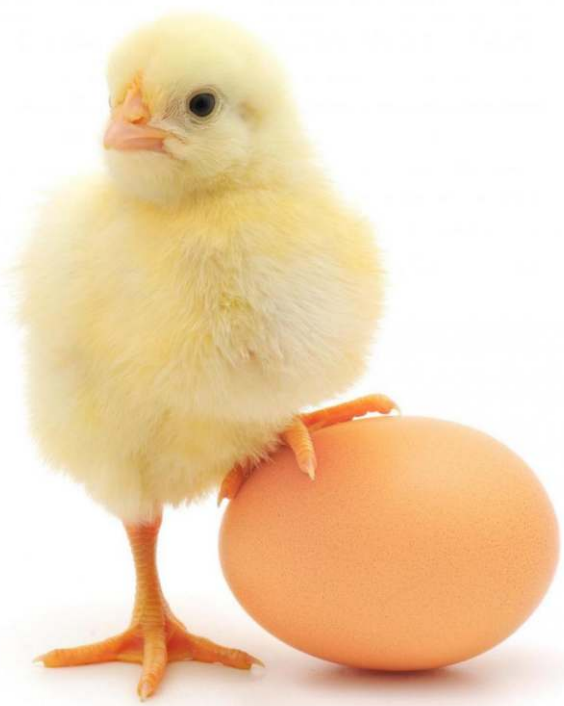
ISSN 1682-8356
ansinet.org/ijps



INTERNATIONAL JOURNAL OF POULTRY SCIENCE

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

International Journal of Poultry Science 7 (8): 743-748, 2008
ISSN 1682-8356

Effect of Dry-Air Chilling on Warner-Bratzler Shear Force and Water-Holding Capacity of Broiler Breast Meat Deboned Four Hours Postmortem[1]

H. Zhuang[2], E.M. Savage, D.P. Smith and M.E. Berrang
USDA, Agricultural Research Service, Russell Research Center, Athens, Georgia, 30604-5677, USA

Abstract: Advantages of air chilling (AC) methods over immersion chilling (IC) methods in quality retention and improvement of deboned chicken breast meat depend on experimental conditions, such as deboning time. The objective of this study was to evaluate the effect of a dry-AC method on shear force and water-holding capacity (WHC) of broiler breast meat deboned 4h postmortem compared to hot-boned (no chill) or immersion-chilled meat. Ready-to-cook broiler carcasses were hot-boned, chilled by ice water immersion (0.3°C, 50 min) or chilled by cross-flow cold, dry air (0.7°C, 150 min). Pectoralis (p.) major and p. minor were removed from the bone at 4 h postmortem. Shear force was measured using a Warner-Bratzler (WB) method and WHC was estimated using cooking yield, drip loss, amount of bound water (filter paper method) and water uptake (swell/centrifugation method). Regardless of muscle type, the WB shear force value of AC samples was significantly lower than that of hot-boned samples; however, there was no difference in the shear force between AC and IC. Regardless of measurement methods, there were no differences ($P > 0.05$) in WHC between the three treatments. These results demonstrate that when compared to no chill, AC followed by 4 h postmortem deboning can lead to a difference in WB shear values while WHC properties can be retained. For broiler breast meat deboned 4 h postmortem, AC does not result in any significant differences in shear force and WHC when compared to IC.

Key words: Broiler breast, air chilling, immersion chilling, shear force, water-holding capacity

Introduction

The quality effect of air-chilling (AC) on chicken meat was studied in the 1970's and early 1980's, when the Council of the European Communities introduced and implemented an EEC (European Economic Community) directive to ban the continuous water-immersion chilling (IC) (Lillard, 1982; Thomson *et al.*, 1974; James *et al.* 2006). However, as more U.S. chicken processors are adopting the AC method for a niche in the poultry meat market (Durham, 2008; Crews, 2006), research interest has been renewed (Bauermeister *et al.*, 2001; Perumalla *et al.*, 2006; Huezo *et al.*, 2007a,b; Carroll and Alvarado, 2008). Published reports demonstrate that the quality effect of AC on chicken breast meat compared with IC apparently depends upon deboning time and varies with experimental conditions. Four hours has been demonstrated to be a critical postmortem aging time for tenderness of broiler breast meat (Pool *et al.*, 1959; Stewart *et al.*, 1984; Lyon *et al.*,1985) and the optimum length of time when considering both quality and operation efficiency (Goodwin, 1984; Shelton, 1985). It is of interest to investigate how AC methods affect the quality of chicken breast meat deboned at 4 h postmortem compared with IC methods. Since the tenderness or shear force, moisture retention and water-holding capacity (WHC, including cook yield) have been among the most important quality parameters measured for meat products, the purpose of this study was to evaluate the effect of a dry-air, cross-flow AC method on shear force and WHC of chicken breast meats, pectoralis major (p. major) and/or pectoralis minor (p. minor), deboned 4h postmortem compared to muscles that were deboned at the same postmortem time after an ice-water IC method. A hot-boned (no chill) sample was also used in the study as a control.

Materials and Methods

Broiler carcasses: Soft scalded and ready-to-cook (RTC) carcasses (from approximately 42 d old broilers) were obtained from a commercial processing plant before chilling (total 120 birds and 4 replications). Carcasses were placed in a cooler and transported to the laboratory within 20 min (Carcass temperatures were 32°C on arrival) where they were randomly selected, numbered with wing tags, weighed and assigned to 1 of 3 treatments:i) no chill hot boned, ii) ice water IC and iii) dry-AC.

Chilling treatments: The carcasses for immersion chilling were submersed in 151 L of a mixture of ice and tap water (average temperature 0.3±0.1°C and average chlorine level of 0.5 ppm) in a pilot scale paddle-type, agitated chill tank. The paddles in the chiller were operated at 1.6 rpm for the duration of the 50-min chill. The chilling water and carcass (breast) temperatures were measured every 5 min during chilling using a Digi-Sense handheld digital thermometer (Cole Parmer Instrument Co., Vernon Hills, IL 60061) fitted with a

Physitemp hypodermic needle microprobe (Physitemp, Clifton NJ, 07013). After immersion chilling, carcasses were hung by their hocks in shackles and allowed to drip for 15 min before being weighed and sealed in 1 gallon Ziploc® freezer bags (SC Johnson and Son, Inc., Racine, WI 53403). Carcasses were then held in a cold room (0.3°C) for another 175 min (total 240 min or 4 h) before deboning.

Air-chill carcasses were cooled for 150 min using a cross-flow AC method. Air chilling was conducted in a refrigerated room (average 0.7±0.4°C) which measured 5.5 by 6.7 m (minus a 2.1 by 2.7 m area in one corner). Carcasses were hung by the legs from shackles which were attached to a bar and rack placed 5.3 m from a series of three circulation fans within the cooling unit. Carcasses were randomly assigned to shackles which were arranged in 2 staggered rows. The cooling unit 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). The relative humidity (RH) was measured every 15 minutes (Cox Recorders, Belmont, NC) during the air chill treatment (average 86±3% RH). Temperatures of the carcasses and the chilling chamber were recorded using a 12-channel Digi-sense scanning thermometer model 92000-00 (Barnant Co., Barrington IL 60010) and Physitemp hypodermic needle microprobes. After AC, the carcasses were weighed, placed in 1-gallon Ziploc® freezer bags (1 bird/bag) and held at 0.3°C for 90 min (total 4 h postmortem) before deboning.

Deboning and storage: Breast muscles of hot boned samples were manually removed from the carcasses within 15 to 25 min of arrival at the laboratory (between 30-45 min postmortem). Breast muscles of IC and AC samples were removed at 4 h postmortem. Breast fillets (p. major) and tenders (p. minor) were individually weighed and vacuum packed (508 mm Hg) in cooking bags (Seal-a-Meal bag, The Holmes Group, El Paso, TX). One fillet and both tenders from individual carcasses were stored in a refrigerator (at 2°C) overnight prior to WB shear and cook yield measurements. The other fillet from each carcass was stored in a -20°C freezer. The frozen fillets were thawed in a refrigerator (2°C) for 24 hours prior to analyses for moisture content, drip loss, bound water (filter paper method) and water uptake (swelling/centrifuge method).

Moisture, water-holding capacity, cooking yield and Warner-Bratzler shear force measurements: Moisture content was measured by the AOAC method (AOAC, 1990). Five grams of minced meat was dried in an aluminum pan at 100°C for 18 h. The sample was weighed after being cooled to room temperature in a desiccator.

Drip loss was determined as described by Rasmussen and Anderson (1996). Chicken breast muscle samples (30 g) were suspended on screen wire mesh in covered Fisherbrand 4 oz/118 mL containers (Fisher Scientific, Pittsburgh, PA) for 48 h at 2°C. Drip loss was expressed as a percentage of the weight lost in 48 h over the initial sample weight.

The filter paper press method described by Honikel and Hamm (1994) was used to determine the amount of bound water in the frozen/thawed broiler fillets. Three hundred mg of meat tissue from the cranial end of fillets was placed on filter paper (11 cm diameter Whatman No. 1 filter paper) and pressed at 50 kg (a 50 kg-load cell) for 5 min by a TA-XT*Plus* Texture Analyzer (Stable Micro Systems, Surrey, UK). The wet filter paper was then scanned into a computer using a Canon scanner (Model: CanoScan LIDE 60, Canon USA, Inc. Lake Success, NY 11042). The meat area and the total fluid area were measured using the computer with Adobe Photoshop software (CS3 Extended, San Jose, CA 95110). The results were expressed as a ratio of meat area over total fluid area (Kauffman *et al.,* 1986) to estimate amount of bound water in meat.

A swelling/centrifugation method similar to that developed by Wardlaw *et al.* (1973) was used for estimation of water uptake by the freezer-stored fillets. Each minced meat sample (10 g) and 15 mL of 0.6 M NaCl solution were added into a 50-mL centrifuge tube and mixed with a Vortex mixer for 1 min. The tube was then refrigerated at 4°C for 15 min before being centrifuged at 4°C at 3,000 g for 15 min. The water uptake (%) was determined by the formula:

$$\text{Water uptake} = 100 \times (W_{pellet} - W_{raw}) / W_{raw}$$

where W represents sample weight, pellet refers to the solid material at the bottom of the tube after centrifugation and raw refers to the chicken meat sample used for the analysis.

For cook yield and Warner-Bratzler (WB) shear force measurements, the fresh vacuum-bagged p. major and p. minor were cooked in a Henny Penny MCS-6 combi oven (Henny Penny Corp. Eaton, OH 45320) at 85°C (185°F) with the tender steam setting to an internal temperature of 78-80°C. The endpoint temperatures were checked in the thickest part of the meat with a hand-held Digi-Sense digital thermometer fitted with a Physitemp hypodermic needle microprobe. Cook yield was calculated by:

$$100 \times (W_{cooked} / W_{after\ deboning})$$

For the WB shear force measurement, room temperature samples (strips with 19 mm width) were sheared perpendicular to the longitudinal orientation of the muscle fibers by a TA-XT *Plus* Texture Analyzer

(Stable Micro Systems, Surrey, UK) fitted with a 30 kg load cell and Texture Exponent 32 version 3.0.3.0 software. A TA-7 WB shear type blade was used. Test settings included a button type trigger, 55 mm travel distance, 4 mm per second test speed, and calibration return distance of 1 mm. Maximum force measured to cut the strips was expressed in Newton/1.9 cm. For each cooked chicken breast muscle, one strip was sheared in 2 locations and the strip heights at each shear point were recorded and used for data analysis (Zhuang *et al.*, 2007).

Statistics: The data were subjected to analysis of variance with the GLM procedure of SAS (SAS version 9.1, SAS Institute Inc., Cary, NC). Replication and chilling treatment were used as the main effects. Main effects and their interactions were tested for statistical significance using the residual error ($P < 0.05$). When the interaction between replication and chilling treatment was found to be significant, it was used as the error term to test the main effects. Chilling treatment means were separated using the LSD multiple comparison procedure with a significance level of $P < 0.05$. A paired *t*-test of the readings from the same carcass was used to test the significance of changes in carcass weight after chilling treatments.

Results and Discussion

Carcass weight changes after chilling: Table 1 shows the changes in RTC broiler carcass weight after AC or IC. Both chilling methods significantly affected RTC carcass weight ($P < 0.05$). One hundred fifty minutes of the AC process resulted in reduced carcass weight by 2.4%; however, IC resulted in carcass weight gain by 4.6% after 50 min chilling followed by 15 min drain. Perumalla *et al.* (2006) found that during chilling processes of RTC carcasses, IC birds had significantly higher percentages of water uptake (4.08%) than AC birds (-2.12%). Huezo *et al.* (2007a) reported that AC carcasses lost 2.5% of prechill weight. In a recent review paper on chilling methods for poultry carcasses, James *et al.* (2006) summarized that in AC, losses of 1-1.5% are common and can be up to 3%, while weight gains of 4-8% occur in immersion chillers. Our data agree with these reports, indicating that the chilling processing methods used in our study were typical.

Effect of chilling methods on Warner-Bratzler shear force: Warner-Bratzler shear force is the most popular indicator for meat texture or tenderness (Culioli, 1995). The WB shear has been widely used to estimate tenderness or texture quality of poultry breast fillets, with higher WB shear values associated with less tender poultry breast fillets (Lyon and Lyon, 2001; Xiong *et al.*, 2006). Table 2 shows the chilling method effects on the average WB shear force values of the chicken breast meat. The WB shear force values of AC and IC p. major were less than 50% (< 46 Newton) of that of no chill p. major (> 92 Newton). The average WB shear values of AC and IC p. minors were about one-third less than that of no chill p. minors. Regardless of muscle type, there were significant differences in average WB shear force values between the AC and the no chill samples; however, there were no significant differences between the AC and IC samples. These results demonstrate that AC followed by 4h postmortem deboning can result in reduced shear force of chicken breast when compared to no chill (hot-boned). However, the AC did not affect the shear force of the chicken muscles when compared with IC followed by the same length of postmortem aging time. These findings are consistent with numerous previous reports documenting a significant difference in WB shear force between chicken breast fillets deboned prechill and those chilled with ice-water and deboned 4 h postmortem. Lyon *et al.* (1985) reported average WB shear force values of 15.2 kgf (kg force, 1 kgf = 9.8 Newton) for broiler breast meat removed from carcasses prechill; however, it was 7.7 kgf for the meat removed 4h postchill. Young and Lyon (1997) reported that the WB shear force of cooked chicken breast meat was reduced more than 50% as PM deboning time increased from 0 (5.69 kgf) to 4 h (2.54 kgf). Our finding is also in agreement with the results published by Huezo *et al.* (2007b), in which there was no significant difference in average Allo-Kramer (AK) shear values when IC fillets deboned 1.67 h postchill (2.5 h postmortem) were compared with AC fillets deboned 0h postchill (2.5 h postmortem) and when both AC and IC

Table 1: Weight and % weight change of ready-to-cook broiler carcasses after chill (mean±SE, n = 36 for no chill, n = 32 for immersion chilling, n = 36 for air chilling)

Processing stage	No Chill (Hot-boned)	Immersion Chill	Air Chill
	ready-to-cook carcass weight (g) or % change		
Pre-chill	1361±31	1321±28^{b}	1358±28^{a}
Post-chill	N/A	1382±31^{a}	1326±27^{b}
% Change	N/A	4.6±0.3	-2.4±0.1

^{ab}Mean values with no common superscript in the same column are significantly different from each other ($P < 0.05$).
SE = standard error.

Table 2: Chilling method effects on average Warner-Bratzler shear force values (Newton/1.9 cm) of chicken breast muscle, p. major and p. minor (mean±SE, n = 72)

Muscle	No Chill (Hot-boned)	Immersion Chill	Air Chill
	Warner-bratzler shear force (newton/1.9 cm)		
P. major	92.2^{a}±2.9	45.7^{b}±1.5	44.7^{b}±2.3
P. minor	30.5^{a}±1.0	21.6^{b}±1.0	20.7^{b}±0.6

^{ab}Mean values with no common superscript in the same row are significantly different from each other ($P < 0.05$). SE = standard error.

fillets were deboned 24 h postchill. Our study also shows no evidence that there were differences between AC and IC regarding instrumental texture quality or tenderness of chicken breast meat deboned at 4 h postmortem. Chilling, either IC or AC, followed by 4 h postmortem deboning time results in significant reduction in shear force of p. minor when compared with no chill (hot boned).

Effect of chilling methods on water-holding capacity: Water-holding capacity is a very important quality characteristic for meat and meat products. It directly affects product appearance, production efficacy/profitability and consumption quality such as juiciness. Various methods have been developed or used to estimate meat WHC. For example, drip loss is a good estimate for weepage after raw meat is placed in a plastic package. Cook yield can be a good estimate for production yield of deli and ready-to-eat meat. The swelling/centrifuge method could be used to indicate uptake of added water by meat or marination yield. Filter paper results supply evidence of bound water contents in meat. Table 3 shows the effect of AC on cook yield of fresh chicken p. major and p. minor and Table 4 shows the effect on moisture content and WHC of frozen/thawed chicken fillets measured by the drip loss, filter paper and swelling/centrifuge methods. There were no statistically significant differences ($P > 0.05$) in WHC (including cook yield) between the three treatments. There were also no significant differences in moisture content between treatments, indicating that the WHC measurement results obtained in our study did not result from the differences of the initial moisture content of meat used. These results demonstrate that compared to no chill and IC, AC followed by 4 h postmortem deboning did not affect WHC of chicken fillets. These findings differ from some published results. The effect of AC on WHC measured with cook yield of chicken can be found in numerous reports. In most cases the higher cook yield was associated with AC fillets when compared to IC fillets. Huezo *et al.* (2007b) reported that cook yield of AC fillets was significantly higher than that of IC fillets deboned either 2.5 h or 24 h postmortem. Bauermeister *et al.* (2001) found that the average cook loss for AC breast fillets decreased the longer the muscle stayed on the carcass. It was lower than the cook loss of the IC fillets. Pedersen (1982) reported a 4% difference in cook loss between AC (22.9%) and IC (26.9%) samples. However, in the same paper, Pedersen also found that the cook loss (or cook yield) for wet-chilled chickens was dependent upon the amount of water absorbed. By lowering the amount of water absorption, the cooking loss can be reduced as well. For example, 8% of water uptake in chickens resulted in a cooking loss of 27.5%. However, 2% water uptake gave 22.2% cooking loss.

Table 3: Chilling method effects on average cooking yield of chicken breast muscle, p. major and p. minor (mean±SE, n = 36 for p. major and n = 72 for p. minor)

	Cook yield (%)		
Muscle	No Chill (Hot-boned)	Immersion Chill	Air Chill
P. major	84.1^a±0.4	84.5^a±0.4	85.2^a±0.8
P. minor	87.1^a±0.3	86.9^a±0.3	86.4^a±0.3

^{a}Mean values with no common superscript in the same row are significantly different from each other ($P < 0.05$). SE = standard error.

There was more than 5% difference in cooking loss. The different results in cook yield between our present study and Huezo *et al.* (2007b) could have resulted from water uptake by IC fillets. In Huezo's study, the water uptake was 9.3% compared to 4.6% in our study.

The effect of AC on drip loss in our study was consistent with a previous report by Perumalla *et al.* (2006), in which they found that there was no significant difference in drip loss of fillets deboned at 3h postmortem between AC and IC. In addition to cook yield and drip loss of chicken fillets, our study also demonstrated that AC did not significantly affect cook yield of p. minor and did not result in significant changes in the amount of bound water (measured by filter paper method) and water uptake (measured by swelling/centrifuge method) of frozen/thawed chicken fillets when compared to no chill and IC treatments. These results suggest that AC followed by 4 h postmortem deboning will not affect marination pickup or marination yield. Both Perumalla *et al.* (2006) and Huezo *et al.* (2007a) have reported that there were no significant differences in marination pickup and marination retention of fillets between AC and IC treatments.

In summary, based on the chilling conditions and raw materials used in the present study, for the chicken breast meat deboned at 4h postmortem, AC did not affect either WB shear force or WHC when compared to IC. This result suggests that an AC method results in the same tenderness of chicken breast meat as an IC method when the breast meat is removed from carcasses at 4 h postmortem time. When compared with hot-boned chicken breast muscle, both AC for 150 min and IC for 90 min followed by 4 h postmortem deboning resulted in significantly reduced WB shear force, indicating that chilling either AC or IC, can affect the tenderness of chicken breast meat. Our research also shows that AC did not significantly affect the cook yield, drip loss, bound water status and water uptake when compared to no chill or IC, indicating that air-chilling can retain WHC of chicken breast meat. AC has the same effect on texture and cook yield of chicken breast muscle p. minor as on those of p. major.

Table 4: Chilling method effects on moisture content, drip loss, bound water and water uptake of frozen chicken fillets (p. major) (mean±SE, n = 6)

	Moisture/water-holding capacity		
Attributes	No Chill (Hot-boned)	Immersion Chill	Air Chill
Moisture content (%)	$26.1^{a}\pm0.2$	$26.0^{a}\pm0.2$	$26.1^{a}\pm0.3$
Drip loss (%)	$3.6^{a}\pm0.6$	$2.3^{a}\pm0.3$	$2.5^{a}\pm0.4$
Bound water (Ratio)[1]	$0.63^{a}\pm0.02$	$0.63^{a}\pm0.02$	$0.61^{a}\pm0.02$
Water uptake (%)[2]	$104.6^{a}\pm1.9$	$98.8^{a}\pm3.1$	$99.8^{a}\pm3.6$

^{a}Mean values with no common superscript in the same row are significantly different from each other ($P < 0.05$). SE = standard error. [1]Bound water is estimated using filter paper press method and calculated by meat area/total area. [2]Water uptake is estimated using swelling/centrifuge method and calculated by 100 x (pellet weight- raw meat weight)/raw meat weight.

Acknowledgments

The authors wish to express their sincere thanks to Allan Savage, Hillary Johnson and Joseph Stanfield for their technical assistance during the study.

References

AOAC, Association of Official Analytical Chemists, 1990. Official methods of analysis. 15th ed. Washington, D.C.

Bauermeister, L.J., S.J. Lewis, A. Velsquez, M. Tamayo, A. Aguilar and S.R. McKee, 2001. Tenderness of chicken breast fillets processed in a commercial air-chill facility. Poult. Sci., 80 (Suppl.): 138.

Carroll, C.D. and C.Z. Alvarado, 2008. Comparison of air and immersion chilling on meat quality and shelf life of marinated broiler breast fillets. Poult. Sci., 87: 368-372.

Crews, J., 2006. A niche evolves. Meat and Poul., December: 20-23.

Culioli, J., 1995. Meat tenderness: Mechanical assessment. In: Ouali, A., DeMeyer, D.I., Smulders, F.J.M. (Eds.), Expression of Tissue Proteinases and Regulation of Protein Degradation as Related to Meat Quality. ECCEAMST, Utrecht, The Netherlands, pp: 239-266.

Durham, S., 2008. Chillin" Chickens-Which method works best? Agric. Res., April: 20-21.

Goodwin, T.L., 1984. It takes tough discipline to make tender chicken. Broiler Industry, 47: 43-44.

Honikel, K.O. and R. Hamm, 1994. Measurement of water-holding capacity and juiciness. In: Pearson, A.M., Dutson, T.R. (Eds.), Quality Attributes and Their Measurement in Meat, Poultry and Fish Products. Blackie Academic and Professional, Glasgow, UK., pp: 125-161.

Huezo, H., J.K. Northcutt, D.P. Smith and D.L. Fletcher, 2007a. Effect of immersion or dry air chilling on broiler carcass moisture retention and breast fillet functionality. J. Appl. Poult. Res., 16: 438-447.

Huezo, H., J.K. Northcutt, D.P. Smith and D.L. Fletcher, 2007b. Effect of chilling method and deboning time on broiler breast fillet quality. J. Appl. Poult. Res., 16: 537-545.

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.

Kauffman, R.G., G. Eikelenboom, P.G. van der Wal, B. Engel and M. Zara, 1986. A comparison of methods to estimate water-holding capacity in post-rigor procine muscle. Meat Sci., 18: 307-322.

Lillard, H.S., 1982. Improved chilling systems for poultry. Food Tech., 58: 58-67.

Lyon, B.G. and C.E. Lyon, 2001. Meat Quality: sensory and instrumental evaluations. In Sams, A.R. (ed), Poultry Meat Processing. CRC Press, Boca Raton, FL., pp: 97-120.

Lyon, C.E., D. Hamm and J.E. Thomson, 1985. pH and tenderness of broiler breast deboned various times after chilling. Poult. Sci., 64: 307-310.

Pedersen, R., 1982. Immersion chilled fresh chickens. Organoleptic characteristics, shelf-life and determination of water uptake. Fleischwirtschaft, 62: 1448-1450.

Perumalla, A.V.S., A. Saha, Y. Lee, J.F. Meullenet and C.M. Owens, 2006. Marination properties of air chilled and water chilled broiler breast fillets. Poult. Sci., 85 (Suppl.): 59.

Pool, M.F., D. De Fremery, A.A. Campbell and A.A. Klose, 1959. Poultry tenderness. II. Influence of processing on tenderness of chicken. Food Tech., 13: 25-29.

Rasmussen, A.J. and M. Anderson, 1996. New method for determination of drip loss in pork muscles. Proc. 42nd Int. Cong. of Meat Sci. and Tech. Lillehammer, Norway, p: 286-287.

Shelton, T., 1985. Broiler industry in the year 2000. Broiler Industry, 48: 36, 38, 40-42, 44.

Steward, M.K., D.L. Fletcher, D. Hamm and J.E. Thompson, 1984. The influence of hot boning broiler breast muscle on pH decline and toughening. Poult. Sci., 63: 1935-1939.

Thomson, J.E., W.K. Whitehead and A.J. Mercury, 1974. Chilling poultry meat-a literature Review. Poult. Sci., 53: 1268-1281.

Wardlaw, F.B., L.H. McCaskill and J.C. Acton, 1973. Effect of postmortem muscle changes on poultry meat loaf properties. J. Food Sci., 38: 421-423.

Xiong, R., C.M. Owens, J.F. Meullenet and L.C. Cavitt, 2006. Comparison of Allo-Kramer, Warner-Bratzler and razor blade shears for predicting sensory tenderness of broiler breast meat. J. texture studies, 37: 179-199.

Young, L.L. and C.E. Lyon, 1997. Effect of postchill aging and sodium tripolyphosphate on moisture binding properties, color and Warner-Bratzler shear values of chicken breast meat. Poult. Sci., 76: 1587-1590.

Zhuang, H., E.M. Savage, S.E. Kays and D.S. Himmelsbach, 2007. A survey of the quality of six retail brands of boneless, skinless chicken breast fillets obtained from retail supermarkets in the Athens, Georgia area. J. Food Qual., 30: 1068-1082.

[1]Mention of a product or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable

[2]To whom correspondence should be sent. TEL: (706) 546-3011; FAX: (706) 546-3607;