Chapter 3

Quality and sensory characteristics of post rigor, early de-boned broiler breast meat tenderized using a hydrodynamic shock wave

3.1 Abstract

The first objective was to determine the effects of explosive and distance of the explosive to the meat surface in the Hydrodyne process. Early de-boned (EB) breasts were removed immediately after initial chill (45 min post-mortem), stored for 24 hours (4^{o}C), and subjected to one of four treatment combinations. Breasts were water cooked to an internal temperature of 78^{o}C. Hydrodyne treatment (HYD) of 350 g at 20 cm produced the greatest increase in Warner-Bratzler shear (1.9-cm wide strips) tenderness (28.3%), and was the only treatment to increase tenderness (peak force 4.3 kg) to a level equivalent ($P>0.05$) to aged controls (CA; peak force 3.1 kg). These results suggested that the pressure front relative to the amount of explosive and distance of the explosive to the meat surface affect the degree of tenderization.

The second objective of this research was to determine the quality and sensory characteristics of Hydrodyne treated broiler breasts as compared to CA and EB. Early de-boned breasts were treated with the combination of 350 g at 20-cm and analyzed for quality characteristics including tenderness, purge loss, cooking loss, color, and flavor. Initial pH values for CA (5.86) and EB (5.71) breasts were different ($P<0.05$). Warner-Bratzler and Lee-Kramer shear values (1.0-cm wide and thick strips) for CA (1.56 kg; 6.0 kg*mm/g, respectively) were different from both HYD (3.7 kg; 11.0 kg*mm/g, respectively) and EB breasts (4.7 kg; 12.1 kg*mm/g, respectively). CA resulted in more tender, flavorful, and juicer breasts than HYD and EB. HYD was lower in initial

moisture release than EB. HYD treatment does not adversely affect quality of EB breasts.

EB breasts with significant tenderness problems can be tenderized by the Hydrodyne process based on instrumental shear results. However, higher levels of explosive may be required to optimize the tenderness improvement of EB breasts that vary significantly in initial tenderness. Incorporation of this technology, once optimized, on an industry production level would benefit poultry processors in reducing or eliminating broiler breast aging.

3.2 Introduction

A major limiting factor in broiler processing is the need to age broiler breasts prior to de-boning. Consumers have found early de-boned breasts to be unacceptably tough (Lyon et al., 1985; Lyon and Lyon, 1990a). A delayed boning time of 4 to 7 hours postmortem (which alleviates the tenderness problem) results in a costly conversion process as it involves additional handling, extra storage space, added refrigeration, and results in considerable product shrinkage due to purge (Dickens and Lyon, 1995; Lyon et al., 1989). Poultry aging is the term for the mechanical restraint of chilled broiler breast meat on intact carcasses. The bones prevent shortening of the sarcomeres as rigor develops (Papa and Lyon, 1989). Any muscle that is restrained during rigor formation has the tendency to be tender due to less structural integrity resulting from the lack of overlapping thick and thin filaments of the myofibrils (Smith et al., 1991).

Many technologies including electrical stimulation (Sams et al., 1989; Maki and Froning, 1987), wing restraints or tensioning (Birkhold et al., 1992; Birkhold and Sams,

1993), marination (Young and Lyon, 1997), and a combination of these methods (Sams, 1990; Sams et al., 1991) have provided positive results in improving early de-boned broiler breast tenderness. In addition to decreasing shear values of turkey breasts, electrical stimulation significantly decreased Hunter Lab L values of cooked meat (Maki and Froning, 1987). However, as reviewed by Li et al. (1993), research with electrical stimulation of broiler breasts has produced inconsistencies due to different times of electrical stimulation application, aging techniques, electrical parameters such as voltage, frequency and wave cycle, variable tenderness analysis procedures, and biological and physiological variations. Therefore, none of the aforementioned technologies assure broiler breast tenderness.

Ultrasound has been investigated as a method to tenderize meat. Lyng et al. (1997) suggested that ultrasonic techniques cause lysosomal rupture as well as myofibrillar protein and connective tissue disruption that result in tenderization of the meat. In a study of low frequency, high intensity ultrasound baths on beefsteaks, Lyng et al. (1997) reported that the baths were not effective in improving tenderness of intact beef steaks. These results are inconsistent with a study in which high intensity, low frequency (26 kHz) ultrasound was determined to tenderize *semitendinosus* beef muscle when sonicated for 2 and 4 min (Smith et al., 1991).

Hydrostatics is the study of characteristics of liquids at rest or the force that a liquid imposes on a submerged object (Solomon et al., 1997a). MacFarlane (1973) researched the effects of hydrostatic pressure on beef and lamb. An improvement in tenderness was determined when the meat was treated with hydrostatic pressure of 1.05 x 10^7 kg/m^2 at 30 to 35^{o}C for a two-minute duration. Kennick et al. (1980) confirmed the

results of the previous study and determined that hydrostatic pressure accelerated meat aging and improved tenderness. Water holding capacity was decreased due to cellular disruption in pressurized samples (Kennick et al., 1980). Further sensory studies have not been conducted to determine the consumer response to pressurized meat. Kennick et al. (1980) reported obvious visual contraction of treated muscles and MacFarlane (1973) reported a notable change in raw firmness of treated muscles. This technology lacks extensive development and industrial applications seen in other areas.

The Hydrodyne process, redesigned by John Long, (U.S. Patent #5,273,766 and #5,328,403) is a novel technology being developed and tested by the USDA's Agricultural Research Service Meat Science Research Laboratory to tenderize beef, pork and lamb (Solomon et al., 1996; Solomon et al., 1997a; Solomon et al., 1997b). The Hydrodyne process is the use of a hydrodynamic force of a shock wave on an object in a fluid. The shock wave travels rapidly through the fluid (water) and any objects (in the fluid) which are an acoustical match to water (Kolsky, 1980). Since meat is composed of 75% water (Pearson, 1987), the wave passes through the sample and ruptures proteins during the Hydrodyne treatment. The sarcomeres are ruptured indiscriminately through the myofibrillar proteins, z disks, and surrounding structures (Zuckerman and Solomon, 1997; Solomon et al., 1997b). The explosive used to create a shock wave is a combination of nitromethane (liquid) and ammonium nitrate (solid). These components are not explosive until combined (Solomon et al., 1997a). The amount of explosive and the distance of the explosive to the surface of the packaged meat product determine the amount of force imposed on the meat (Personal communication, Morse Solomon, 1997).

A three-part study conducted by Solomon et al. (1997a) analyzed the effectiveness of the Hydrodyne process on fresh, frozen, and hot boned beef muscles. These studies were conducted in a small scale Hydrodyne unit consisting of a plastic container (208-L capacity and 51-cm diameter) fitted with a 2-cm thick steel plate (Solomon et al., 1997a). The container was situated below ground level and filled with water. The first part examined different amounts of explosive (50, 75, and 100 g) suspended at 30.5 cm from the meat surface and the effects of multiple Hydrodyne treatments. Fresh and frozen longissimus muscle (LM) steaks were treated. Solomon et al. (1997a) reported a reduction in Warner-Bratzler shear force of 49 to 72% for the fresh cooked LM steaks. The meat treated with two concurrent blasts (Hydrodyne treatment) resulted in the largest shear-force improvement (72%). The second study consisted of fresh beef *biceps femoris* treated with the Hydrodyne process (50, 75, and 100 g of explosive). Based on shear force data, these muscles were considered initially tender; however, the Hydrodyne process still resulted in a 19 to 30% reduction in shear values. No differences in raw appearance or color were noted in the muscles post-treatment. In the third study, selected loin and round muscles were hot-boned from 2-year-old Holstein cows and stored (1 day at 4^{o}C), subsequently frozen (-34 ^{o}C), and then thawed before Hydrodyne treatment. LM tenderness was improved by 66%, and the round muscles were improved as much as 53 to 59% using the Hydrodyne process (100 g of explosive) compared to untreated muscles. The authors suggested that the high shear values in the non-hydrodyne treated muscles were due to cold shortening; therefore, the Hydrodyne treatment effectively tenderized cold-shortened meat (Solomon et al., 1997a).

Currently, there is no known published material utilizing the Hydrodyne technology on tenderizing early de-boned broiler breasts. The objectives of this study were first to determine the effect of different combinations of explosive amount and distance of explosive to meat surface for tenderizing early de-boned broiler breasts using the Hydrodyne process. From the results of the first objective, the most effective Hydrodyne treatment was selected for determining the sensory and quality characteristics of Hydrodyne treated early de-boned broiler breast meat.

3.3 Materials and Methods

3.3.1 Sample preparation and treatment

Fresh boneless, skinless chicken breasts (*Pectoralis superficialis*) were obtained during two different weeks (for each objective) from a Virginia processor and stored overnight at 4^{o}C until treatment. The samples were treated within one-day postmortem. The treatment groups included: 1) control aged breasts (CA; stored on ice at least 6 hours prior to deboning), 2) early de-boned breasts (EB; de-boned immediately after the initial chill time during processing; approximately 45 minutes postmortem), and 3) Hydrodyne treated early de-boned breasts (HYD). Relative to the latter two treatments, for each breast, one lobe was assigned to the EB treatment and the companion lobe was assigned to a Hydrodyne treatment. Each lobe was labeled with brine tags inserted through the thin, posterior end of the breast with a tagging gun.

For objective 1, four treatments were tested using specific explosive levels and distance of explosive to meat surface combinations including: 200 g at 20 cm; 350 g at 23 cm; 275 g at 20 cm; and 350 g at 20 cm. Based on explosive modeling curves developed

for the Hydrodyne forces by John Long, these combinations produced pressure fronts of 142 MPa (20,600 psi), 159 MPa (23,000 psi), 163 MPa (23,600 psi), and 177 MPa (25,700 psi), respectively. The initial explosive level and distance combinations used in this study were determined based on a non-replicated preliminary study (unpublished data). The explosive level of 200 g at 20 cm and 26.4 cm was tested to determine effectiveness of the Hydrodyne process on early de-boned broiler breasts. The 200 g at 20 cm produced a higher improvement in tenderness as compared to the 200 g of explosive at 26.4 cm. Lobes (five per bag) designated for Hydrodyne treatments were vacuum packaged[1] in sized and sealed 35 x 37.5-cm bone-guard bags.[2] Lobes were treated for each pressure front level, and each treatment was replicated three times. The packaged lobes were positioned in the bottom center of the stainless steel 1,060 L capacity Hydrodyne tank with the skin-less skin side of the lobes closest to the explosive. The Hydrodyne tank was supported by eight-rubber gasket lined mounting braces. A certified explosive expert performed the handling and detonation of the explosive. The Hydrodyne process was conducted in a commercial pilot plant facility.[3]

For objective two, one lobe from each EB was assigned to the EB treatment and the companion lobe was assigned to a Hydrodyne treatment. A separate set of aged broiler breasts was evaluated as CA samples. HYD samples were treated with the most effective explosive level and distance from explosive to meat surface combination of 350 g at 20 cm (25,700 psi) and compared to CA and EB lobes. Approximately 10 lobes per

[1] model LV10 Hollymatic with dual seam; seal settings 6.0, full vacuum
[2] B-6250, bone-guard, Cryovac North America, Division of WR Grace & Co. Duncan, SC 29334
[3] Tenderwave Inc., Buena Vista, Virginia 24416

bag were vacuum packaged. Replications 1 and 2 were vacuum packaged[4] in 48 Ga PET adhesive laminated multilayer sealant LLDPE.[5] Replications 3 and 4 were vacuum packaged in coextruded film bags with an EVOH barrier, LLDPE sealant and nylon structural layers.[6] The different bags were used since there was not one bag type that was previously established to prevent bag failure when used in the Hydrodyne process. Based on unpublished data, differences in bags have not had any significant effect on the efficacy of the Hydrodyne process (Personal communication, Morse Solomon, 1997). The packaged products were positioned in same manner in the Hydrodyne tank as in objective 1.

3.3.2 Sample Cookery

The breast lobes were individually vacuum packaged[7] after the Hydrodyne process and cooked at three days postmortem using a sous vide method modified from Lyon and Lyon (1990b). The lobes were cooked fresh instead of from the frozen state and cooked to an internal temperature of 78^{o}C, instead of 77 ^{o}C in an in-house manufactured circulating water bath preheated and maintained at 78^{o} C. Several representative samples were placed in different locations in the water bath with type T thermocouples[8] inserted into the thickest part of the lobes to monitor core temperature. Temperature data was collected using an automatic data recorder.[9] Another deviation from the procedure of

[4] model LV10 Hollymatic with dual seam; seal settings 5.0, full vacuum
[5] H6230B, Cryovac North America, Division of WR Grace & Co. Duncan, SC 29334
[6] 9450-AA, Curlon grade, Curwood Inc., Oshkosh, WI 54901
[7] 030026 501655, 3 mil Std Barrier, Nylon/PE Pouch; Koch Supplies Inc., 1524 Vernon, Kansas City, MO 64116
[8] Omega Engineering, Inc., Stamford, CT 06907
[9] model 5100, Datalogger, Electronic Controls Design, Inc., Milwaukie, OR 97222

Lyon and Lyon (1990b) was that once the lobes reached an internal temperature of 78°C, the samples were held at that temperature for 10 minutes. The lobes were removed from the bath and immediately cooled in ice slush for 10 minutes and then stored at 4°C until further analysis.

3.3.3 Shear Force Measurements

Tenderness was assessed the same day (within 5 hours) that the lobes were cooked. For objective 1, a modified objective texture method (Lyon and Lyon, 1990b) was used. The strips were modified by using a 3.0-cm strip length cut medially and adjacent to one another, rather than cut in half lengthwise. Five lobes equilibrated to room temperature from each treatment were used for shear force determinations. Two adjacent 1.9-cm wide strips were cut from the medial area of the cooked lobe parallel to the muscle fibers. Each strip was sheared two to three times and an average was calculated. Samples were sheared perpendicular to the muscle fibers using a Warner-Bratzler shear attachment mounted on an Instron.[10] A fifty-kg load transducer and a crosshead speed of 200 mm/min was used.

For objective two, nine lobes equilibrated to room temperature from each treatment were used for shear force determinations. Two adjacent 1.0-cm strips (width and height) were cut from the medial area of the cooked lobe parallel to the muscle fibers. The first cut of the breast was made 2-cm from the thick anterior end of the lobe. A strip was then cut parallel to the muscle fibers. Once muscle orientation was determined for that strip, the strip was trimmed to a 1.0-cm size. This process was

[10] model 1011, Instron Corp., Canton, MS 39046

repeated for each strip. All strips were cut from the center of each breast and were trimmed to a length of 3.0 cm. The first, second and third strips from the anterior to posterior end of each breast were allotted to sensory, Warner-Bratzler shear, and Lee-Kramer shear, respectively. This sampling strip method was determined in preliminary studies to allow for the control of fiber direction. One strip was sheared perpendicular to the muscle fibers using a Warner-Bratzler shear attachment mounted on the Instron. A fifty-kg load transducer and a crosshead speed of 200 mm/min was used. The strip was sheared three times and an average calculated. The second 1.0-cm strip was weighed and sheared using a Lee-Kramer shear attachment mounted on the Instron. To determine the total energy (kg*mm) per gram, 500-kg load transducer and a crosshead speed of 200 mm/min was used.

3.3.4 Sensory Evaluation

Nine panelists consisting of employees at Virginia Tech evaluated CA, EB and HYD treated samples. The panelists were trained in four training sessions lasting approximately one hour each. The panelists evaluated the tenderness, moisture release (initial and sustained), and chicken flavor of the samples. The tenderness characteristic was based on myofibillar tenderness and was measured within the first five chews. Tenderness was defined as the ease of fragmentation or the ability for the teeth to cut across the meat fibers. By altering cooking techniques for aged broiler breasts, the reference standards for tenderness were developed. Breast samples were sous vide cooked to three internal temperatures (85^{o}C, 78 ^{o}C, and 74^{o}C) to provide a range of tenderness (not tender to very tender). The reference standards for moisture release

(initial and sustained) consisted of a modified wetness scale (Meilgaard et al., 1991). A carrot (low initial, low sustained), apple (high initial, low sustained), and ham (moderate initial, high sustained) were used for the initial training phases to train the panelists for the moisture release characteristic. Initial moisture release was measured within the first five chews. Sustained moisture release was measured as the amount of moisture released as the sample was masticated until it was suitable for swallowing. In the latter stages of training, moisture release was evaluated on sous vide breast samples cooked to three internal temperatures (85^{o}C, 78 ^{o}C, and 74^{o}C). Chicken flavor was defined as the amount of chicken flavor in a sample. By boiling chicken thighs in water (237 ml of water per chicken thigh), the reference standards for flavor were created. The thighs were boiled for three hours and the thighs removed. The stock was chilled and skimmed of excess fat. This stock was used for the high end (strong chicken flavor) of the line scale for flavor. The bones from the boiled thighs were removed and boiled (3 hours) in 237 ml water per thigh bone, chilled and skimmed of excess fat to create the anchor definition of slight at the low end of the scale.

Nine lobes cooked by the aforementioned sous vide method were evaluated by the experienced sensory panel within three hours of cooking. The third 1.0-cm strip taken from each breast with the procedure outlined in shear evaluations was used for sensory evaluation. All strips were trimmed to a length of 3.0-cm, stored individually in capped plastic containers (4^{o}C) and then served at room temperature. Nine panelists evaluated 1.0-cm strip samples for tenderness (0=not; 15= very), initial moisture release (0=none; 15=extreme) and sustained moisture release (0=not; 15= very), and chicken flavor (0=slight; 15=strong) on unstructured line scales (15.0 cm). Panelists were instructed to

cleanse their palate with water between each sample and wait 60 seconds before tasting the next product. The panelists conducted the sensory evaluation in a sensory panel booth under red lighting to eliminate any color differences. The strip samples were randomly presented in capped containers coded with randomly selected three digit codes. Each panelist evaluated the samples independently. For each panelist, the early de-boned sample was paired with its corresponding early de-boned Hydrodyne treated breast sample; however, the panelists were not aware of the pairing and only one sample was served at a time.

3.3.5 Purge Losses and pH

Two lobes from each treatment were weighed prior to treatment, and after 24 hours of refrigerated storage. Two CA lobes, EB lobes, and companion HYD lobes were stored in oxygen permeable PVC wrap and patted dry before weighing at room temperature. The percentage of weight loss was calculated for storage purge losses using the equation: (initial weight-24 hr weight)/initial weight *100. The initial pH of the CA and EB lobes was measured using a pH probe[11] inserted into the thick anterior region of the lobes.

3.3.6 Breast Plumpness

The thickness of two lobes per treatment of similar weight was measured every 2 cm of the lobe length from the anterior (thick end) to posterior end before and after

[11] model IQ200, pH05 stainless steel ISFET probe with a 60^{o} tip, IQ Scientific Instruments, Inc., San Diego, CA 92198

Hydrodyne treatment. EB breasts were measured and then treated with the Hydrodyne process. Measurements were taken by piercing the lobes with a metal probe (0.2-cm diameter) in the same locations prior-to and after Hydrodyne treatment.

3.3.7 Cooking Loss

The cooking loss was determined on all samples cooked for sensory determination. The surface of the raw and cooked samples was patted dry weighed at refrigerated temperature (4^{o}C). Cooking loss values were calculated based on the equation of (raw weight - cooked weight)/raw weight * 100. An average cooking loss was determined for each treatment group (CA, EB, and HYD).

3.3.8 Instrumental Color

Fresh, untreated breasts destined for the Hydrodyne treatment were analyzed for CIE L*a*b* readings using a chroma meter.[12] The chroma meter was calibrated using a standard calibration plate.[13] Three readings were taken on two breasts per treatment (EB, HYD, and CA) on the lateral (skin side) and medial (bone side) sides of the breast lobes, before the Hydrodyne treatment and after treatment. Breasts were exposed to air for 30 minutes prior to color analysis by suspending the breast by the thin, posterior end of the muscle.

Cooked color of two samples from each treatment was analyzed using the chroma meter calibrated against the standard white plate. Three readings were taken on

[12] model CR-200, Minolta Corporation, Ramsey, NJ 07446
[13] white plate, No. 20933026; CIE L* 97.91, a* -0.70, b* +2.44, Minolta Corporation, Ramsey, NJ 07446

the medial and lateral side of the breast lobes and an average by each location (medial and lateral) was calculated.

3.3.9 Statistical Analysis

Objective 1: Early de-boned breasts with mean peak force values less than 3.62 kg and their corresponding treatment lobes were eliminated from the data set. This was done because Lyon and Lyon (1990b) reported that breast meat with a peak force of 3.62 kg was determined to be "very tender" in consumer studies.

For both objectives: The peak force shear values were averaged over breast for each treatment, as each breast within a blast represented a sub-sample. CA and HYD treatment significance was determined by the analysis of variance (ANOVA) procedure using the General Linear Models (GLM) procedure of SAS (1992). Paired sample t-tests (proc univariate) were utilized to evaluate differences between EB and paired, HYD treated early de-boned samples. The t-test was used due to a lack of independence between the two samples. Additionally, the significance between CA and EB controls was determined with a two-sample t-test (proc ttest) of SAS (1992).

These same statistical procedures were also utilized to determine differences in raw color, cooking loss, cooked color, purge losses, and for each characteristic of sensory evaluation. The sensory scores were averaged for each treatment within a replication. The paired EB and HYD samples were evaluated with paired sample t-tests (proc univariate) for each of the aforementioned characteristics. The CA and EB controls as well as the CA and HYD samples were compared with two-sample t-tests (proc ttest) of SAS (1992) for each characteristic.

Plumpness was analyzed by the paired t-test procedure of SAS (1992). This procedure was used due to a lack of independence for each measurement within a breast. Initial pH analysis was determined using a two sample t-test (proc ttest) of SAS (1992).

3.4 Results and Discussion

3.4.1 Shear Force Measurements

Objective 1:

The original data set contained 15 samples for each treatment (three replications) except treatment 4 that contained 13. The number of lobes varied by treatment due to standardization of the data to eliminate pairs with shear force values <3.62 kg which would correspond to chicken that was considered very tender (Lyon, and Lyon, 1990b). Sams and Janky (1986) reported that early de-boning of broiler breast meat results in unacceptable tenderness, and the variability of tenderness in early de-boned samples is increased between carcasses.

The broiler breasts treated with a explosive and distance combination of 350 g at 20 cm (treatment 4) were more tender ($P<0.05$) than their paired early de-boned breasts (Table 1-A) and were also similar ($P>0.05$) to the aged controls (Table 1-B). These data indicate that treatment 4 was the most effective explosive and distance combination of those levels examined. Treatment group 2 was the only other group that produced a lower ($P<0.05$) shear force using the Hydrodyne treatment compared to the companion non-treated early de-boned lobes. However, this treatment did not improve tenderness to a level equivalent to the aged controls. The mean Warner-Bratzler shear value of the aged controls was 3.1 kg, which would correspond to a breast rated as tender on the

sensory scale developed by Lyon and Lyon (1990b). Treatment 4 mean shear value of 4.3 kg corresponded to breasts rated in the slightly to moderately tender category (Lyon and Lyon, 1990b).

Although not statistically analyzed, EB breasts resulted in higher shear force means than aged controls. This agrees with Lyon and Lyon (1990b) in which breasts were de-boned prior to 2 hours post-mortem resulted in higher shear force values than aged (6 hours) breasts.

The shear sample width (1.9-cm) was controlled for each sample. However the thickness of the shear samples were left as the natural breast thickness (approximately 1.3 cm to 1.9 cm) which was consistent with Lyon and Lyon (1990b) and Papa and Lyon (1989). This irregularity may also in part explain some of the differences among early de-boned control groups. In objective 2, the thickness, as well as the width of the samples were controlled.

A 28.3% improvement in broiler breast tenderness was realized for treatment 4. In other Hydrodyne studies with hot-boned beef muscles stored for 24 hours before Hydrodyne treatment, a 53% to 66% range of tenderness improvement was realized (Solomon et al., 1997a). This percentage range was related to differences in the muscles tested (longissimus, 66%; biceps femoris, 53%). The explosive and distance combinations used in our study produced a pressure front range of 142 MPa (20,600 psi) to 177 MPa (25,700 psi). In the beef study, the pressure fronts were measured in the range of 6.05×10^6 to 7.03×10^6 kg/m^2. The differences between percentage improvement in tenderness of beef versus chicken may be related to differences in the physical nature of the meat. In general, beef is a firmer and more rigid muscle than

chicken, which is soft, and pliable (Judge et al., 1989). Additionally differences between Hydrodyne tenderization may be due to fiber orientation in beef steaks versus chicken breast fillets. As shock waves change the microstructure of solids and subsequently the mechanical properties of the solids subjected to shock loads, an increase in hardness may occur (Batsanov, 1994). This hardening effect occurs in metals such as steel alloys. The amount of hardness developed can change as super high pressures decrease metal hardness due to residual heating (Batsanov, 1994). The shock wave generated during the Hydrodyne process may compress and compact the chicken fibers, causing hardening, to result in a less tender product. No known literature exists on the effects of shock waves on biological tissues in relation to food quality characteristics. The texture of the chicken breasts did not appear to be over-tenderized (visually or physically mushy).

Objective 2:

There was a 19.1% improvement in tenderness of the HYD over the EB for the Warner-Bratzler (WBS) shear measurements and a 9.1% improvement in Lee-Kramer (LK) total energy measurements (Table 2). However, the Hydrodyne treatment did not produce a product of similar tenderness to the CA as determined by WBS and LK shear measurements. The magnitude of the improvement in tenderness (19.1%) was less than that determined in objective 1 (28.3%). The EB breasts were not standardized for initial tenderness as done in objective 1 since the sampling method was changed from objective 1 to objective 2. In objective 1, the samples were obtained using the same method as Lyon and Lyon (1990b); therefore, the data set could be standardized.

In efforts to determine the cause of increased variation of tenderness, several researchers have investigated location effects of aging on tenderness (Papa and Fletcher,

1988; Papa and Lyon, 1989; Lyon and Lyon, 1997). Papa and Lyon (1989) suggested that during cooking the thin caudal end of the breast would harden more than the cranial end. The authors further reported that aged intact caudal end of the samples were rated (sensory panel) as harder and chewier than the cranial location. The reverse situation was found for hot-boned groups (Smith et al., 1988; Papa and Lyon, 1989). Conversely, Papa and Fletcher (1988) reported no significant difference between the anterior, middle or posterior sections of aged (24 hours) intact *pectoralis* muscle. Similarly, Lyon and Lyon (1997) noted that no differences in shear were observed due to location on the carcasses.

The sample strips for our study (objective 2) were cut starting from the thick, anterior end of the lobes. Then the strip was trimmed of the outer edges until a middle 1.0-cm wide and thick strip (parallel to muscle fibers) was obtained. Only the widths (1.9-cm) of the strips were controlled in objective 1. The three strips from objective 1 resulted in a greater area of the breast required for sampling. Since these strips were larger, the thinner, posterior end of the breast was included in some samples depending on breast size. The strips in objective 2 were more controlled and were obtained from the same thick, anterior end of the breast. These differences in strip sampling may provide evidence for differences in CA shear values in objective 1 (3.1 kg) and objective 2 (1.6 kg). The Lee-Kramer values reported for CA in our study (12.1) are slightly higher than values reported by Bilgili et al. (1989) of 10.1 and 11.1 kg/g for 0^{o}C and 14^{o}C aging (4 hours) temperatures, respectively. Additionally the sample size in our study (1.0 cm x 1.0 cm x 3.0) was larger than the Bilgili et al. (1989) study sample size (0.2 cm x 0.4 cm x 0.3 cm).

3.4.2 Sensory Evaluation

CA was more ($P<0.05$) flavorful and tender than EB (Table 3-A) which agrees with our instrumental tenderness results. No differences ($P>0.05$) in moisture release between CA and EB were noted which agrees with Lyon and Lyon (1996). Lyon and Lyon (1991) reported that juiciness was not correlated with instrumental tenderness. It was expected that a less intense flavor of the EB breasts would correspond to increased moisture release since EB breasts have more contracted sarcomeres (Dunn et al., 1993) and decreased spatial ability to bind water (Judge et al., 1989). The instrumental differences in tenderness were not at a perceivable difference for the experienced panel in this study.

The initial moisture release for the HYD breasts was lower ($P<0.05$) than the EB. Therefore the HYD samples were juicier within the first five chews of the sample. No other differences were noted between HYD and EB (Table 3-B). However, both the WBS and LK tenderness measurements indicated that the HYD was more ($P<0.05$) tender than the EB breasts. The experienced panel did not perceive this difference (Table 3-B).

HYD had a less intense ($P<0.05$) flavor, lower ($P<0.05$) initial and sustained moisture release and was less ($P<0.05$) tender than CA (Table 3-C). Meaty flavor associated components are contained in the water soluble fractions of muscle tissue (Judge et al., 1980). HYD had the highest cooking loss of all treatments and this extra moisture loss may contribute to lower flavor response in HYD breasts.

3.4.3 Plumpness

Although not statistically analyzed, breast plumpness decreased from anterior to posterior ends regardless of treatment (Table 4). The overall mean plumpness value was not determined, because plumpness was determined at specific incremental distances along the breast. Hydrodyne treatment decreased ($P<0.05$) breast plumpness at sample locations of 2, 4, 6 and 8-cm compared to the companion EB breasts (Table 4). Beyond the 8-cm measurement, there were not any differences in plumpness between EB and HYD.

3.4.4 pH and Purge Loss

The initial pH of EB breasts (5.71) was lower ($P<0.05$) than the CA (5.86) which agrees with Dunn et al. (1993). In contrast, Sams et al. (1990) reported a chill-boned breast (de-boned 1 hour post-mortem) final pH of 5.86 which was similar to the age-boned breast final pH of 5.80. The aged controls in our study were aged for 6 hours prior to de-boning, whereas the Sams et al. (1990) age-boned breasts remained intact for 24 hours. Conversely, Dunn et al. (1995) reported pH values of 5.93 for aged controls (24 hours). pH for Hydrodyne treated breasts was not determined.

Purge loss was not affected by treatment (Table 5). In contrast, Solomon et al. (1996) reported that Hydrodyne treated pork longissimus muscles had a 14% decrease in purge loss compared to non-Hydrodyne treated samples. Our study agrees with Froning and Ujttenboogaart (1988) who reported that expressible moisture was not affected by de-boning time when broilers were held at 15^{o}C.

3.4.5 Cooking Loss

There were no differences in cooking loss between CA and EB (Table 5-A). HYD had a higher cooking loss than the EB samples (Table 5-B). The higher cooking loss for HYD samples would support the lower initial moisture release determined by sensory testing. The CA breasts were not different ($P>0.05$) in cooking loss than HYD (Table 5-C). Bilgili et al. (1989) determined that post-mortem aging temperatures of 28 or 41^{o}C increased cooking losses and an aging temperature of 0^{o}C decreased cooking losses compared to aging at 14 ^{o}C.

3.4.6 CIE L*a*b* Color

The raw CA breasts were more red ($P<0.05$) than the EB breasts (Table 6-A). HYD treated breasts were darker ($P<0.05$) on the skin side than EB breasts. No other color differences were determined between HYD and EB (Table 6-B). HYD resulted in breasts that were less ($P<0.05$) red than CA regardless of location (Table 6-C). No other color differences were noted between CA and HYD.

In replication 1, an undetermined amount of the bags failed during the Hydrodyne treatment. This may have allowed for the possibility of contaminants coming in contact with some of the breasts resulting in a darker color. The explosive used to create the shock wave was a combination of nitromethane (liquid) and ammonium nitrate (solid). A potential by-product produced during treatment is nitric oxide. In meat, nitric oxide acts as a ligand to bind to the heme iron of metmyoglobin to produce nitric oxide metmyoglobin which is a brown pigment (Judge et al., 1989). When this pigment is reduced to nitric oxide myoglobin, it forms a red pigment (Fox, 1987; Judge et al., 1989).

Therefore, if nitric oxide reacted with the heme iron in the Hydrodyne treated broiler breasts, oxidation to a brown color would have resulted in less red, darker breasts as compared to CA.

The raw color of the bone side of the CA breast was characterized as more ($P<0.05$; Table 7) red (higher a* value) and more ($P<0.05$) yellow (higher b* value) than the skin side of the breast. Conversely, the EB was lighter ($P<0.05$) on the inside of the breast. Similarly, both the EB and HYD was more ($P<0.05$) yellow (higher b* value) on the bone side of the breast compared to the skin side. Additionally, the HYD sample color followed the same trend as the CA such that the samples were also more ($P<0.05$) red on the bone side of the breast.

No differences in cooked color of the CA and EB were noted for all characteristics (Table 8-A). The skin side of the HYD breasts were darker ($P<0.05$) than the EB breasts (Table 8-B) which was consistent with the raw color of the breasts. The skin sides of HYD breasts were darker ($P<0.05$) in cooked color than the CA breasts (Table 8-C) which was not found in the raw breasts. Despite a difference in redness of the raw breasts between HYD and CA, this difference did not exist in cooked breasts. No other differences were noted between EB and HYD, as well as CA and HYD.

Myoglobin, hemoglobin, and cytochromes are water soluble sarcoplasmic proteins largely responsible for meat color (Judge et al., 1989). Native reduced myoglobin (oxymyoglobin and deoxymyoglobin) is characterized as a red to dark red pigment. Cooking denatures myoglobin producing the brown pigment hemichrome (Fox, 1987). Due to denaturation of the meat pigments, cooking may have reduced the color differences noted between treatments in the raw breasts. Additionally, the darker color of

the HYD breasts compared to EB and CA may be related to the higher cooking loss of the HYD breasts. Pale pork color is associated with a high amount of free water that reflects light (Fox, 1987). There may have been less surface water in the HYD to reflect light resulting in a darker color.

The CA breasts follow the same pattern for cooked color as raw color in which the bone side was more ($P<0.05$) red and more ($P<0.05$) yellow than the skin side breast (Table 9-A). The EB breasts were also more red ($P<0.05$) on the bone side compared to the skin side (Table 9-B). This difference was not determined in the raw breasts. Although there were difference in CIE L* and b* values in raw breasts, there were not differences ($P>0.05$) in the cooked EB breasts between locations. The HYD breasts were characterized as more ($P<0.05$) red and darker ($P<0.05$) on the bone side compared to the skin side (Table 9-C). This darkness difference was not measured in the raw HYD breasts. In addition, the difference in yellowness between HYD location in the raw breasts was not apparent in the cooked breasts.

3.5 Summary and Conclusions

Based on shear values, the Hydrodyne process may be used to tenderize (19.1% to 28.3% improvement) early de-boned broiler breasts. The explosive level and distance combination of 350 g at 20 cm produced a product with similar shear values to CA. However, this level of treatment was not sufficient to improve EB breast tenderness to a level equivalent to CA based on sensory response of an experienced panel. Plumpness was decreased in Hydrodyne treated breasts as compared to the thick early de-boned breasts. Cooking reduced the color differences between treatments in raw breasts. The

purge loss was not affected by the Hydrodyne process or de-boning treatment. Higher-pressure fronts may be necessary to increase the efficacy of improving early de-boned broiler breast tenderness. If successful, poultry processors would benefit financially from the reduction or elimination of the standard broiler breast aging time of 4 to 6 hours.

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Table 1--Warner-Bratzler shear peak force values for Hydrodyne treated skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts cooked to 78°C

Part A--Differences in mean shear values for companion early de-boned Hydrodyne treated and non-treated breasts

Treatment Group[c]	N=	Peak force (kg) for early de-boned breasts		SD[d]
		Non-Hydrodyned	Hydrodyned	
1	10	6.2[abx]	5.4[x]	1.8
2	10	7.5[ax]	5.6[y]	2.5
3	8	5.4[bx]	4.7[x]	1.1
4	11	6.0[bx]	4.3[y]	1.2
		(MSE 1.84)		

Part B--Differences between Aged control and Hydrodyne lobes

Treatment Group[c]	N=	Peak force (kg)
Aged	15	3.1[a] ± (0.9)[e]
1	10	5.4[b] ± (2.0)
2	10	5.6[b] ± (2.0)
3	8	4.7[b] ± (1.7)
4	11	4.3[ab] ± (1.9)
		(MSE 2.34)

[ab] Means within a column and part with unlike letters are different at P<0.05 by Duncan's New Multiple Range test.

[c]Treatment Group: Aged = breast lobes removed 6 hour post-mortem; Treatment groups 1 through 4 represent different Hydrodyne treatments, listed as grams of explosive and distance of explosive to meat surface; 1 = 200 g @ 20 cm (20,600 psi); 2 = 350 g @ 23 cm (23,000 psi); 3 = 275 g @ 20 cm (23,600 psi); 4 = 350 g @ 20 cm (25,700 psi).

Part A:

[xy]Means within a row with unlike letters are different at P<0.05. Due to a lack of independence within a chicken breast, a paired t-test was used to compare the non-hydrodyned versus the hydrodyned treatments.

[d]Standard Deviation for paired differences between companion lobes (Hydrodyne minus Non-hydrodyne).

Part B:

[e]Standard deviation for means.

Table 2--Mean Warner-Bratzler (WBS) and Lee-Kramer (LK) shear force values for Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts

Part A--Differences between aged and early de-boned controls

Treatment	N=	WBS Peak force (kg)	N=	LK Total Energy (kg*mm/g)
Aged	36	1.6[a] ±(0.3)	36	6.0[a] ±(1.8)
Early de-boned	36	4.7[b] ±(2.6)	33	12.1[b] ±(3.8)

Part B--Differences between early de-boned controls and companion Hydrodyne treated lobes

Treatment	N=	WBS Peak force (kg)	N=	LK Total Energy (kg*mm/g)
Early de-boned	36	4.7[a]	27	12.1[a]
Hydrodyne	36	3.8[b]	27	11.0[b]
SD[c]		(2.1)		(2.9)

Part C--Differences between aged controls and Hydrodyne treated lobes

Treatment	N=	WBS Peak force (kg)	N=	LK Total Energy (kg*mm/g)
Aged	36	1.6[a] ±(0.3)	36	6.0[a] ±(1.8)
Hydrodyne	36	3.8[b] ±(1.8)	29	11.0[b] ±(4.0)

[ab] Means±(SD) within a column and part with unlike letters are different at P<0.05 by two sample t-tests with degrees of freedom adjusted using a Satterthwaite correction, because variances were unequal (therefore no pooled MSE is reported).
[c]Standard deviation for paired differences between companion lobes (Hydrodyne-Early de-boned).

Table 3--Mean sensory values for flavor (FLV), initial moisture release (IMR), sustained moisture release (SMR), and tenderness (TEND) of Hydrodyne treated skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts evaluated by a trained sensory panel

Part A[c]--Mean score comparisons of aged with early de-boned controls

	Sensory Characteristic[d]			
	FLV	IMR	SMR	TEND
Aged	8.6[a]	8.0[a]	9.2[a]	10.9[a]
Early de-boned	7.1[b]	7.4[a]	8.1[a]	6.0[b]
MSE[e]	(7.4)	(7.3)	(6.9)	(9.3)

Part B[f]--Differences in mean scores for early de-boned controls and companion Hydrodyne treated lobes

	Sensory Characteristic[d]			
	FLV	IMR	SMR	TEND
Early de-boned	7.1[a]	7.4[a]	8.1[a]	6.0[a]
Hydrodyne	6.3[a]	5.8[b]	6.9[a]	6.7[a]
SD[g]	(3.6)	(3.0)	(3.6)	(4.2)

Part C[c]--Mean score comparisons of aged with Hydrodyne treated breasts

	Sensory Characteristic[d]			
	FLV	IMR	SMR	TEND
Aged	8.6[a]	8.0[a]	9.2[a]	10.9[a]
Hydrodyne	6.3[b]	5.8[b]	6.9[b]	6.7[b]
MSE[e]	(6.3)	(7.6)	(8.8)	(8.6)

[ab] Means within a column and part with unlike letters are different at $P<0.05$.

[d]Sensory characteristics were rated on a 15-cm line scale: FLV is the intensity of chicken flavor with 0=slight and 15=strong; IMR is the initial moisture release evaluated in the first five chews with 0=none and 15=extreme; SMR is the amount of moisture released as the sample was masticated until it was suitable for swallowing with 0=not and 15=very; TEND is the myofibrillar tenderness measured in the first five chews with 0= not to 15= very tender.

Part A and C:

[c]Two sample t-tests were used to analyze differences with equal variances.

[e]Mean Square Error

Part B:

[f]Paired differences between companion lobes were analyzed with paired t-tests.

[g]Standard Deviation for paired differences between companion lobes (Hydrodyne-Early de-boned).

Table 4--Plumpness for skinless early de-boned broiler breasts and companion Hydrodyne treated (350 g explosive at 20 cm) breasts

	Location[c]					
Treatment[d]	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm
Early De-boned	1.9[a]	1.7[a]	1.4[a]	1.2[a]	0.8[a]	0.6[a]
Hydrodyne	1.7[b]	1.5[b]	1.3[a]	1.0[b]	0.8[a]	0.6[a]
SD[e]	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	(0.3)

[ab] Means within a column with unlike letters are different at P<0.05 by paired t-tests.
[c]Location of plumpness measurement taken every 2-cm of the breast length beginning at the thick, anterior end (2-cm) and ending at the thin, posterior end (12-cm) of the breast.
[d]Early de-boned breasts removed from the carcasses immediately after the initial chill (45 minutes post-mortem) and stored for 24 hours. Early de-boned breasts (N=8) were measured using a metal probe (0.2-cm diameter) by piercing the breast at each location. These breasts were then treated with the Hydrodyne process and re-measured at the exact locations as prior to treatment.
[e]Standard Deviation for paired differences between Hydrodyne and Early de-boned breasts.

Table 5--Purge and cooking losses for Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts after 24 hour storage at 4°C

Part A[c]--Mean comparisons of aged controls with early de-boned controls

Treatment	N=	Purge Loss (%)	Cooking Loss (%)
Aged	8	0.86[a]	20.5[a]
Early de-boned	8	0.84[a]	20.1[a]
MSE[d]		(0.4)	(7.3)

Part B[e]--Differences between early de-boned controls and companion Hydrodyne treated lobes

Treatment	N=	Purge Loss (%)	Cooking Loss (%)
Early de-boned	8	0.84[a]	20.1[a]
Hydrodyne	8	0.55[a]	22.2[b]
SD[f]		(0.8)	(3.9)

Part C[c]--Differences between aged controls and Hydrodyne treated lobes

Treatment	N=	Purge Loss (%)	Cooking Loss (%)
Aged	8	0.86[a]	20.5[a]
Hydrodyne	8	0.55[a]	22.2[a]
MSE[d]		(0.7)	(13.1)

[ab] Means within a column and part with unlike letters are different at $P<0.05$.

Part A and C:
[c]Two sample t-tests were used to analyze differences with equal variances.
[d]Mean Square Error

Part B:
[e]Paired differences between companion lobes were analyzed with paired t-tests.
[f]Standard Deviation for paired differences between companion lobes (Hydrodyne-Early de-boned).

Table 6--Raw color (CIE L*a*b* values) for Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts for skin and bone side of the breasts

Part A[c]--Differences between aged and early de-boned controls

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Aged	8	56.94[a]	2.54[a]	1.28[a]
Early de-boned	8	58.26[a]	1.38[b]	1.72[a]
MSE[d]		(10.0)	(0.7)	(3.2)
Bone side				
Aged	8	55.98[a]	3.30[a]	3.26[a]
Early de-boned	8	54.91[a]	2.78[a]	4.07[a]
MSE[d]		(9.0)	(1.5)	(2.1)

Part B[e]--Differences between early de-boned controls and companion Hydrodyne treated lobes

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Early de-boned	8	58.26[a]	1.38[a]	1.72[a]
Hydrodyne	8	56.34[b]	1.30[a]	1.10[a]
SD[f]		(2.3)	(0.5)	(1.2)
Bone side				
Early de-boned	8	54.91[a]	2.78[a]	4.07[a]
Hydrodyne	8	55.58[a]	1.76[a]	3.16[a]
SD[f]		(3.0)	(1.8)	(1.2)

Part C[c]--Differences between aged controls and Hydrodyne treated lobes

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Aged	8	56.94[a]	2.54[a]	1.28[a]
Hydrodyne	8	56.34[a]	1.30[b]	1.10[a]
MSE[d]		(12.0)	(0.4)	(5.0)
Bone side				
Aged	8	55.98[a]	3.30[a]	3.26[a]
Hydrodyne	8	55.58[a]	1.76[b]	3.16[a]
MSE[d]		(9.3)	(0.4)	(3.1)

[ab] Means within a column, part, and location with unlike letters are different at P<0.05.

Part A and C:

[c]Two sample t-tests were used to analyze differences with equal variances.

[d]Mean Square Error.

Part B:

[e]Paired differences between companion lobes analyzed with paired t-tests.

[f]Standard Deviation for paired differences between companion lobes (Hydrodyne-Early de-boned).

Table 7--Raw color (CIE L*a*b* values) for the skin and bone sides of Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts

Aged Controls		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	56.94[a]	2.54[a]	1.28[a]
Bone side	8	55.98[a]	3.30[b]	3.26[b]
SD[c]		(2.8)	(0.6)	(1.3)

Early De-boned		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	58.26[a]	1.38[a]	1.72[a]
Bone side	8	54.91[b]	2.78[a]	4.07[b]
SD[c]		(3.7)	(2.1)	(1.3)

Hydrodyne		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	56.34[a]	1.30[a]	1.10[a]
Bone side	8	55.58[a]	1.76[b]	3.16[b]
SD[c]		(2.4)	(0.3)	(1.2)

[ab] Means within a column with unlike letters are different at P<0.05 by paired t-tests.
[c]Standard Deviation for paired differences between skin and bone sides of the breast.

Table 8--Cooked color (CIE L*a*b* values) differences for Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts for skin and bone sides of the breasts

Part A[c]--Comparison of aged and early de-boned controls

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Aged	8	84.14[a]	2.30[a]	9.58[a]
Early de-boned	8	84.55[a]	2.42[a]	9.84[a]
MSE[d]		(5.3)	(0.4)	(0.9)
Bone side				
Aged	8	83.58[a]	2.95[a]	10.40[a]
Early de-boned	8	82.62[a]	3.43[a]	10.82[a]
MSE[d]		(6.5)	(0.8)	(0.8)

Part B[e]--Comparison of early de-boned controls and companion Hydrodyne treated lobes

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Early de-boned	8	84.55[a]	2.42[a]	9.84[a]
Hydrodyne	8	84.04[b]	2.84[a]	9.89[a]
SD[f]		(2.3)	(0.5)	(1.2)
Bone side				
Early de-boned	8	82.62[a]	3.43[a]	10.82[a]
Hydrodyne	8	81.29[a]	3.51[a]	10.31[a]
SD[f]		(3.0)	(1.8)	(1.2)

Part C[c]--Comparison of aged controls and Hydrodyne treated lobes

Treatment and Location		CIE Values		
Skin side	N=	L*	a*	b*
Aged	8	84.14[a]	2.30[a]	9.58[a]
Hydrodyne	8	84.04[b]	2.84[a]	9.89[a]
MSE[d]		(4.2)	(0.5)	(1.2)
Bone side				
Aged	8	83.58[a]	2.95[a]	10.40[a]
Hydrodyne	8	81.29[a]	3.51[a]	10.31[a]
MSE[d]		(5.0)	(0.3)	(0.9)

[ab] Means within a column, part, and location with unlike letters are different at P<0.05.

Part A and C:

[c]Two sample t-tests were used to analyze differences with equal variances.

[d]Mean Square Error.

Part B:

[e]Paired differences between companion lobes analyzed with paired t-tests.

[f]Standard Deviation for paired differences between companion lobes (Hydrodyne-Early de-boned).

Table 9--Cooked color (CIE L*a*b* values) of the skin and bone side of Hydrodyne treated (350 g explosive at 20 cm) skinless early de-boned broiler breasts, companion early de-boned (no treatment) breasts, and aged (control) breasts sous-vide cooked to an internal temperature of 78°C

Aged Controls		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	84.14[a]	2.30[a]	9.58[a]
Bone side	8	83.58[a]	2.95[b]	10.40[b]
SD[c]		(2.1)	(0.6)	(0.6)

Early De-boned		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	84.55[a]	2.42[a]	9.84[a]
Bone side	8	82.62[a]	3.43[b]	10.82[a]
SD[c]		(2.4)	(0.5)	(1.5)

Hydrodyne		CIE Values		
Location	N=	L*	a*	b*
Skin side	8	84.04[a]	2.84[a]	9.84[a]
Bone side	8	81.29[b]	3.51[b]	10.31[a]
SD[c]		(2.1)	(0.5)	(1.1)

[ab] Means within a column with unlike letters are different at $P<0.05$ by paired t-tests.
[c]Standard Deviation for paired differences between skin and bone sides of the breast.