach an internal temperature of 4.4°C was 45 min (Figure 1A) during the IC processing and 130 min (Figure 1B) during the dry-AC processing. Among the 3 muscle locations monitored in AC carcasses, the last part or location of the chicken breasts to reach 4.4°C was halfway from the muscle center to the ribs (3/4 depth) instead of the center location. May et al. (1961) reported that during IC, muscle in chicken thigh cooled much faster than that in breast and the point to cool last in a broiler carcass was in the center of the thickest breast muscle. Our time-temperature profile data, however, suggest that the point to cool last in the broiler carcass is the location more toward the cavity rather than the center when the cross-flow AC method is used. It has been claimed by a supplier of AC systems that an infrachill method can save the chilling time required in a conventional down-flow tunnel (Anonymous, 2008). Huezo et al. (2007a) reported that it took only 90 min to reduce the temperature of chicken carcasses to 4.4°C with a chilling method similar to the infrachill (cold air was distributed directly into the abdominal cavity of each carcass). To our knowledge, our result is the first published data to indicate that the temperature of chicken breast meat close to the abdominal cavity needs more chilling time if cross-flow cold air is used. The practice of introducing cold air directly into the cavity could reduce AC time.

The mean, SE, and mean separations of the prechill carcass weights and the fillet pH and color measurements are shown for each treatment in Table 2. There

Table 1. Sensory attributes and definitions used by descriptive analysis panel to evaluate test samples

Attribute	Definition	Anchor terminology	Texture reference = intensity
Texture phase 1. First few bites			
Cohesiveness	Distance you can bite into the sample before it breaks, cracks, crumbles – first bite	Not cohesive to very cohesive	Cornbread = 1[1] Soft pretzel = 8[1] Gum = 15[1]
Hardness	Force to compress the sample with the molars during first 2 bites	Not hard to very hard	Cream cheese = 1[1] Cheese = 4.5[1] Olive = 6[1] Almond = 11[1]
Juiciness/dryness	Amount of moisture coming from the sample during the first 5 chews	Not juicy to very juicy	Banana = 1[1] Mushroom = 4[1] Cucumber = 8[1] Watermelon = 15[1]
Texture phase 2. Chew sample to bolus – evaluate			
Cohesiveness of mass	Degree the chewed sample holds together in a wad	Loose wad to tight wad	Carrot = 2[1] Frankfurter = 7.5[1] Caramel = 15[1]
Bolus size	Change in sample size with formation of bolus or wad	No wad to greatly increased wad	Extreme chicken = 14[2]
Wetness of wad	Amount of moisture in the bolus or wad	Dry wad to very wet wad	Pork rinds = low[3] Pound cake = mid[3] Gelatin = high[3]
Rate of breakdown	Size of particles in the wad during chew down	Fast rate to slow rate	Cotton candy = fast[3] Pringle = mid[3,4] Brisket = slow[3]
Texture phase 3. Evaluate at time of swallow			
Chewiness	Amount of work to chew the sample to the point of swallow (or spit out)	Not chewy to very chewy	Rye bread = 1.5[2] Gum drop = 6[2] Tootsie roll = 13[2,5]
Texture phase 4. Evaluate after swallow			
Residual loose particles	Amount of small loose particles in mouth after swallow	None to very much	
Toothpack	Fibers stuck between teeth after swallow	None to very much	
Tooth stick	Degree to which the teeth stick together	None to very much	
Residual stringiness/ connective tissue	Amount of large pieces of product (epimyosin) that did not chew down and are left in the mouth after swallow	None to very much	
Flavor phase 1. Aromatics	Aromatic taste sensation associated with:		Aromatic references = intensity
Chickeny	Cooked white or dark chicken muscle	None to very much	Soda in unsalted cracker = 2[1] Grape in grape Kool-Aid = 5[1,6] Orange in orange juice = 7[1] Grape in grape juice = 10[1] Cinnamon in Big Red gum = 12[1,7]
Brothy	Meat stock	None to very much	
Barnyard/wet feathers	A chicken coop; combination of manure, moldy hay, feed, and poultry odors including wet poultry feathers	None to very much	
Bloody/serumy/metallic	Raw or rare lean meat, blood, serum, or metal/iron	None to very much	
Cardboardy	Cardboard, wet paper	None to very much	
Flavor phase 2. Basic tastes	Taste on the tongue stimulated by:		Basic taste references = intensity
Sweet	Sugars and high-potency sweeteners	Not sweet to very sweet	2, 5, and 10% sucrose in water = 2, 5, and 10[1]
Salty	Sodium salts, especially sodium chloride (table salt)	Not salty to very salty	0.2, 0.35, and 0.5% sodium chloride = 2.5, 5, and 8.5[1]
Sour	Acids	Not sour to very sour	0.05, 0.08, and 0.15% citric acid = 2, 5, and 10[1]
Bitter	Caffeine or quinine	Not bitter to very bitter	0.05, 0.08, and 0.15% caffeine = 2, 5, and 10[1]

[1]The reference and intensity for basic taste and texture were from Meilgaard et al. (1999).

[2]The scales were developed for this study.

[3]The reference and intensity for basic texture were from Rutledge (2004).

[4]Procter & Gamble Co., Cincinnati, OH.

[5]Tootsie Roll Industries, Chicago, IL.

[6]Kraft Foods Inc., Northfield, IL.

[7]Wm. Wrigley Jr. Co., Peoria, IL.

were no significant weight differences between the 3 treatments and the overall average carcass weight was 1,346 g (data not shown). Both chilling processes resulted in significantly increased L* values (lighter meat color) and reduced pH values compared with the no-chill control. No significant changes occurred in the a* and b* values. There were no differences in color and pH between AC and IC samples. These results are consistent with reported observations of the changes in pH (decreased) and lightness (increased) of chicken breast fillets with aging time (Lyon et al., 1985; Young et al., 1999; Cavitt et al., 2005) and also agree with previous studies that showed no significant differences between AC and IC for pH, L*, a*, and b* values of raw breast fillets deboned at the same postmortem time (Fleming et al., 1991; Huezo et al., 2007b).

Sensory Descriptive Profiles of Chicken Pectoralis Major and Pectoralis Minor Muscles

Table 3 shows ANOVA and average intensity scores for 12 texture and 9 flavor sensory attributes of the cooked breast meat, fillets, and tenders. Also shown is the statistical significance of the main effects that were analyzed: chilling method, muscle type, and chilling method by muscle type. Regardless of muscle type, there were no significant differences between the average intensity scores of the 3 chilling methods-treatments for the flavor attributes, the moisture-related texture attributes, wetness of wad and juiciness, and the texture attributes evaluated after swallow. There were also no significant differences between the fillets

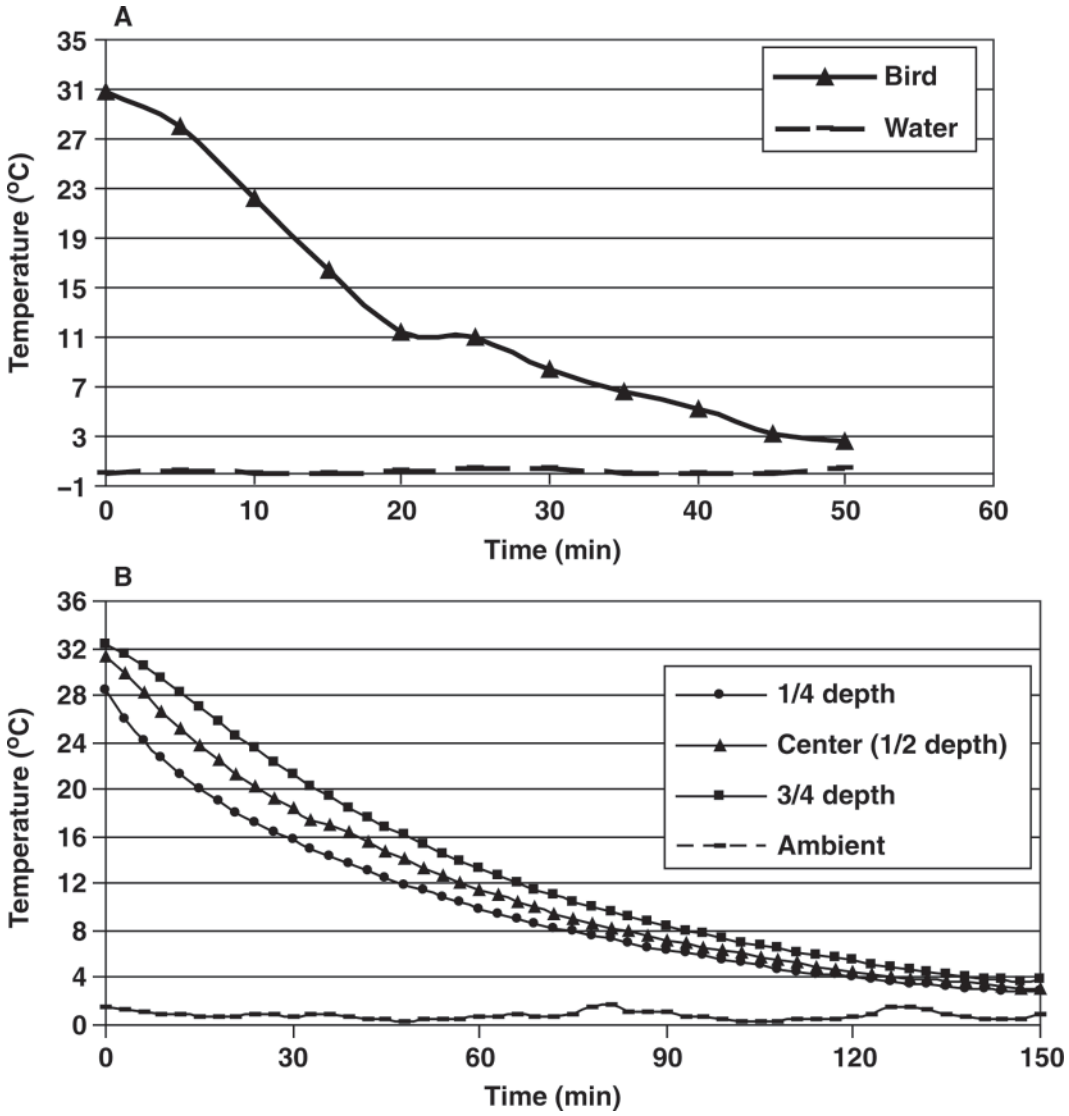

Figure 1. Time-temperature profile of breast muscle of broiler carcasses during chilling. A. Immersion chilling (average carcass weighed 1,321 g; total 9 carcasses/chiller, 151 L of ice water, and rotation rate 1.6 rpm in a processing area). B. Dry air chilling (average carcass weighed 1,358 g; total 9 carcasses/room, 86% RH, air flow rate 76.2 m/min); 1/4 depth = halfway from skin to the center of chicken breast; center (1/2 depth) = halfway from skin to the ribs; 3/4 depth = halfway from the center to the ribs; ambient = air chilling room.

Table 2. Raw weight of prechill chicken carcasses and color and pH of chicken fillets (mean ± SE, n = 36)

		Chicken breast fillet			
Item	Prechill carcass weight (g)	L* (lightness)	a* (redness)	b* (yellowness)	pH
No chill	1,361 ± 31	49.4[b] ± 0.4	−0.7 ± 0.2	9.6 ± 0.3	6.13[a] ± 0.02
Immersion (at 240 min)	1,321 ± 28	55.4[a] ± 0.6	−0.5 ± 0.1	10.0 ± 0.3	6.06[b] ± 0.02
Air-chilling (at 240 min)	1,358 ± 28	56.1[a] ± 0.5	−0.6 ± 0.2	10.1 ± 0.2	6.06[b] ± 0.02

[a,b]Mean values with no common superscript in the same column are significantly different from each other ($P < 0.05$).

and tenders for those sensory attributes. The chilling treatments resulted in significantly reduced intensities of 6 texture attributes: cohesiveness, hardness, cohesiveness of mass, bolus-wad size, rate of breakdown, and chewiness, which are involved in mechanical texture aspects of meat. These attributes were also the only sensory characteristics that were significantly affected by muscle type. For the attributes cohesiveness and cohesiveness of mass, overall intensity scores of the fillets were significantly higher than the scores for the tenders. For both the tenders and the fillets, the no-chill samples had significantly higher intensity scores than the chilled samples. There were no muscle-type differences between the no-chill tenders and the chilled fillets. The attributes hardness, rate of breakdown, and chewiness were affected by significant interactions between chilling method and muscle type. For these attributes, there were significant differences in average intensities between the no-chill and chilled samples within each muscle type and between the fillets and tenders. For both muscles, the no-chill scores were higher than the chill scores and the intensities of the no-chill, AC, and IC fillets were significantly higher than the no-chill, AC, and IC tenders. Across both muscles and the chilling methods, the mean separations showed the no-chill fillets significantly higher than the chilled fillets, which were higher than the no-chill tenders which were higher than chilled tenders. For bolus-wad size, the no-chill fillets were significantly higher than the chilled fillets and all of the tender treatments were significantly lower

Table 3. Descriptive panel analysis of chilling method effects on sensory attributes of chicken breast muscle pectoralis major and pectoralis minor (mean ± SE, n = 33)[1]

	Breast muscle						Statistical significance of main effects		
	Pectoralis major (fillet)			Pectoralis minor (tender)					
Sensory attribute	No chill	Immersion chill	Air chill	No chill	Immersion chill	Air chill	Chilling method[2]	Muscle type	Chilling method × muscle type
Texture									
Cohesiveness	6.1[a] ± 0.3	5.0[b] ± 0.2	4.8[b] ± 0.2	4.5[b] ± 0.2	3.6[c] ± 0.2	3.7[c] ± 0.2	*	*	NS
Hardness	6.5[a] ± 0.2	4.9[b] ± 0.1	5.0[b] ± 0.2	4.2[c] ± 0.2	3.2[d] ± 0.2	3.5[d] ± 0.2	*	*	*
Juiciness/dryness	4.8 ± 0.3	4.7 ± 0.2	4.5 ± 0.3	4.8 ± 0.2	4.8 ± 0.2	4.5 ± 0.2	NS	NS	NS
Cohesiveness of mass	6.6[a] ± 0.3	5.7[b] ± 0.2	5.5[b] ± 0.2	5.2[b] ± 0.2	4.9[c] ± 0.2	4.8[c] ± 0.2	*	*	NS
Bolus/wad size	5.0[a] ± 0.2	3.7[b] ± 0.2	3.8[b] ± 0.2	3.8[b] ± 0.2	3.5[b] ± 0.2	3.5[b] ± 0.2	*	*	NS
Wetness of wad	5.3 ± 0.2	5.7 ± 0.2	5.5 ± 0.2	5.6 ± 0.2	5.9 ± 0.2	5.7 ± 0.2	NS	NS	NS
Rate of breakdown	7.6[a] ± 0.3	5.7[b] ± 0.2	5.8[b] ± 0.2	5.0[c] ± 0.2	4.1[d] ± 0.2	4.1[d] ± 0.2	*	*	*
Chewiness	6.6[a] ± 0.3	4.9[b] ± 0.1	4.8[b] ± 0.1	4.3[c] ± 0.1	3.8[d] ± 0.1	3.7[d] ± 0.1	*	*	*
Residual loose particles	3.3 ± 0.2	3.8 ± 0.2	3.9 ± 0.2	3.4 ± 0.2	3.5 ± 0.2	3.5 ± 0.2	NS	NS	NS
Toothpack	2.5 ± 0.3	2.4 ± 0.2	2.3 ± 0.2	2.2 ± 0.2	2.2 ± 0.2	2.4 ± 0.2	NS	NS	NS
Tooth stick	2.2 ± 0.3	2.6 ± 0.2	2.8 ± 0.3	2.8 ± 0.3	2.6 ± 0.3	3.2 ± 0.2	NS	NS	NS
Residual stringiness/ connective tissue	1.9 ± 0.3	1.7 ± 0.2	1.5 ± 0.2	1.6 ± 0.2	1.5 ± 0.2	1.8 ± 0.2	NS	NS	NS
Flavor									
Chickeny	3.8 ± 0.2	3.8 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	3.8 ± 0.2	NS	NS	NS
Brothy	2.8 ± 0.2	3.0 ± 0.2	3.3 ± 0.2	3.1 ± 0.3	3.1 ± 0.2	3.0 ± 0.3	NS	NS	NS
Barnyard/wet feathers	2.7 ± 0.2	2.3 ± 0.2	2.4 ± 0.2	2.2 ± 0.2	2.2 ± 0.2	1.9 ± 0.2	NS	NS	NS
Bloody/serumy/metallic	3.4 ± 0.2	3.1 ± 0.2	3.1 ± 0.2	3.0 ± 0.2	2.9 ± 0.2	2.9 ± 0.2	NS	NS	NS
Cardboardy	2.2 ± 0.2	2.1 ± 0.2	2.0 ± 0.2	2.4 ± 0.2	2.1 ± 0.2	2.2 ± 0.2	NS	NS	NS
Sweet	2.1 ± 0.2	2.3 ± 0.2	2.3 ± 0.2	2.3 ± 0.1	2.4 ± 0.2	2.3 ± 0.2	NS	NS	NS
Salty	2.2 ± 0.2	2.3 ± 0.2	2.5 ± 0.2	2.4 ± 0.2	2.3 ± 0.1	2.3 ± 0.1	NS	NS	NS
Sour	2.4 ± 0.2	2.3 ± 0.2	2.2 ± 0.2	2.1 ± 0.2	2.1 ± 0.2	2.2 ± 0.2	NS	NS	NS
Bitter	1.0 ± 0.2	1.1 ± 0.2	0.9 ± 0.2	1.1 ± 0.2	1.3 ± 0.2	1.3 ± 0.2	NS	NS	NS

[a–d]Mean values with no common superscript in the same row are significantly different from each other ($P < 0.05$).

[1]Intensities with a higher number are stronger (16-point scale).

[2]Chilling method includes no chill, immersion chilling, and air chilling.

*$P < 0.05$.

than the no-chill fillets. There were no differences between the chilled fillets, the no-chill tenders, and the chilled tenders.

The chicken pectoralis minor has been known for its tender texture. Cason et al. (1997) reported that regardless of deboning time, Warner-Bratzler shear force values of chicken tenders were much lower (less than half) than those of chicken fillets. In the present study, it is demonstrated that there are no significant differences in sensory flavor and moisture content between cooked chicken fillets and tenders. However, cooked tenders are perceived as less cohesive, less hard, less chewy, and easier to break down than the chicken fillets. Chilling processes maintain the profiles of sensory flavor and moisture-related texture properties and result in significant changes in the profiles of the mechanical texture properties of both hot-boned chicken fillets and tenders. In a previous investigation (Zhuang et al., 2007), we also noticed that there were no differences in sensory flavor and moisture-related texture properties of boneless, skinless chicken breast fillets between air-chilled products and immersion-chilled products purchased from local retail stores, indicating that those sensory characteristics appeared not to be significantly affected by different chicken production, processing, and marketing practices. Our present result provides further evidence to show that both chicken breast fillets and tenders have the same sensory flavor characteristics and that meat flavor cannot be significantly affected by chilling methods with aging. There have been numerous reports documenting that IC whole carcass and aging for more than 4 h can result in significant changes in both instrumental and sensory texture properties of deboned broiler fillets compared with the hot-boned samples (Lyon and Buhr, 1999; Cavitt et al., 2004; Xiong et al., 2006). However, there are few published reports on how AC affects instrumental and sensory texture properties of hot-boned fillets. Bauermeister et al. (2001) investigated the optimal deboning time for commercially air-chilled chicken breast fillets. The earliest deboning time in the study was 2 h postmortem followed by every 2 h until 16 h postmortem, and only meat shear force was measured. For an AC process differing from IC, 2 h postmortem could be in the middle of the chilling period, and therefore, 2-h deboned breast fillets might not be a representative sample used for the comparison. In our present study, we used hot-boned samples to compare the effect of AC on sensory quality of chicken breast meat and provided the evidence to show that like IC process, the AC process followed by 4.75 h of postmortem deboning can result in significant changes in the sensory texture quality of hot-boned chicken breast meat or the raw materials used for AC.

Our study also showed that there were no differences in both the sensory flavor and texture profiles between AC and IC methods. These results are consistent with some findings more than 25 yr ago. Pedersen (1982) conducted an evaluation on AC by using whole chickens and 3 to 10 trained persons and did not find any significant differences in overall acceptability, taste, odor, tenderness, and juiciness between air-chilled and wet-chilled samples. A few reports have shown that there were differences in sensory quality of chicken meat between dry and wet chilling (Hale et al., 1973; Grey et al., 1982; Ristic, 1982). However, the results are conflicted. Hale et al. (1973) found that dry-chilled broilers had subtle, but detectable, flavor advantages over immersion-chilled broilers. However, Ristic (1982) reported that water cooling gave better aroma than air cooling, and Grey et al. (1982) reported that flavor of breast meat from air- and immersion-chilled whole chicken carcasses was similar. These results indicate that the effect of AC on sensory quality of chicken meat might depend on experiment materials and methods. Recently, 2 more sensory studies (Zhuang et al., 2007; Lee et al., 2008) were published on commercial boneless, skinless broiler breast fillets including both AC and IC products and showed that AC products were consistently more tender than the no-additive IC products. However, in those studies, the chicken fillets were obtained from local supermarkets and there was no detailed information about the bird producing, processing, and handling parameters before purchases. It has been demonstrated that chicken production practices (or raw materials), processing, and postprocessing handling can significantly affect texture quality of deboned chicken fillets (Berri, 2000; Zhuang and Savage, 2008b). Therefore, it is impossible to conclude if AC has any advantage over IC on improvement of texture quality of chicken breast meat based on these results. In 2007, Huezo et al. (2007b) made the side-by-side comparison of the effects of AC and IC methods on broiler breast fillet quality. However, in their experiments, sensory quality of treated fillets was not measured and the fillets were deboned at either 2.5 or 24 h after the initiation of chilling. It has been recommended that broiler carcasses age at least 4 to 6 h before deboning (Lyon and Buhr, 1999; Sams, 1999). There is a lack of information about the side-by-side comparison of AC and IC effects on sensory flavor and texture quality of chicken breast meat deboned between 4 to 6 h postmortem. Our study was designed to address this need and first demonstrates that sensory quality of chicken breast meat that is chilled with a dry-air method, processed using assimilated modern standard operation practices and deboned 4.75 h postmortem, is the same as the sensory quality of chicken breast meat that is chilled with the ice-water immersion method and deboned at the same postmortem time. In other words, with our experimental materials and methods, IC delivers the same sensory quality chicken as AC.

PCA of Sensory Descriptive Data of Pectoralis Major

Figures 2A and 2b show the results of PCA of the chicken fillet sensory data. In Figure 2A, the main principal component (principal component 1, **PC1**) ex-

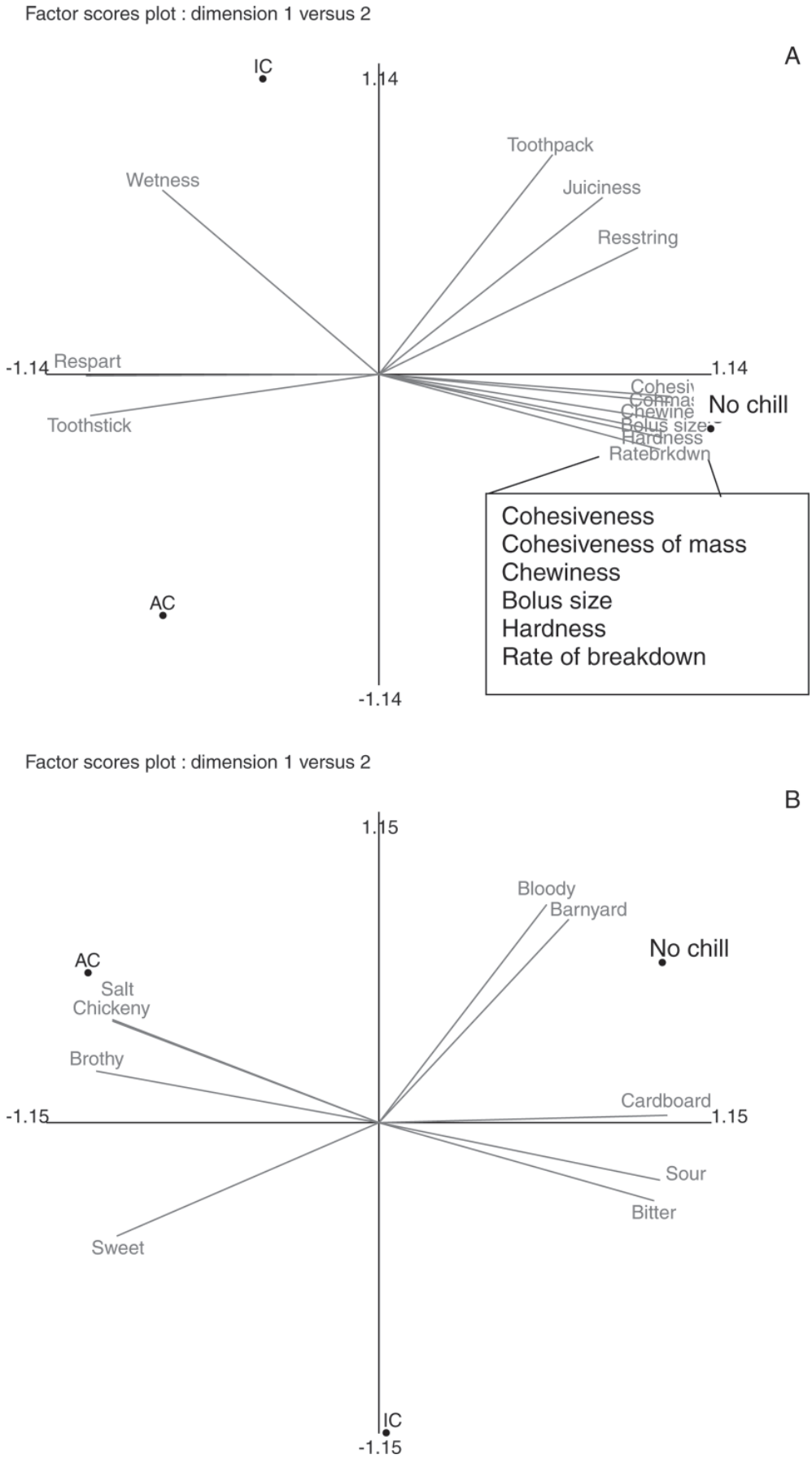

Figure 2. Biplot of principal component analysis of sensory descriptive attributes of deboned chicken fillets (pectoralis major) treated with 3 different chilling treatments. A. Texture; cohmass = cohesiveness of mass; ratebrkdwn = rate of breakdown; respart = residual loose particles; resstring = residual stringiness/connective tissue. B. Flavor; IC = immersion chilling; AC = air chilling.

plained 84% of the variation and had positive loadings for cohesiveness, cohesiveness of mass, hardness, chewiness, and bolus size. Principal component 2 (**PC2**) explained 16% of the variation and had positive loadings for juiciness and wetness of wad. On PC1, the hot-boned sample is totally separated from the chilled samples and is closely associated with cohesiveness, hardness, cohesiveness of mass, chewiness, and bolus size. This relationship is consistent with the previous ANOVA results of our sensory data that there were significant differences in texture attributes cohesiveness, hardness, cohesiveness of mass, and chewiness between the no-chill and the chilled samples, with the no-chill sample having the significantly higher intensity scores. On PC2, the IC sample is well separated from the AC sample and is more associated with the moisture-related texture attributes juiciness and wetness of wad. Our previous investigation (Zhuang et al., 2007) also showed that there was a relationship between the claimed retained water content in boneless, skinless chicken breast products purchased from the supermarket and the sensory texture attributes moisture release and wetness on a PCA chart.

Figure 2B shows the PCA biplot of the sensory flavor data. Principal component 1 explains 79% of the variation and has positive loadings for cardboard, sour, bitter, bloody/serumy/metallic, and barnyard/wet feathers and negative loadings for chickeny, brothy, sweet, and salty. Principal component 2 explains 21% of the variation and has positive loadings for bloody/serumy/metallic, barnyard/wet feathers, salty, and chickeny. The 3 different chilled samples are well separated from each other. The no-chill sample is totally separated from the AC samples by PC1 and its flavor is closely associated with barnyard/wet feathers, bloody/serumy/metallic, and cardboard. The AC is well separated from IC by PC2 and its flavor is associated with chickeny, brothy, and salty. The IC is located by itself far away from all 9 flavor attributes used in our testing. These results suggest that our sensory panel perceived more chickeny and brothy flavor with the AC sample, and the no-chill sample tastes more bloody/serumy/metallic, barnyard/wet feathers, and cardboard, although there were no significant differences in mean intensity scores of all 9 flavor attributes among the 3 treatments.

Based on the chilling conditions and raw materials used in the present study, compared with no-chill broiler breast muscle, pectoralis major and pectoralis minor, AC for 150 min followed by deboning 90 min later did not significantly affect the sensory flavor profiles of broiler breast meat, indicating that AC retains the chicken flavor of no-chill breast fillets. The air-chilled samples showed significantly reduced intensities of mechanical sensory texture properties such as cohesiveness, hardness, cohesiveness of mass, and chewiness, suggesting that AC followed by deboning 4 h after the initiation of chilling can result in a difference in sensory texture profiles of no-chill samples. However, compared with immersion-chilled chicken samples, air-chilled broiler breast meat did not show any significant differences in sensory flavor and texture profiles. This result suggests that the effect of the AC method on sensory flavor and texture quality is the same as that of the IC method when the chicken breast meat is deboned at the same postmortem time. Immersion chilling delivers the same sensory quality chicken as AC.

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