HIGH PRESSURE HYDRODYNAMIC SHOCK WAVE EFFECTS ON TENDERNESS OF EARLY DEBONED BROILER BREASTS.

by

Jennifer K. Schilling

Thesis submitted to the Faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Food Science and Technology
Virginia Polytechnic Institute and State University

Signatures of Advisory Committee and Department Head:

__________________________________________  _______________________________________
Dr. J.R. Claus, Chair                                      Dr. N.G. Marriott

__________________________________________  _______________________________________
Dr. M.B. Solomon                                         Dr. S.E. Duncan

__________________________________________  _______________________________________
Dr. H. Wang                                              Dr. C.R. Hackney, Dept. Head

January 11, 1999
Blacksburg, Virginia

Keywords: Hydrodynamic Shock Wave, Tenderness, Broiler
Jennifer K. Schilling

Abstract

Breast muscles that are deboned prior to 4 to 6 h postmortem are highly variable and lacking in tenderness. The poultry industry currently provides costly storage space for intact broiler breasts during this 4 to 6 h period. This thesis evaluates tenderization techniques that if effective could eliminate the need for this additional 4 to 6 h storage time. The first objective of this study was to determine a relationship between Warner-Bratzler shear values (WBS) (1 cm by 1cm, variable length strips) and consumer tenderness acceptability of broiler breasts. The breasts were divided into five groups based on their WBS values. Consumers were presented with one sample (1 cm by 1 cm by 2 cm strips) at a time and asked to report the acceptability of the sample’s tenderness on a 9-point hedonic scale. Of the 62 panelists, 93.5 % found chicken breasts with WBS values from 2.1 to 3.1 kg to be acceptable. Only 83.9 % of the panelists found the extremely tender chicken breast to be acceptable (1.1 to 1.9 kg). The percentage of consumers that found the samples acceptable decreased as the WBS values increased beyond 3.1 kg (P<0.05).

The second objective determined the effects of high pressure hydrodynamic shockwave (HSW) on tenderness (48 h postmortem) of early-deboned (52 min postmortem) breasts treated 25 minutes after deboning (70 min postmortem) or treated after storage (24 hr postmortem) and compared to the corresponding non-treated companion breasts. The effect of HSW treatment on broiler breasts treated 25 min after early deboning was determined by the following method. Live broiler chickens were slaughtered according to commercial processing standards prior to treatment at 25 min
after deboning. The effect of HSW on early deboned stored broiler breast was examined by deboning broiler breasts 45 min postmortem and storing (4 C) for 24 h. Packaged breasts were placed in the center of a 20.23 cm diameter cylinder which was vertically positioned in the bottom of a water-filled HSW hemishell tank (30.4 cm diameter) and a shockwave was produced by detonating 40 grams of molecular explosive in the water. Early deboned (ED) breasts stored 24 h before treatment (2.5 kg, WBS) were 42% more tender than the companion ED control breasts (4.3 kg, WBS). The HSW treated breasts would be acceptable to approximately 94% of consumers. The ED control breasts would be acceptable to only 67.7% of consumers. Early deboned and treated 25 min after deboning breasts (5.0 kg) were not different in WBS from their companion ED control breasts (4.6 kg). Early-deboned breasts treated immediately may require higher pressure shockwaves or delayed treatment. The HSW process can overcome the problem with tenderness associated with early deboning if the breasts are processed after storage thereby providing processors with the option to debone earlier.

A third objective was to examine the effects of electrically produced shockwaves on early deboned broiler breasts and normally processed turkey breast. Broiler breasts were treated with one Pulse Firing Network (PFN) or two PFN and 45% Energy. Breasts treated with one PFN were not different than controls. Broiler breasts exposed to two PFN were 22% more tender and different from the controls. Turkey breast portions exposed to two PFN and 72% Energy were different (12% lower WBS values) from the control breast portion. Electrically produced shockwaves can tenderize stored, early deboned chicken breasts and aged turkey breasts.
Acknowledgements

There are so many people that have made this project complete. I want to first and foremost thank Dr. Jim Claus. Your encouragement, devotion and persistence have had more impact on me than any other aspect of my education. Thank you for continuing to push me beyond where I thought I could go. Dr. Wang has been instrumental to the completion of this research. I have never met anyone so capable of doing everything and anything. Thank you so much, Dr. Wang, for your help, support, encouragement, and abilities. Dr. Duncan, you have been a great source of support and information both professionally and personally. I especially want to thank Dr. Marriott for stepping in as a great in house academic Dad after Dr. Claus left. It is amazing how a bear hug can lift spirits and boost one’s energy. I salute Dr. Solomon as the forerunner in this area of research. Dr. Solomon, your thoroughness in your published research helped this research become what it is. To my whole committee I say Thank you. I truly feel that I had the benefit of the greatest people possible both professionally and personally for this research. Thank you all for your commitment and experience.

Mark Tolbert, you are amazing!!! Thank you for always being willing and for your creative genius. You are a treasure to the department and the meats area. I also especially want to thank John Long and Stanford Klapper; without their vision and drive this research would never have happened. Thank you to Pete Thomsen for providing so much know how and creativity, to Andres Lozano for his great organization and administration skills, to Ron Smith, the great package expert, and Kimberly Meek for the constant support.
I also want to thank my devoted husband Wes. Thank you for loving me so well through the completion of this research. You are the greatest person in my life and a true gift from God Himself.

Thanks to Jon, Fezzik, Moma Kitty, BABS, Mani, Roboo, Carolyn and my Mom for reminding me how big life really is. Thanks and glory to God for the opportunity and the ability. In the beginning and in the end it all belongs to Him.
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Chapter 1 Introduction

A major limiting factor in broiler processing is the need to age chicken breasts prior to deboning. Early deboned (non-aged) breasts are unacceptably tough to consumers (Lyon et al., 1985). The aging time prior to deboning of 4 to 7 h postmortem results in a costly conversion process as it involves additional handling, extra storage space, and added refrigeration. Many technologies including electrical stimulation and muscle tensioning have provided positive results in improving early deboned broiler breast tenderness (Dickens and Lyon, 1995; Birkhold et al., 1992). However, none of these technologies have been successful in consistently improving breast tenderness.

The Hydrodynamic shockwave (HSW) process is a newly developed technology that uses hydrodynamic shockwaves to instantly tenderize meat. This technology has been tested by the USDA's Agricultural Research Service Meat Science Research Laboratory and was found to effectively tenderize beef, pork, and lamb (Solomon, 1998). Currently, there is no known published material utilizing the HSW technology for tenderizing deboned broiler breasts treated shortly after deboning. HSW technology has been effective in tenderizing stored early-deboned broiler breasts (Meek et al., 2000). To date, HSW treatment has been only applied after storage of the chicken breasts. Effective treatment immediately after carcass chilling and deboning can eliminate costly storage during the currently required 4 to 6 h aging period, facilitate packaging and enhance the shipment of fresh product. HSW technology could greatly increase the efficiency of broiler breast meat processing while improving consumer satisfaction. To date all previous research using HSW has incorporated explosives to generate shockwaves.
Recent adaptations of existing technology by Hydrodyne Inc. have created the possibility of generating a shockwave using electricity. Testing (Chapter Four) was conducted to lead to the development of an approach to treat poultry products with electrically generated shockwaves.

Warner-Bratzler shear (WBS) was the objective measure of choice for testing broiler breast tenderness. A low WBS value assumed a tender product and thus an acceptable product. The need for a relationship between WBS and consumer perception of tenderness became apparent. Lyon and Lyon (1990a; 1990b) have been the lead researchers in developing a relationship between sensory perception and instrumental texture of broiler breasts. Lyon and Lyon (1990a) reported a study in which an 8-member trained panel was used to assess 17 attributes of texture. The information obtained by the trained panel was incorporated with information obtained from a Texture Profile Analysis to evaluate two cooking methods. Correlated results from the panel and the instrumental analysis were reported. In a later study, Lyon and Lyon (1990b) selected an untrained panel of 24 to examine the changes in tenderness and juiciness associated with two cooking methods and postmortem deboning time. These researchers reported a high correlation between sensory tenderness and texture acceptability (r=.97) but they examined breast samples that were not uniform in dimensions. It is well documented that a trained panel can be used to accurately assess tenderness but the use of an untrained panel on broiler breast samples of uniform height, width and thickness has not been reported.
References


Chapter 2 Literature Review

2.1 Poultry Physiology

Postmortem biochemistry and physical activity of broiler muscles is an area of extensive research and diversity. In red meats, the progression of biochemical changes is well known and examined. After animal slaughter, muscles try to maintain ATP levels. In early postmortem, this feat becomes impossible due to lack of oxygen and blood flow. ATP is depleted through anaerobic glycolysis. As anaerobic glycolysis continues, lactate accumulates and muscle pH is lowered (Bate-Smith and Bendall, 1949). As ATP levels decrease, the muscle begins to contract. ATP utilization (as measured by R-Values; ratio of inosine to adenine nucleotides), lactic acid accumulation and glycogen utilization are common parameters used to characterize postmortem metabolism in bovine and porcine muscles. These parameters vary in broiler postmortem metabolism characterization due to the unique muscle traits of this species. These parameters include traits such as a higher circulating glycogen level than red meat species and a variety of fiber types composing different broiler muscles.

Fiber Type

In 1971, Ashmore and Doerr classified muscle fibers as $\alpha$-White, $\beta$-Red, and $\alpha$-Red. They also reported that repeated exercise caused white fibers to convert to red fibers as red fibers are higher in proportion in exercised muscles than white fibers. This conversion of muscle fibers is responsible for changes in muscle fiber proportions over time since the number of fibers is fixed at birth Ashmore et al. (1972). Chiang et al. (1995a) reported on the fiber proportions in various leg muscles of broilers. The authors
reported no differences due to sex of the bird but age influenced the fiber type proportions present. The proportion of β-Red fibers tended to decrease as the birds aged from 2 to 8 weeks of age in the *biceps femoris* superficial part, which is a muscle active in locomotion. The authors reported that in the *gastrocnemius* muscle fiber type proportions did not change with age but in the *iliotibialis lateralis* muscle the α-Red fibers increased while the β-White fibers decreased from 2 to 8 weeks of age. Chaim *et al.* (1995b) reported that the proportion of β-Red fibers decreased throughout the back *sartorius* muscle as samples were evaluated farther from the bone. These authors also reported differences due to sex in the growth patterns of the α-Red and β-White fiber proportions in the *pectoralis superficialis* muscle. The authors suspect that this difference is the result of earlier maturity in female broilers as opposed to male broilers.

Characterization of broiler rigor activity is complicated by the fiber makeup of the major, most valuable meat cuts. The *anterior latissimus dorsi* of a commercial broiler essentially consists of red, aerobic muscle fibers as opposed to the breast muscle (*pectoralis superficialis*) which is composed principally of white, anaerobic muscle fibers (Sams and Janky, 1990). Chaim *et al.* (1995b) also reported that 96.7 to almost 100% of the fibers in the *pectoralis superficialis* muscle are α-White fibers. In poultry, red, aerobic fibers are expected to undergo faster rigor mortis activities than white fibers due to an inability to produce ATP in the absence of blood flow and subsequent oxygen supply (Sams and Janky, 1990). Sams and Janky (1991) found that the length of time required to reach maximum muscle shortening (as associated with rigor mortis) was significantly more for predominantly white, anaerobic muscles than for predominantly red, aerobic muscles. These authors also found that commercial chilling (4°C)
significantly (P<0.10) slowed rigor mortis as determined by contraction in red muscles fibers but not in white muscle fibers.

\textbf{pH}

Substantial information has been published on the pH decline of chicken \textit{pectoralis} from 6.5 to 5.6 in the 24 h period following slaughter (Kijowski \textit{et al.}, 1982; Stewart \textit{et al.}, 1984a, 1984b; and Smith \textit{et al.}; 1992). Smith \textit{et al.} (1992) examined the pectoralis muscles of duckling (considered dark meat) and chicken (white meat) and found that the pH decline was significantly different in the two muscle types. The chicken pectoralis had a slower pH decline than the duckling even though at 24 h postmortem the pH levels were similar.

\textbf{2.2 Meat Tenderness}

Consumer purchasing and repurchasing of products is essential in any industry, including the meat industry. Meat products need to be a satisfactory eating experience for the consumer. This satisfaction involves color, flavor, mouthfeel, tenderness and several other factors. Tenderness is an attribute that consumers and retailers consider a primary component of palatability and thus a measure of the quality of meat (Huffman \textit{et al.} 1996).

Marsh (1977) reported that meat tenderness was determined by two components in the muscle. These components are the connective tissues present and factors within the muscle’s sarcomeres. The connective tissue, mainly tropocollagen, is responsible for the inherent toughness of the muscle. This component is responsible for the protection and functionality of the muscle in the live animal. The overlapping nature of the collagen
molecule and the formation of intermolecular crossbridges are the major features of collagen that influence muscle tenderness. The overlapping nature of collagen provides ample opportunity for crossbridge formation. The crossbridges of collagen are largely responsible for the decrease in tenderness associated with older versus younger animals. As the animals mature, collagen crossbridges become less susceptible to heat and thus do not break down as readily during cooking. Quality and quantity of collagen present are important factors in the tenderness of a muscle (Marsh, 1977).

Marsh (1977) reported that the “contractile unit” of muscle is also integral to the tenderness of the muscle. The state of contraction of the sarcomere is of most importance to the tenderness of muscle. Cold shortening is an example of a decrease in tenderness due to severe muscle contraction. The prerigor muscle is exposed to cold temperature and is thus stimulated to rapidly contract. Efforts to stretch prerigor muscle or enhance glycolysis completion were recommended by Marsh (1977) as areas for future research.

2.3 Aging

Aging of broiler breast meat is necessary to obtain a consistently tender and acceptable product. Early boning of broiler breasts (*pectoralis superficialis*) results in unacceptably tough meat. Pre-rigor deboned meat results in shorter sarcomeres due to lack of skeletal restraint (Stewart *et al.*, 1984a, Sams *et al.*, 1990). Lyon *et al.* (1985) reported an increase in broiler breast toughness in breasts boned as late as 4 to 6 h postmortem. Currently the industry ages the *pectoralis superficialis* intact on the carcasses for at least 6 to 7 h prior to deboning. This time results is a costly conversion process as it involves additional handling, extra storage space, added refrigeration, and results in product shrinkage due to purge.
Post-deboning aging has also been shown to have positive influences on
tenderness. McKee et al. (1997) examined the effects of post-deboning aging (71 h
postmortem on ice at <2°C) on Allo-Kramer shear values (kg/g) of broiler *pectoralis*
muscles. Shear values decreased from 10.34 kg/g to 7.74 kg/g after 71 h of chilled
storage. The results indicate that the improvement in tenderness may have been caused
by myofibrillar fragmentation from calpain-mediated proteolysis only up to 47 h
postmortem. The authors theorized that ionic strength changes was a factor involved in
further tenderization after aging to 71 h postmortem.

Goll et al. (1997) suggested two phenomena that are possibly responsible for
postmortem tenderization in red meats. The first mechanism is the degradation of
cytoskeletal proteins during postmortem storage. Several specific proteins were
mentioned as the primary proteins that when degraded can influence tenderness. These
are nebulin, titin and vinculin and are degraded through the calpain system. Minimal
protein degradation occurs up to 3 days postmortem even though the largest changes in
tenderness are seen in these first three days (Goll et al., 1997). This lack of protein
degradation is inconsistent with the increase in tenderness experienced by meat during
the first 3 days postmortem. Goll et al. (1997) theorized that the increase in tenderness
experienced by meat during the first 3 days postmortem is due to changes in the
actin/myosin interactions. Approximately 30 to 40% of the postmortem tenderization
that occurs after the first three days postmortem until day 19 to 21 is due to proteolysis.

Goll et al. (1997) suggested that changes in the actin/myosin interactions are also
responsible for some postmortem tenderization. Evidence is given for the changing
interactions between actin and myosin over time, such as a decrease in the energy
required to disassociate the proteins over time. The absence of ATP (Adenine Triphosphate) in a postmortem tissue has substantial effect on the actin/myosin chemical state and thus on tenderization of the meat. The authors suggest that proteolysis has the most effect after 72 h postmortem but the changes in the actin/myosin interactions are of the most importance in the first three hours postmortem.

2.4 Electrical Stimulation

Several technologies have been developed and tested to decrease or eliminate aging time. Electrical stimulation (ES) has been applied in the red meat industry and has several potential benefits to offer the poultry industry. These benefits are improved meat quality characteristics, decreased processing time and a possible decrease in microbial cross contamination (Li et al., 1993). ES has been used in red meats to accelerate rigor development thus facilitating earlier deboning without the adverse effects associated with cold shortening or hot boning. Comparison of ES studies in poultry are difficult to make due to several characteristics of ES. ES can be classified as high (greater than 120 V) or low voltage (less than or equal to 120 V) (Li et al., 1993). Five different waveforms have been utilized (AC, AC pulse, DC, DC pulse, and half AC pulse) and the duration applied varies greatly.

Maki and Froning (1987) found that turkeys treated with high voltage ES (800 V AC, pulsed 4 s on and 5 s off for a 36 s) had significantly lower shear values than untreated controls. Froning and Uijttenboogaart (1988) reported that low voltage ES (100 V for 60 s) gave little improvement in the tenderness of hot-cut (0 to 15 min post mortem harvested) broiler breast meat.
Thompson et al. (1987) reported on a variety of ES parameters including three voltages (240 V, 530 V, 820 V) and five duration periods (9, 15, 18, 30, 45 s). The authors report that ES applied to broilers at 2 to 3 min postmortem, significantly accelerated depletion of ATP and subsequent decrease of pH in breast muscle deboned after feather removal and chilling. These effects were not found when the carcasses were ES treated after aging 48 h. They noted that breast muscle deboned after chilling but before aging achieved an acceptable level of tenderness based on shear values. The authors also concluded that high voltage ES improved tenderness by myofibrillar disruption rather than by the depletion of ATP or pH decline.

Dickens and Lyon (1995) researched the effects of ES and extended chilling times on the tenderness of broiler breast muscle. The authors concluded that a 2 h chilling time combined with electrical stimulation would allow for deboning immediately after chilling. Sams (1990) also combined ES (110 V, for 7 or 14 min, 1s on 1s off) with high temperature conditioning and determined that the breasts would be considered acceptable to consumers, but only if cooked at 18 h postmortem. In a different approach, ES combined with muscle tensioning resulted in an increase in the percentage of fillets harvested at 1 h postmortem that would be considered tender by consumers (Birkhold et al., 1992).

2.5 Hydrostatic Pressure Application

Hydrostatic Pressure is the application of a constant and high pressure environment for various amounts of time to a food product to alter certain characteristics of the food product or to enhance the safety of the product. In the meat industry, substantial attention has been given to hydrostatic pressure as a method to increase the
tenderness of meat. Hydrostatic pressure has been applied to pre-rigor and post-rigor meat. Often hydrostatic pressure is applied in combination with a mild to moderate heat treatment. The mechanisms of tenderization resulting from hydrostatic pressure are extensive and diverse.

**Prerigor Application**

In 1973, J.J. Macfarlane reported on a study applying various high pressure environments to sheep and beef muscles. After pressurization at 103 MNm$^{-2}$ for 4 minutes (30°C) WBS values were decreased by 10-15 kg in the treated samples versus the untreated samples. A sensory panel determined that the treated muscles were less juicy than the untreated muscles but more tender. This tenderness was noted even when the pressurization of the meat was only 1 min in duration. Hydrostatic pressure was found to be effective in tenderizing beef (*longissimus dorsi*, *semitendinosus*, *supraspinatus*, and *sternomandibularis*) and ovine (*semimembranosus* and *longissimus dorsi*) muscles (Kennick *et al.*, 1980) after treatment in a 35°C pressure chamber at 103.5 MNm$^{-2}$ for 2 min. Elgasim and Kennick (1980) also reported lower WBS values in beef samples treated with pressurization at 103.5 MNm$^{-2}$ at 37°C for 2 min.

Kennick *et al.* (1980) reported that after treatment in a 35°C pressure chamber at 103.5 MNm$^{-2}$ for 2 min the gross muscle contraction was 50-52% lower than the muscle’s normal on carcass length. Similar muscle shortening was reported by Macfarlane (1973) in that treated muscles shortened greater amounts than untreated muscles. The sarcomeres in the treated samples in Elgasim and Kennick’s (1980) report were 8.2% shorter than the control sarcomeres.
Macfarlane (1973) reported that, based on pH, glycolysis was virtually complete after pressurization at 103 MNm$^{-2}$ for 4 min (30°C). Treated muscles had a lower pH than untreated muscles. Elgasim and Kennick (1980) also reported a lower pH in beef treated with pressurization at 103.5 MNm$^{-2}$ at 37°C for 2 min. Kennick et al. (1980) reported that the 1 h pH reading of treated beef and ovine samples indicated that postmortem glycolysis was almost complete. The treated samples reached a pH of 5.6 within 1 h postmortem as compared to the untreated samples that took 24 h to reach a similar pH. This is similar to results reported by Macfarlane and Morton (1978) who found dense glycogen like granules in the electron micrographs of control samples that were absent in the treated samples. These observations combined with the reported pH values of the treated samples suggest that glycolysis was complete at the end of the pressure treatment.

Elgasim and Kennick (1980) reported on the ultrastructural examination of prerigor beef exposed to high hydrostatic pressure. These researchers subjected beef longissimus muscle to 103.5 MNm$^{-2}$ at 37°C for 2 min. Z line degradation was evident throughout the scanning electron micrographs. These researchers theorized that the Z line degradation was due to the Ca$^+$ dependent protease that was released when the mitochondria and the sarcoplasmic reticulum were affected by the hydrostatic pressure. The H-zone and the M-lines were missing in the treated samples but were present in the controls. Based on the ruptured appearance of the actin filaments in the electron micrographs, Elgaism and Kennick (1982) went on to affirm the results of Macfarlane and Morton’s (1978) report that actin was influenced by high hydrostatic pressure. Kennick et al. (1980) also reported extensive ultrastructure changes in the sarcomere due
to treatment with (35 C) pressure treatment at 103.5 MNm$^{-2}$ for 2 min. These changes were determined by a scanning electron micrograph and were so severe that the researchers theorize that the extensive damage to the sarcomeres may have caused some structural damage to the connective tissue present in the muscle’s endomysium.

**Postrigor application**

In post-rigor beef muscle, Macfarlane (1981) examined combinations of temperature (25°, 50°, or 80° C), pressure (150 MN m$^{-2}$ for 3 h), and sarcomere length on tenderness. High pressure treatment was determined to increase Warner-Bratzler shear values in samples with short sarcomeres after a heat treatment to 25° or 50° C. Substantial changes were discovered in the I-band and M-line areas of these treated muscles. The I-bands lost their integrity and the M-line appeared to have lost material based on electron microscopy photographs. There were also differences in the aggregation of the thin filaments after cooking. The hydrostatic pressure treatment resulted in a disorganized aggregation of proteins rather than the organized side-to-side aggregation present in the non-treated samples. These results confirm those of Macfarlane and Morton (1978) which also found similar I-band and M-line disturbances in pressure treated ovine meat.

Bouton *et al.* (1980) compared the effects of aging and a pressure/heat treatment on the WBS values of various beef muscles. The post-rigor muscles were subjected to various aging periods and a pressure/heat treatment (150 Mnm$^{-2}$ for 30 min /45 min in a water bath at 45° C). Previous aging of the meat did not enhance the effectiveness of the pressure/heat treatment. This research suggests that the components of the meat affected by a pressure/heat treatment are the same components affected by aging. The research
also reported that aging could decrease the ability of a pressure/heat treatment to act on the myofibrillar component of meat.

### 2.6 Hydrodynamic Shockwave Technology

The Hydrodyne technology was invented and patented (U.S. Patents #5,273,466 and #5,328,403) by John Long. The USDA’s Agricultural Research Service Meat Science Research Laboratory in Beltsville, MD was instrumental in the development of hydrodynamic shockwave (HSW) technology. The technology uses a small amount of explosive to generate a shockwave which tenderizes meat. Even though only a small amount of explosive is detonated, the shock wave which lasts less than a millisecond, produces a pressure front of typically 68.9 kPa at the meat surface (Solomon, 1998). As the pressure front travels through the meat, cellular components of the meat are fractured leading to more tender products. Solomon (1998) reported that Kolsky (1980) describes that shock waves pass through objects that are an acoustical match (mechanical impedance) with water. Since meat is composed mostly of water (up to 76%) (Wismer-Pedersen, 1987), the shock wave is a mechanical impedance match with the meat.

Long was not the first to consider using hydrodynamic shockwaves to tenderize meat. Godfrey (1970) patented the use of hydrodynamic shock to explosively produce a shock front. This shock front can travel faster than the speed of sound through a liquid medium and tenderize meat samples. Godfrey’s theory was sound but required a tank with a top that would be difficult to replicate commercially. The configuration of the meat and explosive further complicated the commercially of the design. Long’s (1993,1994) patents (#5,273,766 and #5,328,403) included the use of a steel hemishell
tank that would withstand the explosive detonation and thus be used in commercial applications.

There are two patents filed by John Long (1993,1994) on the application of hydrodynamic shockwaves. The patents differ very little. Patent # 5,273,766 (Long, 1993) is the original patent on the technology and the apparatus. Patent # 5,328,403 (Long, 1994) is the equipment designed for commercial application and uses a steel hemishell (1060 L) to apply the hydrodynamic shockwave. The second patent (#5,328,403) includes details on the type of cover for a hemishell tank and the motion of said cover during explosive detonation. Research has been performed utilizing these patents in one of two containers. The original container was a small (208 L) plastic container (garbage can) that required replacement after each detonation. Thus it did not lend itself to commercialization as well as the steel hemishell which withstood detonation.

**Red Meats**

In 1997, Solomon *et al.* reported that the hydrodynamic shockwave process would tenderize a variety of cuts from beef, pork and lamb. Thirty to 80% reductions in shear force were reported. A variety of binary explosive amounts (100 to 350 g) was used to determine the amount of explosive required to adequately tenderize meat. The observation was also made that less tender samples had a higher reduction in shear force than already tender meat.

Solomon (1998) reported on the results of a multiple study project that evaluated the effects of the HSW process on beef (post-rigor and hot-boned), lamb, and pork. Several studies on lamb, pork and beef were conducted in a small scale HSW unit (plastic
garbage can). Three studies on beef were reported in which the large (1060L) hemishell was used. Overall, the research reported a decrease in Warner-Bratzler shear force of 49 to 72% for the beef treated in the small containers (208 L). Beef treated in the large hemishell tank exhibited a 35 to 57% (controls 6.57, treated 4.32 kg) reduction in WBS value. Pork treated in the small containers showed a 33% (control 4.24 kg to 3.69 kg) reduction in shear forces which was similar to beef treated in the hemishell. HSW treatment at 1-day postmortem was found to produce a similar shear force to aging of pork loin for 40 days. Lamb when treated in the small containers with 100 g of binary explosive resulted in shear force reductions of 67% (control 5.7 kg to 1.90 kg) in normal lambs and 33% (control 6.42 kg to 4.26 kg) in callipyge lambs.

In 1997a, Solomon et al. reported on the effects of hydrodynamic shockwave on four beef muscles (longissimus, biceps femoris, semimembranosus, and semitendinosus) in a variety of experiments. The first series of experiments conducted on the longissimus muscle examined four binary explosive combinations all placed 30.5 cm from the face of the meat (single explosive loads of 50, 75, 100 g each or treatment with two 50 g loads of explosive). A 2 cm thick steel plate was placed in the bottom of the 208-L container to ensure shockwave reflection. Treatment with two shockwaves produced from 50 g of explosive each was found to be the most effective explosive combination. All of the explosive combinations used were successful in tenderizing beef. Application of HSW to frozen beef was also effective in tenderizing but less effective than treating fresh meat.

In the subsequent experiments of Solomon et al. (1997a), treatment with HSW was found effective in tenderizing meat that already had a low Warner-Bratzler shear value. Untreated Bicep femoris muscle with WBS values of 4.3 g were tenderized by as
much as 30%. There were no indications that the samples were excessively tenderized or visually altered. In another set of experiments presented in Solomon et al. (1997a), intentionally “cold shortened” meat of four muscles (*longissimus, biceps femoris, semimembranosus*, and *semitendinosus*) were treated with HSW (100 g binary explosive 30.5 cm from the face of the meat). The meat was successfully tenderized with reductions in WBS values from 53 to 66%.

The HSW treatment results in myofibrillar fragmentation in the I-band region adjacent to the Z-lines (Zuckerman and Solomon, 1998; Solomon *et al.*, 1997c). Solomon *et al.* (1997c) reported on two studies involving beef and used the 208 L containers with 100 g explosive placed 38 cm from the samples. The first study determined that treatment with HSW was equivalent to aging 35 days postmortem. The second study examined the ultrastructure changes caused by the HSW. Physical disruptions in the ultrastructure of the treated meat were observed adjacent to the Z-lines. The treated meat also had clearer M-lines than untreated meat usually displays. The authors point out that these results vary from ultrastructure changes caused by other tenderizing techniques such as aging and electrical stimulation.

Zuckerman and Solomon (1998) examined the effects of HSW on the ultrastructure of beef strip loins (*longissimus* muscle). The HSW was applied in a small container (208 L) using 100 g of explosive placed 30.5 cm from the face of the meat. The HSW decreased the shear force of the treated meat by 37% over the control samples. The most noted alteration in the ultrastructure of the meat was made in the I-band region. Differences in the M-lines of the treated and control samples were noted. The treated samples had a clearer, narrower M-line. In high pressure tenderization and aging, the M-
line is disrupted or disintegrates rather than becoming more clear. The authors conclude that the ultrastructure changes are a major component of the tenderization caused by HSW treatment.

_Poultry_

Meek _et al._ (2000) was the first to report a replicated study using HSW technology on chicken breast fillets. Research was performed using the large (1060 L) steel hemishell with the muffler top located in Buena Vista, VA. The Hydrodyne tank was supported by eight rubber gasket-lined mounting braces. In this initial study, various explosive amounts and various distances from the explosive were incorporated and Warner-Bratzler shear values were examined. The butterflied chicken breasts were split medially into two breast fillets with one breast receiving a HSW treatment and the other breast serving as an early deboned, non-HSW treated reference. Early deboned breasts were removed from the carcass (45 min postmortem) and chilled for 24 h prior to treatment so they would be in the post-rigor state. The HSW treated early deboned breasts were as much as 46% more tender than their counterparts. However, the increase in tenderness was influenced by the distance from the explosive and the location of the meat in the tank.

Meek _et al._ (2000) further evaluated the quality and sensory characteristics of post rigor, early deboned broiler breast meat tenderized using high HSW pressure fronts. HSW treatment of 350 g at 20 cm from the meat produced the greatest improvement in Warner-Bratzler shear tenderness and was the only treatment to increase tenderness (peak force 4.3 kg) to a level equivalent (P>0.05) to aged controls (peak force 3.1 kg). However, the sensory panel did not confirm the increase in tenderness. In addition, it
was determined that control aged breasts were different in flavor and juiciness than hydrodynamic shockwave treated and early deboned breasts.

2.7 Sensory Evaluation

An example of an early publication of a shear value that correlated to sensory tenderness was Simpson and Goodwin (1974). These researchers used various processing methods to produce different levels of tenderness and toughness in broiler breasts. A 5-member untrained panel scored a limited number of samples and the scores were correlated with Allo-Kramer shear values. The authors suggested that the panel was too small to adequately measure sensory perception. A threshold of less than 8 kg/g was considered tender to very tender. This value was often used to classify broiler breast as tender or tough (Lyon and Lyon, 1997); Thompson et al., 1987). The equipment and processing parameters used in Simpson and Goodwin (1974) are very different from the modern processing facility (Lyon and Lyon, 1997).

Lyon and Lyon (1997) provided the most complete report on the sensory characteristics of broiler breast meat. The researchers removed chicken breast meat from the carcass at various times postmortem. Five “clusters” of sensory attributes were individually examined by 11 trained panelists. Each cluster contained one to several individual sensory attributes, such as wetness, hardness, bolus size and several others. Each individual attribute (n=20) was correlated with Warner Bratzler Shear and Allo-Kramer instrumental evaluations. It was found that samples aged 2 h had higher scores in cluster 1, which was associated with the mechanical properties of the sample, than the other aging periods. The values obtained in cluster 1 were highly correlated (Pearson coefficient r=0.75) with the sample’s instrumental shear values.
Lyon and Lyon (1997) reported that sensory perception was “multi-faceted”. Although there were differences in the breast meat from various boning times, the differences did not produce a clear understanding of consumer acceptability. For example, the breast meat from the 2 hr aging period was highest in mechanical properties (ie. less tender) but the samples scored higher in moisture characteristics than the other groups. The sample was juicier but less tender when aged on the carcass for 2 h rather than aged for 24 h postmortem prior to deboning. This research confirmed that WBS values were indicative of only some aspects of consumer’s perception of tenderness.

Lyon and Lyon (1990a) reported a study on the texture profiles of eight treatments (21 birds per treatment in 3 replications of 7 birds each) of broiler breast to examine the effect of cooking method and deboning time. A trained panel of eight evaluated 17 different texture attributes that were classified into four clusters. Cluster 1 related mostly to texture, ie. tenderness. The breasts were examined instrumentally using a compression method (TPA) developed by Szczesniak et al. (1963). The individual breasts were cooked and cut into 2.54 cm cores. The cores were then tested in a series of two compressions (70% of original height) using an Instron testing unit and two speeds (50 and 100 mm per min, respectively). Sensory samples were cut to be 1.27 cm wide, 2.54 cm long and left at natural thickness. Several correlations between individual attributes of sensory perception and instrumental values were found (Lyon and Lyon, 1997). The authors reported that breast thickness and hardness decreased as the time to deboning increased. The TPA method of instrumental analysis was found to be affected by the thickness of the sample. The authors suggested that thickness varied as the state of rigor fluctuated in the breasts deboned at various times.
Lyon and Lyon (1990b) examined the effects of four deboning times (0, 2, 6, 24 h postmortem) and two cookery methods (water cooked in bags and microwave cookery) on the sensory perception and instrumental determination of tenderness. The breasts were cooked by either before mentioned cookery method and then split into two 1.9 cm strips. One strip was evaluated by a 24-member trained sensory panel for juiciness, tenderness and overall texture acceptability, even though the term acceptability is usually reserved for untrained panels. The other strip was used to obtain WBS values and Allo-Kramer shear values. This study was very similar to Lyon and Lyon (1990a) but differed in the results collected. Lyon and Lyon (1990b) found that microwave cookery produced lower shear values than cooking in water impermeable bags in water. The authors also found that the shear values decreased as the time to deboning increased. A WBS value of 6.5 to 3.5 kg was found to correlate (r=.97) with the “slight” to “moderate” tenderness scale. An Allo-Kramer value of 3.2 to 6.0 kg/g sample would be in the “very tender” to “moderately tender” range. In this study, the authors reported that consumers would rank broiler breast with an Allo-Kramer shear value of less than 8 kg/g sample (Simpson and Goodwin, 1974) as “tender” to “very tender”. Using a regression equation, a WBS shear value of 5.8 kg or less, and an Allo-Kramer shear value of 8.1 kg/g or less would correspond to a “good” to “very good” texture acceptability.

2.8 Instrumental Evaluation

Instrumental determination of tenderness has been a topic of concern for many years (Bratzler, 1949). The original idea to shear a sample of meat to determine tenderness came from K.F. Warner and associates in the late 1920s (Warner, 1952).
More recently participants at a Reciprocal Meat Conference made a recommendation that Warner-Bratzler shear force measurement be standardized (Wheeler et al., 1997b). Several attempts at standardization have been evaluated as further research has discovered an increasing list of factors that could influence WBS determination. The factor that has the largest impact on WBS value is orientation of the muscle fibers relative to the testing apparatus. Several studies have demonstrated that parallel muscle fibers obtain the most repeatable and accurate data (Wheeler et al., 1997b). Other factors that can influence WBS values are temperature of the steak prior to cooking, speed of the crosshead and a variety of cooking parameters. As temperature before cooking increases, WBS value decreases (Wheeler et al., 1996). The original Warner-Bratzler machine sheared with a speed of 229 mm/min (9 in/min). The AMSA (1995) guidelines are 200 to 250 mm/min for crosshead speeds.

Wheeler et al. (1997a) reported on a multiple phase project in which five institutions were examined. In phase one, the protocol and application of Warner-Bratzler shear force measurements were left to the discretion of the institutions. In phase two, the institutions were given an established protocol. The repeatability increased for four of the five institutions after the application of an established protocol.

The use and application of standard protocols for the collection of Warner-Bratzler shear data would allow institutions to compare data. Multiple institutions could participate in large experiments with a greater confidence in the comparability of the data. Standard protocols for collection of data within a study’s treatment and control groups are less critical as long as comparisons will only be made within the study.
2.9 Conclusions

Broiler physiology including a variety fiber types are important components of rigor development in broiler muscles. Rigor development has a dramatic impact on treatment of the carcass and meat to provide a tender product. Tenderness is of primary importance to consumers and is determined by several components of the meat. Several attempts have reported to enhance the tenderness of meat. These include aging, electrical stimulation, application of hydrostatic pressure and treatment with hydrodynamic shockwave technology. Tenderness and the effect of these tenderizing techniques can be evaluated both by sensory evaluation and instrumental measurement. The objective of this study is to evaluate consumer acceptability and use the collected information to assess instrumental evaluation of the effect of advanced designs of hydrodynamic shockwave application on broiler breast tenderness.
2.10 References


Chapter 3

Instrumental Texture Assessment and Sensory Consumer Acceptability of Cooked Broiler Breasts Evaluated Using a Geometrically Uniform-Shaped Sample

3.1 Abstract

The relationship between Warner-Bratzler shear values and consumer acceptability of chicken breast samples with a controlled configuration has not been published. The objective of this study was to determine the percentage of consumer acceptability of cooked chicken breast within each of six different tenderness categories predetermined from Warner-Bratzler shear (WBS) testing. Anatomically paired broiler breasts were obtained from a commercial processor. One breast from each bird, alternating right and left, was sous vide cooked (78°C internal) and an average WBS value (kg) was determined. The remaining companion breasts were sorted into one of five ranges (1.1-2.0, 2.1-3.1, 3.2-4.0, 4.2-5.0, 5.2-6.7 kg) based on shear value. Cooked breasts were cut into 1 cm x 1 cm x 2 cm samples parallel to the muscle fibers. Consumer panelists (n=62) were presented one sample at a time and asked to evaluate only tenderness on a 9-point hedonic scale. Of the 62 panelists, 93.5% found chicken breasts with WBS values from 2.1 to 3.1 kg to be acceptable. Panelists (83.9%) indicated that the extremely tender (1.1 to 2.0 kg) chicken breasts to be slightly less acceptable than those breasts ranging in tenderness from 2.1 to 3.1 kg. The percentage of consumers that found the samples acceptable decreased as the WBS values increased beyond 3.1 kg. This sample cutting procedure is particularly useful when evaluating tenderness of early
deboned chicken breasts which are variable in natural thickness and therefore cannot be appropriately sampled by simply removing standard width strips.

3.2 Introduction

Previous research has documented the relationship between consumer perception and instrumental tenderness values obtained from breast samples that were uniform in height and width but not uniform in thickness (Lyon and Lyon, 1990a, 1990b, and 1997). Meek et al. (1997) found that natural breast thickness varied significantly in early-deboned broiler breasts. Lyon and Lyon (1990a) suggested that the thickness of the broiler breast varied as the state of rigor differed in breasts deboned at various times. Lyon and Lyon (1990a; 1990b) also determined that breast thickness was highly variable in meat deboned at less than 6 h postmortem. Lyon and Lyon (1990a) reported a high positive correlation between breast thickness and several sensory perceptions relating to texture. Utilization of samples of varying thickness has a large impact on a consumer’s perception of texture.

A trained sensory panel has often been used to compare to instrumental analysis of various traits (Lyon and Lyon, 1990a; 1990b). However, the use of a trained panel does not indicate how a consumer would perceive the product or trait. A trained panelist perceives a certain level of a trait and scores that trait based on reference standards and scaling techniques used during the training experience. Information obtained from this method does not reflect how consumers would perceive the product based on likes and dislikes. Panels trained by different persons could report different values. Only consumer evaluation can provide information relating objective tenderness measurements and consumer response (Wheeler et al., 1997). A relationship between consumer
perception of tenderness and instrumental tenderness values for a standardized sample
dimensions of broiler breast has not been reported.

3.3 Materials and Methods

Chicken Procurement

Fresh boneless, skinless chicken breasts (*pectoralis major*) were obtained from a
commercial processor (Rocco Farm Foods, Edinburg, Virginia) for this study. One
hundred broiler breasts were deboned at the plant at 0.75, 2, 4, 6, and 24 hr postmortem
to provide significant variation (Sams and Janky, 1986) in tenderness. Twenty butterflied
breasts from each deboning time were transported on ice to the Virginia Polytechnic and
State University Meats Laboratory (Approx. 2.5 hrs). The whole butterflied breasts were
medially split into a left and right breast upon arrival. A brine tag identified individual
left and right breasts from each bird and boning time. One breast from each bird was
designated for sensory analysis and the alternating companion breast was designated for
WBS determination. The breasts were individually vacuum packaged (Model # X180,
Koch Supplies Inc, Kansas City, MO, 64108) with settings at 99% vacuum in 15.2 X 20.3
cm, 3 ml standard vacuum bags (item #030026, Docket 501655, Koch Supplies Inc.,
Kansas City, MO, 64108) and frozen at -25°C (3 days). Eighty total breasts were
selected based on WBS values and sorted into five WBS ranges (1.1-2.0, 2.1-3.1, 3.2-4.0,
4.2-5.0, 5.2-6.7 kg) used in the study. The remaining 20 breasts were discarded due to a
defect in the companion breast or a WBS value outside of the selected ranges.
Cookery Method

The breasts were individually vacuum packaged (Cn610 Boil in bags, Cryovac/Sealed Air Corporation, Duncan SC 29334) in 22.8 X 61.0 cm vacuum bags and cooked using a sous vide method (Meek et al., 2000). The breasts were cooked to an internal temperature of 78°C in a circulating water bath. The water bath was custom made and maintained in the Fruit and Vegetable Processing Laboratory at Virginia Polytechnic Institute and State University. The water was preheated and maintained at 80°C during cooking. Several representative breasts were placed in different locations in the water bath and were inserted with T-type thermocouples in 16 G needles through adhesive patch (.64 cm width, 2.54 length, Thermwell, Inc., Patterson, NJ.) on the vacuum bag. These T-type thermocouples monitored core temperature and were inserted into the thickest part of the breasts. Temperature data were collected using an automatic data recorder (model 5100, Electronic Controls Design, Inc., Milwaukie, OR). The breasts were removed from the bath and cooled at room temperature for 30 min. Subsequent analysis of WBS or sensory was performed on the same day the samples were cooked.

Warner-Bratzler Shear Force Determination

Tenderness was assessed by an objective texture procedure of Meek et al. (2000). Cooked breasts were placed in closed plastic bags (Quart Size #487435, Ziploc Brand Bags, S.C. Johnson & Son, Inc., Racine, WI 53403-2236) in 60°C water for 5 min prior to shear force determination. Six to 8 adjacent 1.0-cm strips were cut from the frontal area of the cooked breast parallel to the muscle fibers and then trimmed to a thickness of 1 cm. Each strip was sheared once and the mean was calculated for each breast. Samples
were sheared perpendicular to the muscle fiber using a Warner-Bratzler shear attachment mounted on an Instron (Model 1011, Instron Corp., Canton, Mass.) using a 50-kg load transducer and a crosshead speed of 200 mm/min.

**Sensory Analysis**

Consumer panels were conducted on three separate days. Participates were recruited with an advertising sign and word of mouth for participation. A consumer was not allowed to repeat their participation on subsequent testing days. Sensory samples were cut parallel to the muscle fibers into 1 cm x 1 cm x 2 cm strips. Samples were cooked and served on the same day. The samples were identified with random three digit numbers. The samples were placed in a closed plastic bag (Quart Size #487435, Ziploc Brand Bags, S.C. Johnson & Son, Inc., Racine, WI 53403-2236) and suspended in 60°C water for 5 min prior to sensory analysis. Panelists were presented the samples in sensory booths under red lights. Consumers (n=62) were asked to report the acceptability of the sample’s tenderness on a 9-point hedonic scale. The category definitions are as follows: 1-Like extremely; 2-Like very much; 3-Like moderately; 4-Like slightly; 5-Neither like nor dislike; 6-Dislike slightly; 7-Dislike moderately; 8-Dislike very much; 9-Dislike extremely (Resurreccion, 1998; Meilgaard et al., 1991). Panelists were asked to rinse their mouth with water between samples. Panelists were presented with one sample at a time from each of the five WBS ranges resulting in five total samples. All panelists signed a standard informed consent form (Appendix A) as provided by the University. Demographic information on the panelists was collected and examined. Panelists were asked to report their age, occupation, and frequency of chicken consumption. The information reported by the panelists was analyzed as percentages.
Statistical Analysis

Mean sensory responses were calculated for each predetermined tenderness grouping based on WBS values. Consumer sensory data was analyzed using frequencies (SAS, 1996). Percentages were determined by using the formula of total responses divided by number responses multiplied by 100.

3.4 Results and Discussion

Demographic Information

The respondents were 52% male and 48% female (Table 1). The most frequent response for age (58%) was in the 20 to 29 years old range. Only 8% of the panelists were less than 20 years old. Fifteen percent of the panelists were between 30 and 39 years old and 11% ranged from 40 and 49 years of age. The remaining 8% of the panelists were over 50 years old. The most common occupation response was 'student' which included undergraduate and graduate students and equaled 63% of the panelists. The remaining occupation responses were sorted into two categories, those being employees of the University (13%) and those not affiliated with the University (24%).

Consumption frequency revealed that 24% of the panelists ate chicken several times a month. Seventy-one percent of the panelists reported that they consumed chicken several times a year. Only 5% reported consuming chicken several times a week.

This demographic breakdown may affect the results of this study. The most common panelist was a student between the ages of 20 and 29. The consumption habits of this population can have an effect on their perception of tenderness. The high number
of panelists and the variety of ages represented should decrease the effects of any outliers in the statistical analysis.

**Sensory Tenderness Results**

Sams and Janky (1986) and Lyon and Lyon (1997) found that deboning broiler breast meat prior to 6 h postmortem decreased tenderness and increased variation among individual broilers. Deboning broiler breasts at the intervals used in this current study (0.75, 2, 4, 6, and 24 hr postmortem) resulted in a variety of Warner-Bratzler shear (WBS) values from 1.1 kg to 10.8 kg in the one hundred breasts sampled. Postmortem deboning time was not a clear indicator of tenderness (Figure 1). Only eighty breasts were sorted into the five ranges used in the consumer testing. The companion breasts used to establish the different tenderness groups produced similar shear force values as reported by Lyon and Lyon (1990b) with 6.5 to 6.7 kg representing the maximum shear force value for the least tender range.

Of the 62 panelists, 93.5% found chicken breasts with WBS values from 2.1 to 3.1 kg to be acceptable (Table 2). Panelists (83.9%) indicated the extremely tender (1.1 to 2.0 kg) chicken breasts to be slightly less acceptable than breast in tenderness group 2 (WBS values between 2.1 and 3.1 kg). Their comments included 'too mushy' and 'too tender' which might indicate a dislike for excessive tenderness.

The percentage of consumers that found the samples acceptable decreased as the WBS values increased beyond 3.1 kg. Lyon and Lyon (1990b) used a trained panel to determined that sensory texture acceptability was highly correlated with sensory tenderness (r =0.97) and objective measurements of texture such as the Warner-Bratzler (r=.83) and the Allo-Kramer (r=.81) techniques. Lyon and Lyon (1990b) reported that a
small number of panelists (n=24) was able to demonstrate a decrease in acceptability as tenderness decreased.

At the least tender range of WBS values 5.2 to 6.7 kg, the percentage of consumers that found the chicken acceptable was 61.3% (38 out of 62 panelists). Lyon and Lyon (1990b) reported that WBS values (1.9 cm wide, variable thickness and length; cooked to 82°C internal) in the range of 3.5 to 6.5 kg were considered 'moderate' to 'slight' in tenderness.

3.5 Conclusions

Based on this sample of consumers, it can be concluded that chicken breast with a corresponding WBS value of 2.1 to 3.1 kg is acceptable to a majority of consumers. Processes or treatments that produce chicken breast with WBS values in this range would be acceptable to consumers and ideal for the retail market.

3.6 References


Table 1- Demographic information on consumer panelists.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Category</th>
<th>Description of Category</th>
<th>Number of Respondents</th>
<th>Percentage of Total</th>
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<td>&lt;20</td>
<td>5</td>
<td>8</td>
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<td>15</td>
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<td>4</td>
<td>40-49</td>
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<td>11</td>
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<td></td>
<td>2</td>
<td>Female</td>
<td>30</td>
<td>48</td>
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Table 2- Percentage results of consumer panel (n=62) to determine acceptability of broiler breasts (sous-vide cooked, 78°C internal) sorted by Warner-Bratzler Shear ranges and uniformly sampled (1 cm x 1 cm x 2 cm standard size strip).

<table>
<thead>
<tr>
<th>Tenderness Grouping</th>
<th>Warner-Bratzler Shear (kg)</th>
<th>Consumer Panel Response</th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Percentage Unacceptable (Scr (^a) &lt;5(^b))</td>
<td>Percentage Min Acceptable (Scr (^a) 5-6(^b))</td>
<td>Percentage Acceptable (Scr (^a) &gt;6(^b))</td>
<td>Total Percentage Acceptable (Scr (^a) 5-9(^b))</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.1-2.0</td>
<td>16.1</td>
<td>4.8</td>
<td>79.0</td>
<td>83.9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.1-3.1</td>
<td>6.5</td>
<td>25.8</td>
<td>67.7</td>
<td>93.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.2-4.0</td>
<td>21.0</td>
<td>27.1</td>
<td>51.6</td>
<td>78.7</td>
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<td>32.3</td>
<td>16.1</td>
<td>51.6</td>
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<td>5.2-6.7</td>
<td>38.7</td>
<td>17.8</td>
<td>43.5</td>
<td>61.3</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) scr=score  
\(^b\) Hedonic scale: A sensory score of one represented ‘extremely dislike’ and a score of nine represented ‘like extremely’ (Resurreccion, 1998; Meilgaard et al., 1991). A score of five represented “Neither acceptable nor unacceptable” and was included in the minimally acceptable calculation (Scr=5-6).
Figure 1. Mean Warner-Bratzler Shear (WBS) force versus postmortem deboning time of broiler breast (n=100; 20 in each postmortem deboning time)
Chapter 4

High Pressure Hydrodynamic Shockwave Effects Using a Cylinder Processor on Tenderness of Early Deboned Broiler Breasts Treated 25 min after Deboning and broiler breasts treated after Storage.

4.1 Abstract

Chicken breasts were deboned at 45 min postmortem and either exposed to high pressure hydrodynamic shockwaves (HSW) after 24 h of storage (4°C) or 25 min after deboning (70 min postmortem). HSW were produced in a cylindrical HSW unit with 40-g explosive. Warner-Bratzler shear values (WBS), raw and cooked color values (CIE L*a*b*), and cooking loss were determined. The HSW treatment decreased (P<0.05) the WBS values of the stored breasts by 42.0 % compared to the controls. WBS values of the HSW breasts treated at 70 min postmortem were not different than the controls. Cooking loss was not affected by HSW. In general, raw and cooked color were not affected by the HSW. HSW treatment at 25 min after deboning (70 min postmortem) may require a higher pressure front or delayed treatment to improve tenderness.

4.2 Introduction

A major limiting factor in broiler processing is the time needed to age chicken breasts prior to deboning. Early deboned (non-aged) breasts are unacceptably tough to consumers (Lyon et al., 1985). The aging time prior to deboning of 4 to 7 h postmortem results in a costly conversion process as it involves additional handling, extra storage space, added refrigeration, and results in considerable shrinkage due to purge (Meek et al., 2000). Many technologies have provided positive results in improving early deboned broiler breast tenderness (Dickens and Lyon. 1995; Birkhold et al, 1992). However, none
of these technologies have demonstrated a consistent and applicable improvement in breast acceptability for the poultry industry.

The Hydrodyne process was invented by John Long (1993,1994) (U.S. Patents #5,273,466 and #5,328,403) and initially developed to tenderize red meats. This technology incorporates HSW produced by the detonation of a small amount of explosive in a water filled container to physically tenderize the myofibrillar structures within the myofibrils. Solomon (1998) found that HSW effectively tenderized beef, pork and lamb.

HSW has been effective in tenderizing early-deboned broiler breasts (Meek et al., 2000) when the shockwave treatment was applied after storage (24 h postmortem). Meek et al. (2000) used the 1060 L hemishell design (including 8 suspension supports) for the application of HSW to broiler breasts. This equipment was designed as a large batch type operation and as such would not be a viable approach for processing poultry. Currently, there is no known published material utilizing the HSW technology on tenderizing deboned broiler breasts treated immediately after deboning.

This study was designed to serve as a first step in the evaluation of an equipment design that could lead to the development of a continuous, online HSW processor. This processor design would be intended specifically for use in the broiler industry.

4.3 Materials and Methods

Cylinder and Packaging System

All explosive testing was conducted in a specially designed 2.54 cm thick stainless steel cylinder (Cylinder Research Prototype 1, Hydrodyne Inc., San Juan, Puerto Rico) having an outer diameter of 20.32 cm and a height of 48 cm. The breasts were
suspended in the center of cylinder between two strip explosive charges taped to metal inserts (2.5 cm by 48 cm) suspended at 180° from each other on the inner wall of the cylinder. The cylinder was placed in the hemishell for containment during detonation. The samples (n=2) were packaged in 0.5 cm thick, 3.8 cm inner diameter, 46 cm long vinyl tubing (#5233K-76, McMaster-Carr, New Brunswick, New Jersy) and sealed using 3.8 cm diameter, 5.1 cm length plastic plugs (# 003003 Plastisol, Rutland Plastic Tech, Pineville, NC). Two plastic cable ties were used on each end of the tube to secure the plugs. The vinyl tubing was then sealed on both ends by heating the ends with a heat gun (model AH-751, Master Appliance Corp., Racine, WI, 53401) and then clamping the hot ends together until cooled. The sealed ends of the tubing were filled with water by a hypodermic needle and the needle hole sealed with duct tape. The breasts were packaged in water with special attention given to avoid air bubbles in the package. The cylinder was placed 12 cm above the bottom of a water filled (approx. 13°C) research hemishell (Model hemishell-Unit 2, Hydrodyne Inc., San Juan, Puerto Rico)

*Explosive and Handling*

Sheet explosive (# DCEX35, PBX Sheet, Donovan Commercial Industries, Inc., Nortonville, KY) were used in all testing. A certified explosive expert performed the handling and detonation of all explosive. Two detonation devices were used for each shot with one device on each piece of the sheet explosive.

*Preliminary Cylinder Testing*

Fresh early deboned skinless chicken breasts (*pectoralis major*) were obtained from a Virginia Processor for use in this preliminary testing. The treatments included
early deboned (deboned 45 min postmortem) chicken breasts that were HSW treated at 24 h postmortem. Each breast was individually labeled with a brine tag. The treated breasts were packaged according to aforementioned specifications. Each packaged breast was HSW treated using one of several different explosive levels (60, 30, 20, and 15 grams). Two breasts were used for each shockwave combination. The objectives for the preliminary testing were: 1. Determine if the breasts would remain intact allowing for instrumental analysis; 2. Pretest the designed packaging system; and 3. Pretest for any unforeseen mechanical flaws in the general design.

*Hydrodynamic Shockwave Treatment of Breasts 24 h after Early Deboning*

Fresh boneless, skinless chicken breasts (*pectoralis major*) were obtained from a poultry processor (Rocco Farm Foods, Inc., Edinburg, Virginia). The treatments included breasts that were early deboned at 45 min postmortem and 1) HSW treated at 24 h postmortem, or 2) the non-treated companion breasts of the treated breasts. Treated and non-treated (control) breasts were alternated between the right and left breast. The shockwave treatment used was 20 g of explosive on either side of the packaged breasts for a total of 40 g of explosive. This study (fifteen replications/two birds per replication) provided the comprehensive testing of the HSW treated breasts at 24 h postmortem.

*Hydrodynamic Shockwave Treatment of Breasts at 25 min after Deboning*

Live broiler chickens (n=16) were transported via truck from a commercial poultry company (Rocco Farm Foods, Inc., Edinburg, Virginia). The birds were held off feed overnight following arrival at the Meats Laboratory of Virginia Polytechnic Institute
and State University resulting in a 36 h fast before slaughter. The birds were allowed
free access to water. The birds were electrically stunned (Model VS 200, Midwest
Processing Systems, Minneapolis, MN,) for 8 sec (stunner dial setting, 4). The birds were
immediately bled for 15 sec. The carcasses were placed in a custom built scalding bath
(62°C, 25 sec), mechanically defeathered (Model BP21, Brower, Inc., Houghton, IA,
52631) and eviscerated by hand. Carcasses were placed in ice slush at 12 min
postmortem and chilled for 40 min. Breasts were hand deboned prior to HSW treatment.

Treatments included breasts that were early deboned at 45 min postmortem and 1) HSW treated 25 min after deboning, or 2) the non-treated (control) counterpart breasts of
the treated breasts. Treated and non-treated breasts alternated between the right and left
breasts. Control and treated breasts were packaged by the aforementioned specifications.
The HSW treatment used was 20 g of explosive to each side of the packaged breasts.
This study (six replications/2 birds per replication) provided the comprehensive testing of
the shockwave treated breasts treated 25 min after deboning.

**Instrumental Color Determinations**

Color (CIE L*a*b*) of the breasts treated with HSW and the controls were
determined using a chroma meter (Model CR-200, Minolta Camera Co., Ltd., Osaka,
Japan). The chroma meter was calibrated using a standard white Minolta calibration
plate (No. 20933026; CIE L* 97.91, a* -0.70, b* +2.44). Three readings were taken on
each raw and cooked breast on the skin and bone side. Raw breasts were exposed to air
for 2 min prior to color analysis by suspending the breast by one end. An average was
calculated for each breast.
Cookery Method and Cooking Loss Determinations

Control and treated breasts were individually vacuum packaged (in 15.2 X 20.3 cm, 3 mL barrier bags, Item # 030026, Docket # 501655, Koch Supplies, Inc., Kansas City, MO) and cooked using a sous vide method (Meek et al., 2000). The breasts were cooked to an internal temperature of 78°C in a circulating water bath custom made at Virginia Polytechnic Institute and State University, preheated, and maintained at 80°C. Several representative breasts were placed in different locations in the water bath with type T thermocouples inserted through adhesive patches (.64 cm width, 2.54 length, Thermwell, Inc., Patterson, NJ.) into the samples to monitor core temperature. Temperature data was collected using an automatic data recorder (Model 5100, Datalogger, Electronic Controls Design, Inc., Milwaukie, OR). The breasts were removed from the bath when a 78°C internal temperature was reached and cooled at room temperature for 30 min. After cooling, Warner-Bratzler shear values were determined on individual breasts. The cooking loss was calculated for on all samples cooked for tenderness determination. Cooking loss values were calculated based on the equation: (raw weight minus cooked weight) divided by raw weight times 100.

Shear Force Measurements

Tenderness was assessed by an objective texture procedure described by Meek et al. (2000). Two to three adjacent 1.0-cm strips were cut from the frontal area of the cooked breast parallel to the muscle fibers and then trimmed to a thickness of 1 cm. Each strip was sheared once and an average was calculated. Samples were sheared perpendicular to the muscle fiber using a Warner-Bratzler shear attachment mounted on an Instron (Model 1011, Instron Corp., Canton, MA.) testing machine using a fifty-kg
load transducer and a crosshead speed of 200 mm/min. Peak force (kg) data was recorded and an average calculated for each breast.

Statistical Analysis

Warner-Bratzler shear, cooking loss and color data were statistically analyzed as a t-test with each having a control and a shockwave treatment (breasts processed after storage, 16 replications; breasts processed immediately, 6 replications) using a t-test (SAS, 1996).

4.4 Results and Discussion

Warner-Bratzler Shear Force Values

The HSW treated after 24 h storage early deboned breasts were 42% more tender (P<0.05) than their companion control breasts (Figure 1). In comparison, Meek et al. (2000) used 350 g of a binary explosive at 20 cm from the meat face in a hemishell (1060 L) and reported a 19.1 to 28.3 % improvement in tenderness in early deboned broiler breasts (stored 24 h) after shockwave treatment. In our study, the large increase in tenderness improvement was most likely due to increased efficiency in the cylinder design in which the HSW was applied to the broiler breasts. In the hemishell design, a centrally located explosive is detonated in which only 50 % of the energy is directed at the product (Personal Communication, John Long). In contrast, the explosive in the cylinder when detonated has a majority of the energy directed toward the centrally suspended product. The shockwave treated breasts had an average WBS force value of 2.5 kg, which would be acceptable to approximately 94% of consumers. Consumer acceptability was established by a separate study in our laboratory (Chapter 3, Table 2).
Control breasts had an average shear value of 4.4 kg, which would be acceptable to only 68% of consumers.

The early deboned breasts that were treated 25 min after deboning were not different (P>0.05) in WBS values than their companion control breasts (Figure 1). In some cases, the control breast had lower WBS values (Figure 1). This apparent increase in WBS values of the treated breasts may have been a result of ultrastructure shearing caused by the HSW releasing intact sarcomeres to contract to a greater extent than sarcomeres within intact myofibrils. Muscles with shorter sarcomeres have been reported to produce less tender meat (Birkhold et al., 1992; Sams et al., 1990). It has been theorized that in order for HSW to tenderize early deboned chicken breast when processed soon after deboning, much greater structural damage must occur to overcome the impact of sarcomere shortening in comparison to tenderizing stored (24 h) breasts.

Lyon and Lyon (1997) found a wide range in WBS values in early deboned breasts. The breasts decreased in WBS as the deboning time increased. The authors did not find a difference in the side of the carcass with the breast (right or left) in shear values based on postmortem deboning time. The standard deviations for the left and right breasts deboned at 2 h postmortem were 3.09 and 3.12 kg, respectively. The standard deviation decreased as time before deboning increased. Meek et al. (2000) reported a standard deviation of 2.1 kg for the paired differences between early deboned and high pressure shockwave treated breasts. In this study, the HSW treatment appeared to decrease the WBS variability as the standard deviation was 0.90 for the 24 hr treated (standard deviation, 1.90 control) and 0.78 for the treated 25 min after deboning (standard deviation, 1.40, control).
**Instrumental Color**

There were no differences (P>0.05) in raw color between HSW treated samples and control companion breasts (Tables 1 and 2) regardless of treatment time. Meek *et al.* (2000) found a difference in the L* values of the treated breasts on the skin side. The differences in Meek’s study and the current were most likely due to the differences in packaging. The breasts in this study were packaged in a water-filled tube. The breasts in their study were packaged and treated in water-impermeable vacuum bags in the absence of water.

In the cooked samples (Table 1), the CIE b* values of the skin side of the HSW breasts stored 24 h before treatment were lower (P<0.05) (less yellow) than the control breasts. In contrast, Meek *et al.* (2000) did not report differences in the CIE b* values. There were no differences in cooked color between the HSW breasts treated 25 min after deboning and the control breasts.

**Cooking Loss**

There were no differences (P>0.05) in cooking loss between treatments (Table 3). Cooking loss was higher than the values reported by Meek *et al.* (2000) by an average of 5%. Meek *et al.* (2000) packaged chicken breasts in moisture impermeable vacuum bags for hydrodynamic shockwave treatment. Broiler breasts in this study were packaged in water to mimic possible future applications of the HSW technology in commercial applications. It is possible that the breasts in this study initially absorbed water to a point that cooking loss was increased. In comparison, Lyon and Lyon (1993) reported a cooking loss very similar to this study for the breasts stored 24 h. Lyon and Lyon (1993) deboned chicken breasts at 24 h and water cooked the breasts in a manner very similar to
the cooking used in this study. Cooking loss for chicken breasts deboned at 2 h and water cooked in Lyon and Lyon (1993) were approximately 5% above the breasts that were deboned at 45 min postmortem in this study.

4.5 Conclusions

The hydrodynamic shockwave process can overcome the problem of tenderness associated with early deboning if the breasts are processed after storage (24 h) thereby providing processors with the option to debone earlier. However, early-deboned breasts treated immediately after deboning may require higher pressure shockwaves or delayed treatment with hydrodynamic shockwaves to produce breasts with acceptable tenderness.

4.6 References


Table 1. Color (CIE L*a*b* values) for early deboned (45 min postmortem) broiler breasts stored 24 h before hydrodynamic shockwave treatment and the control breasts.

<table>
<thead>
<tr>
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<th>a*</th>
<th>b*</th>
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<td>60.88&lt;sup&gt;a&lt;/sup&gt;</td>
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<sup>ab</sup> Means within a column and raw or cooked group with unlike letters are different (P<0.05). Parenthetical values are standard deviations of the means. Fifteen replications per treatment. Two sample T-tests were used to analyze differences with equal variances.
Table 2. Color (CIE $L^*a^*b^*$ values) for early deboned (45 min postmortem) broiler breasts treated immediately after deboning with hydrodynamic shockwave treatment and the control breasts.

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<th>a*</th>
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<td>56.57$^a$</td>
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<td>(4.71)</td>
<td>(2.03)</td>
<td>(2.91)</td>
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| Bone Side              |            | Control   | 12 | 57.42$^a$ | 2.18$^a$ | 1.80$^a$ |
|                        |            | (3.49)    | (1.26) | (2.30) |     |
|                        |            | Hydrodynamic Shockwave | 12 | 57.38$^a$ | 2.39$^a$ | 1.71$^a$ |
|                        |            | (4.32)    | (1.60) | (2.33) |     |

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<td>(2.12)</td>
<td>(1.06)</td>
<td>(0.92)</td>
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| Bone Side              |            | Control   | 12 | 81.51$^a$ | 3.72$^a$ | 12.00$^a$ |
|                        |            | (2.44)    | (.87) | (1.24) |     |
|                        |            | Hydrodynamic Shockwave | 12 | 81.36$^a$ | 3.54$^a$ | 11.78$^a$ |
|                        |            | (2.69)    | (.99) | (2.23) |     |

$^a$ Means within a column and raw or cooked color group with unlike letters are different (P>0.05). Parenthetical values are standard deviations of the means. Fifteen replications per treatment. Two sample T-tests were used to analyze differences with equal variances.
Table 3. Cooking loss for hydrodynamic shockwave treated and control companion broiler breasts that were early deboned (45 min postmortem) and sous vide cooked to 78°C internal temperature.

Hydrodynamic Treatment after 24 h of Storage at 4°C

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<sup>a</sup> Means within a column with unlike letters are different (P<0.05). Parenthetical values are standard deviations of the means. Fifteen replications per treatment. Two sample T-tests were used to analyze differences with equal variances.

Hydrodynamic Shockwave Treatment 25 min after Deboning (70 min Postmortem)

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Figure 1. Mean Warner-Bratzler shear values of early-deboned (45 min postmortem) broiler breast treated after storage (24 h) or 25 min after deboning and respective control companion breasts. Means within a treatment pair with unlike letters are different (P<0.05).
Chapter 5

Tenderization of Chicken and Turkey Breasts with Electrically produced Hydrodynamic Shockwaves

5.1 Abstract

Eighty chicken breasts were exposed to two levels (20 controls, 20 treated per level) of electrically produced hydrodynamic shockwave (HSW). The number of Pulse Firing Networks (PFN) being employed defined levels of HSW application. In addition, twenty-one turkey breasts were split into two portions in which one portion was exposed to HSW and the other portion of the same breast was used as a control. All samples were water cooked in bags to 78°C internal temperature. Warner-Bratzler shear (WBS) values were determined for each sample. Cooking loss and raw weight change due to treatment was recorded in some samples. Chicken tenderness was not affected (P>0.05) with one PFN but HSW treatment with two PFN resulted in a 22% (control, 4.67 kg) decrease (P<0.05) in WBS values. WBS force of the turkey breast decreased (P<0.05) by 12% (control, 3.20 kg) as a result of HSW treatment with two PFN. HSW did not affect (P>0.05) raw weight in the turkey breast portions. Cooking loss was lower (P<0.05) in the turkey breast portions but not in the chicken breasts. The electrically produced shockwave process has the potential to provide chicken processors with the ability to early debone and produce tender breasts and to provide turkey processors with tenderness-enhanced fillets.
5.2 Introduction

A concern for the broiler industry is the need to store carcasses intact for 4 to 6 hours postmortem prior to deboning to ensure a tender product (Lyon et al., 1985). This storage of product requires added financial input for the poultry processor. The issue with turkey is not the aging time prior to deboning but rather that turkey has a somewhat limited retail market exposure due to the inherent lack of tenderness associated with fresh turkey breast meat. To optimize tenderness of the turkey breast generally requires that the meat be slow cooked utilizing moist heat cookery. In addition, the majority of turkey goes into further processed products and whole bird market shares (Romans et al., 1994). The tenderization of turkey breast meat would facilitate the opening of a retail market for turkey breast fillets similar to the broiler breast fillet market.

HSW produced using explosives have been reported to be effective in tenderizing poultry (Meek et al., 2000) and a variety of red meats (Solomon, 1998). This technology was invented by John Long (1993, 1994) (U.S. Patents #5,273,466 and #5,328,403) for original use in red meats. HSW are produced by detonating a small amount of explosive in a water-filled container. The HSW travel through the water and anything that is an acoustical match with water (Kolsky, 1980). Meat is made up of about 75% water, which makes meat an acoustical match to water. As the HSW travels through the meat, ultrastructure damage is inflicted upon the meat (Zuckerman and Solomon, 1998). These changes in the ultrastructure of red meat result in an increase in tenderness (Zuckerman and Solomon, 1998).

Meek et al. (2000) found a 19.1 to 28.1% increase in tenderness in early-deboned broiler breast when treated with explosive produced HSW. Previous research in this
laboratory (Chapter 4) found a 42% improvement in Warner-Bratzler shear values when treated with explosive produced HSW in a cylinder configuration.

Further development of the explosive generated shockwave process for poultry has not been pursued because of the limitations of the batch-type process and the packaging requirements when using explosives. Hydrodyne Incorporated has recently adapted existing electrical-based technology (U.S. Patent Pending) to the application of hydrodynamic shockwave to food. Pulsed Plasma Technologies, Inc. (Spring Valley, California) is the manufacturer of equipment (U.S. Patents #4,345,650, #5,368,724, and #5,397,961) that uses electricity to produce hydrodynamic shockwaves. Hydrodyne Inc. in collaboration with Pulsed Plasma Technologies Inc. development a small self-contained unit that can rapidly produce HSW at a variety of energy flux densities and rapid sequential energy discharges.

The objective of the current study was to determine if the electrically produced shockwaves are effective in decreasing the Warner-Bratzler shear values of stored, early-deboned chicken breasts and normal deboned turkey breasts.

5.3 Materials and Methods

Experiment One, Broiler Breast

Eighty butterflied broiler breasts were obtained from a local processor (To Ricos Inc., Aibonito, Puerto Rico) and early deboned at 45-min postmortem. These breasts were transported on ice to the Hydrodyne, Inc. pilot plant (Canovanas, Puerto Rico) and stored 24 h (4°C) before treatment. Butterflied breasts were split medially and one breast was treated and the other breast used as a control. Ten breasts were used as a replication
for a total of four replications per level of shockwave. HSW was applied using a Pulsed Plasma Generator (600C Pulsed Power Technologies Inc.; Patents #4,345,650, #5,368,724, and # 5,397,961; Spring Valley, CA). The HSW machine settings were 45% Energy- with either one Pulse Firing Networks (PFN) or both PFN activated.

**Experiment Two, Turkey Breast**

Fresh, boneless turkey breasts (*pectoralis superficialis*) were shipped on ice overnight from a commercial turkey processor (North Carolina) to the Hydrodyne, Inc. pilot plant in Puerto Rico. The turkey breasts were kept refrigerated at 4°C until use. The frontal portion of 21 breasts were removed and trimmed parallel to the fibers. This frontal portion of the breasts were then cut in half with one half serving as a control and the corresponding half being treated. The inner surface where the breast portions were separated was identified with branding ink. Three portions were treated at a time for a total of seven replications. The HSW machine settings were 72% Energy- with both Pulse Firing Networks (PFN 1 and 2) activated.

*Product handling, cookery, and shearing*

All samples were placed in cotton netting (#32SMR-0301C, Jiff-Pack Industrial Netting, Carlsbad, CA, 92008) for placement in the shockwave machine. The treatment breasts were placed into the machine and positioned in the treatment area filled with 8°C water. The control breasts were handled and placed in 8°C water to mimic the treatment conditions.

Samples were water cooked in a jacketed steam kettle (Model # KET-12-T, Cleveland Steam Cooking Specialists, Cleveland Range, Ltd., Toronto, Canada)
maintained at 80°C. Samples were vacuum packaged (Model Easypack, Koch Supplies, Inc., Kansas City, MO, 64108) in 15.2 X 20.3 cm bags (VAK 3 L #01BS1116-155205, Docket #148052-1, Koch Supplies, Inc., Kansas City, MO). Breast portions were cooked to an internal temperature of 78°C. Internal temperature was monitored with T-type thermocouples (Model # 91100-20, Cole-Parmer Instrument Company, Vernon Hills, IL).

Cooked samples were allowed to equilibrate to room temperature before Warner-Bratzler shear (WBS) determination. Breast portions were cut into 1 cm by 1 cm, variable length strips parallel to the muscle fibers for shear force determination. Six to eight strips were taken from each breast portion and sheared (perpendicular) once per strip. Samples were sheared with a tabletop Warner-Bratzler shear machine (G-R Electrical Manufacturing Co., Manhattan, KS). A mean was calculated for each breast portion.

The cooking loss was determined on all turkey samples and half of the chicken samples cooked for tenderness determination. Cooking loss values were calculated based on the equation of: (raw weight minus cooked weight) divided by raw weight times 100. Pretreatment weights were taken on 12 individual chicken breasts (24 portions; 12-treated, 12-control). Change due to treatment was calculated by the equation: (post-treatment weight minus pretreatment weight) divided by post-treatment weight times 100.

Statistical Analysis

Chicken samples were analyzed as a completely randomized block design. Two independent tests were conducted with one using one PFN and the other with two PFN. This was done because the chicken for each group was not processed on the same day. Paired portions from the same individual turkey breast were compared using a General
Linear Model (SAS, 1996) with treatment and replication as blocking factors. Means were evaluated by examination of least square means (SAS, 1996).

### 5.4 Results and Discussion

**Experiment One, Broiler Breast**

*Warner-Bratzler shear*

The control breasts had an average WBS value of 5.34 kg which is similar to the WBS values reported by Meek *et al.* (2000) for early deboned broiler breasts. Treatment with one PFN was not sufficient to decrease (P>0.05) WBS values compared to the control breasts (Table 1). However, treatment with two PFN decreased (P<0.05) the WBS values by 22.1% compared to the controls. Based on the equipment design, two PFN which provided greater energy flux density than one PFN was necessary to tenderize the chicken. Similarly Meek *et al.* (2000) demonstrated that increasing the amount of explosive increased the degree of tenderization for all categories of early deboned broiler breast (Table 1). A high variation was expected in early deboned broiler breast (Lyon *et al.* 1985) and could provide a reason for the lack of significance due to treatment with one PFN. The reduction in WBS in samples treated with two PFN was similar to the 19.1 to 28.3 % decrease reported by Meek *et al.* (2000) in a 1060 L hemishell HSW unit. Previous research in this laboratory (Chapter 4) found a 42% increase in tenderness due to treatment with an explosive generated hydrodynamic shockwave created in a cylinder-shaped Hydrodyne unit. The lower decrease in WBS values reported in this current study could be due to differences in the force of the shockwave or waveform of the shockwave produced by the electrically generated system in contrast to that produced by explosives.
Cooking loss

Cooking loss was not affected (P>0.05) by HSW with one or two PFN in the broiler breasts (Table 1). However, Meek et al. (2000) reported a difference in the cooking loss in early deboned broiler breasts treated with explosive produced hydrodynamic shockwave.

Experiment Two, Turkey Breast

Warner-Bratzler Shear

Warner-Bratzler shear values were different (P<0.05) for the treated and the control breast portions (Table 2). The treated breast portions were 12.5% more tender than the untreated companion portion. These turkey breasts were aged bone-in as conducted commercially, which resulted in an increased uniformity of tenderness from breast to breast, within breast, and between birds as compared to early deboned chicken. A similar apparent percentage change was seen in chicken using the one PFN which was not different than the control chicken breasts. This degree of difference was significant in the turkey and was most likely associated with the uniformity in tenderness among and within the turkey breasts.

McKee et al. (1997) reported that storing broiler breasts on ice (<2°C) for 71 h postmortem resulted in a 2.6 kg/g reduction in Allo-Kramer shear values. This shear value reduction until 47 h postmortem was due to proteolysis. The turkey used in this study may have experienced post deboning aging and proteolysis before treatment, resulting in lower initial shear values in comparison to breast meat immediately after
deboning. The turkey in this study was cooked immediately after treatment which would have prevented any post additional treatment aging effects.

Cooking Loss

The treated turkey breast portions were 1.3% higher (P<0.05) in cooking loss than the untreated control breast portions. Meek et al. (2000) found no differences in cooking loss in broiler meat due to treatment with hydrodynamic shockwaves. Meek et al. (2000) reported a 20.1% and a 22.2% cooking loss for early deboned and treated broiler breasts, respectively. The standard deviation reported for those cooking loss values was higher (3.9) than the standard deviation in this study. The higher standard deviation may have been the cause of a lack of significance in the Meek et al. (2000) study versus these results.

Change in weight due to treatment

The control turkey breast portions (n=20) increased in weight by 1.7 % as a result of contact with water. The treated breasts increased in weight by 2.3 %, however this increase was not different (P>0.05) from the control breasts.

5.5 Conclusions

Application of the electrically produced shockwaves did not affect moisture uptake in uncooked muscle. Cooking loss was not affected in broiler breasts but was higher in turkey breasts after treatment. Electrically produced shockwaves can tenderize stored, early deboned chicken breasts and aged turkey breasts. Increasing the energy input from one pulse firing network to two improved the degree of tenderization. Further
improvements may be necessary to produce early deboned broiler breasts with tenderness similar to non-early deboned broiler breasts.

5.6 References


Table 1- Warner-Bratzler shear values and cooking loss for early-deboned (45 min. postmortem) and stored (24 h) chicken breasts treated with electrically produced hydrodynamic shockwaves.

<table>
<thead>
<tr>
<th>Pulse Firing Units (PFN)</th>
<th>Cooking Loss (%)</th>
<th>Warner-Bratzler Shear (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Hydrodynamic Shockwaves</td>
</tr>
<tr>
<td>One PFN (Std. Dev.)</td>
<td>24.33 a</td>
<td>26.32 a</td>
</tr>
<tr>
<td></td>
<td>(3.48)</td>
<td>(3.20)</td>
</tr>
<tr>
<td>Two PFN (Std. Dev.)</td>
<td>24.68 a</td>
<td>25.19 a</td>
</tr>
<tr>
<td></td>
<td>(1.82)</td>
<td>(1.99)</td>
</tr>
</tbody>
</table>

ab Means within a row and subject with unlike letters are different (P<0.05). For each PFN level, there were 40 breast pairs. Breasts were alternated between the control and hydrodynamic shockwave treatments.

1 HSW produced with machine setting of 45% energy.

Table 2 Warner-Bratzler shear and cooking loss of turkey breast portions treated with electrically produced hydrodynamic shockwaves.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Warner-Bratzler Shear (kg)</th>
<th>Cooking Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.20 a</td>
<td>20.4 a</td>
</tr>
<tr>
<td></td>
<td>(0.7)</td>
<td>(2.4)</td>
</tr>
<tr>
<td>Hydrodynamic Shockwave Treated</td>
<td>2.80 b</td>
<td>21.7 b</td>
</tr>
<tr>
<td></td>
<td>(0.5)</td>
<td>(1.5)</td>
</tr>
</tbody>
</table>

ab Means within a column with unlike letters are different (P<0.05). Parenthetical values represent standard deviations.

1 HSW produced with machine setting of 72% energy and both Pulse Firing Networks.
Appendix A

Standard Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

INFORMED CONSENT FORM FOR PARTICIPATION IN SENSORY EVALUATION

Project Title: Determining tenderness acceptability using sensory and Warner-Bratzler data.

Principal Investigators: Dr James R. Claus and Jennifer E. Knowles

I. PURPOSE OF THE PROJECT

You are invited to participate on a sensory panel. The purpose of the panel is evaluating tenderness in chicken breasts. Your participation is voluntary.

II. PROCEDURES

As a participant, you are asked to taste and evaluate 5 samples of chicken breasts. The test will take approximately 10 minutes to complete. Although you are required to taste the sample, if you find a sample objectionable, you may choose to spit it out.

III. BENEFITS/RISKS OF THE PROJECT

Your participation on the panel will provide information on the tenderness of chicken breasts. You may receive a summary of results when the project is complete. Certain individuals are sensitive to some foods such as milk, eggs, wheat gluten, strawberries, chocolate, artificial sweeteners, etc. If you are aware of any food or food allergies, please list them in the following space: ______________________________. There may be some risk involved if you have an unknown food allergy.
IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

Results of your performance as a panelist will be kept strictly confidential. All participants will be referred to by code for analysis and for any reports of the results.

V. COMPENSATION/FREEDOM TO WITHDRAW

It is important to the project for you to complete the evaluation. If after becoming familiar with the project you decide not to participate, you may withdraw without any penalty.

VI. APPROVAL OF RESEARCH

This project has been approved by the Institutional Review Board for Projects Involving Human Subjects at Virginia Polytechnic Institute and State University and by the human subjects review of Department of Food Science and Technology.

VII. SUBJECT’S PERMISSION

I have read through the Informed Consent Form and have been given the opportunity to ask questions regarding the sensory evaluation panel. I agree to participate on the panel as described in the Informed Consent Form.

__________________________________  ________________________________
Signature                              Date

Just in case we need to contact you. Information will be kept strictly confidential.

__________________________________  ________________________________
Address                              Phone Number

PLEASE KEEP THE ACCOMPANYING FORM REGARDING CONTACT INFORMATION.
THANK YOU !!!!!

If you have any questions regarding the panel, please contact:

Jennifer Knowles                   (540) 231-8679
Department of Food Science and Technology

James R. Claus, Ph.D.              (540) 231-3283
Department of Food Science and Technology

Susan E. Duncan, Ph.D.             (540) 231-8675
Department of Food Science and Technology

Tom Hurd                           (540) 231-5281
Director, Sponsored Programs
Appendix B Preliminary Testing

Pectoralis major tenderness of spent hens utilizing a hydrodynamic shockwave process in a research hemishell unit

J. E. Knowles, and J.R. Claus

Department of Food Science and Technology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24060

Abstract

The objective of this study was to determine the effect of hydrodynamic shock wave (HSW) treatment on prerigor, postrigor, and early deboned chicken breast tenderness. Prerigor boneless chicken breasts were HSW treated within 30 min of slaughter. The early deboned chicken breasts were deboned within 15 min of slaughter and stored 24 h (2°C) before HSW treatment. The postrigor treatment group was stored 24 h (2°C) on the carcass before deboned and HSW treated. No significant differences were determined between the HSW treated breast and the control breasts. There was a tendency for an increase in the Warner-Bratzler shear values of the prerigor group. The HSW treated postrigor and early deboned groups had larger fiber diameters and a decrease in cooking loss. The prerigor treatment group had smaller fiber diameters in the HSW treated group and experienced an increase in cooking loss. The lack of significant differences may have been associated with the treatment number used in this study. More work is needed with more severe HSW treatments and larger treatment groups.

1 TO whom correspondence should be addressed.
Introduction

Currently the broiler industry controls tenderness in broiler meat by utilizing storage time of the intact carcasses. Broiler meat requires a aging time of 4 to 6 hours of storage time on the bone to ensure adequate tenderness of the meat (Lyon et al., 1985). Any deboning of the meat before this time period will result in unacceptable lack of tenderness in the meat. This storage time increases processing costs by requiring substantial storage space that must be refrigerated. The storage time also raises microbial concerns. Contamination of a carcass can result in a 4 to 6 hour growth time for psychotropic bacteria. A delay in boning of chicken carcasses even to ensure acceptable tenderness results in increased processing costs that are then deferred to the customer in the price of the chicken. The cost of processing a broiler must include the operation costs of refrigerating that carcass for 4 to 6 h postmortem. These costs include refrigerant, employees, equipment maintenance, and fixed facility/equipment expenses.

Consumers want a product that is consistently tender and high quality. The industry can produce this high quality tender product through very efficient management and carcass handling. The processing of chicken is slowed considerably by a 4 to 6 hour hold time required for maximum tenderness in the meat (Lyon et al., 1985). Tenderization techniques to tenderize this meat after deboning and thus eliminate the hold time are an area of great research interest.

Electrical stimulation of broiler carcasses post mortem has shown an increase in broiler tenderness when combined with muscle tensioning (Birkhold and Sams, 1993). Lower voltage electrical stimulation has not demonstrated the same tenderization even when combined with muscle tensioning (Walker et al. 1994). Electrical stimulation in
poultry is still inconclusive based on the varying results in the literature. The variation seems to be the result of varying techniques in applying the electricity, varying treatments times post mortem and different processing and sampling methods employed by the various researchers (Li et al. 1993). The high number of systems to apply electrical stimulation and the variances in the type of electricity applied also complicate the use of electrical stimulation in the poultry industry. Although some improvements in tenderization of poultry meat has been realized by electrical stimulation, the poultry industry could still use a consistent, efficient technique for rapid tenderization.

The HSW process (U.S. Patent #5,328,403 and #5,273,766) uses a shock wave caused by an explosive force to disrupt cellular components of muscle. The shock wave travels through water in a specially designed tank and ultimately the meat. The explosive force is generated by a small amount of explosive suspended in water above the meat samples. Tenderization of the meat is accomplished instantaneously. This process has been found effective in a variety of red meats (Solomon et al., 1997) and poultry (Meek et al., 1997).

Spent hens are birds that are commercial layers that have surpassed peak production and have been designated for slaughter. These birds can be a variety of ages when they are slaughtered but they are usually significantly older than commercial broilers slaughter age (approx. 22 weeks). This makes these birds less tender and thus lowers the economic value of the carcasses. Often these birds are used in commuted meat soup products, pet foods or the buffalo wing industry. Tenderization of these carcasses would increase the value of the carcasses and allow them to be used in areas of
the industry that would reject a less tender product. Therefore tenderization of the layer
meat with HSW would be an asset to commercial producers of layers.

Materials and Methods

Bird Procurement and Slaughter:

Twenty-seven laying hens were obtained from a White Rock ancestry line that
Dr. Paul Seigel developed at Virginia Polytechnic Institute and State University. The
birds had been selected on body weight for 36 generations. These hens were the fifth
generation out of this line in which selection had been relaxed and mating decisions were
made at random. The hens were 54 weeks old at time of slaughter. The birds were
obtained on the day of slaughter and electrically stunned, and bled for thirty seconds
before any further treatment. Deboning time and storage time was dependent on
treatment. There were three treatments consisting of a early deboned, postrigor
deboned, and a prerigor (HSW within 30 min of slaughter) treatment. Left and right
breast breasts were randomized between control and treatment with in each boning time.

Treatment Definitions:

Seven hens were selected for the postrigor testing group. The postrigor group had
the breast removed intact (sternum, ribs, pectoralis superficialis, and pectoralis minor) and
stored in slush ice for 24 h. After 24 h the breast were separated from the bone,
individually labeled, and vacuum packaged. One breast from each breast was processed
in the HSW. The corresponding breast was not treated any further and served as a
reference.

The early deboned group contained eight birds. After bleeding, the breast meat
was removed (15 min postmortem), labeled, and vacuum packaged. This meat was
vacuum packaged and stored 24 h in slush ice before a HSW treatment was applied to one breast of each breast.

The prerigor group consisted of 12 hens that were deboned within seconds of bleeding. The breast meat was removed and each breast was identified. The breast meat was immediately vacuum packaged and one breast was HSW treated within 30 min of slaughter.

All the breasts were vacuum packaged and stored in Koch\textsuperscript{2} 6 inch by 8 inch 3ml standard barrier vacuum bags. The vacuum packager was operated with settings at a 99\% vacuum.

**HSW Procedure:**

The HSW unit had a total of four explosions. These were set up as replications with each having prerigor breasts(3), early deboned (2) and postrigor (1-2) breasts. The individual breasts were placed at the bottom of the HSW tank avoiding overlap. A binary explosive consisting of 75 grams of ammonium nitrite and nitromethane, detonated with an electric bridge wire detonator was used for each replication. The explosive was placed 12 inches from the bottom of the HSW tank. The companion breasts to those HSW treated were placed in a water bath of comparable temperature to the water in the HSW.

**Transmission Electron Microscopy:**

One breast per replication from the prerigor treatment was sampled for transmission electron microscopy (TEM). One sample of the early deboned and the post rigor treatments was also taken for TEM evaluation. These samples were fixed in 4%

\textsuperscript{2} Item #030026, Docket 501655,Koch,Supplies Inc., Kansas City, MO, 64108.
Gluten aldehyde in a phosphate buffer. These samples were turned over to the Virginia Maryland School of Veterinary Medicine for further preparation.

Fiber Diameter:

Tissue samples were taken from the breasts that were sampled for TEM and fixed in 4% Gluten aldehyde in a phosphate buffer for measuring fiber diameter. One breast set (left and right breasts) was taken of the early deboned and the post rigor treatments and also fixed for fiber diameter determination. The tissue samples were teased apart. Three fibers were examined under a microscope and diameter was taken using a video caliper.

pH Determination:

pH was determined on one breast from each HSW replication of the prerigor samples. This was done to determine if the samples were still undergoing rigor. The pH probe was inserted into the thickest part of the breast and the measurement was taken as close to the center of the breast as possible.

Cooking Procedures:

The individual breasts were cooked in a circulating water bath (maintained at 80°C) to an internal temperature of 78°C. Thermocouples and an automatic data recorder were used to record internal temperature. The thermocouples were placed in

---

3 Cue Micro 300 Video Caliper, Olympus Corp, Lake Success, NY 11042.

4 Model IQ 200, IQ Scientific Instruments, SanDiego, CA 92198

5 Model 5100, Datalogger, Electronic Controls Design, Inc. Milwaukee, OR 97222
the thickest part of the breast. The samples were immediately emerged in an ice bath after reaching the desired internal temperature.

Cooking Loss:

Cooking loss for each breast was determined. Cooking loss was determined by subtracting the cooked weight from the raw weight and then dividing by the raw weight. This value multiplied by 100 was the percentage loss.

Shear Force measurements:

Tenderness was determined using Warner-Bratzler shear determination. Strips were cut medially out of the center of each breast. The several strips were cut parallel to the muscle fibers and were trimmed to a one-cm height and width. The strips were allowed to equilibrate to room temperature before shearing. Three to 4 shear values were taken from each breast. A fifty-kg load transducer was used on an Instron with a Warner-Bratzler shear attachment. A crosshead speed of 200 mm/min and a load range of 50 were used. Statistics were performed on these values using SAS (1992).

Results and Discussion

pH Determination:

The pH measurements of the various breasts are displayed in table one of Appendix A. The pH measurements are high enough to indicate that rigor was not complete when the breasts were placed in the HSW. Prerigor breasts (treated 25 min postmortem) had an average pH of 6.39. At 24 h postmortem the average pH was 5.61.

Shear Value Determination:

6 Model 1011, Instron Corp., Canton, MA 39046
Although there were no statistically significant differences between the non-treated and HSW treated breasts, the trend was apparent for the HSW to reduce the shear forces for the postmortem and early deboned spent hen breasts (Appendix A Table 2). Also keep in mind that these tests were conducted on Hens (older birds) and not broilers.

As for the prerigor HSW treated chicken, the opposite trend was noted as HSW increased the shear force. This was not necessarily unexpected nor is it discouraging. The theory on treating prerigor (still twitching) breasts was that we could cause enough damage to overcome normal rigor shortening associated with excised muscle. Under HSW conditions of 75 grams of explosive at 30.5 cm from the meat, this did not happen. However the data from the prerigor breasts does substantiate the theory that if only selective portions of the muscle fiber are damaged then the remaining portion is free to contract and cause addition toughening. Higher pressure fronts will have to be treated if prerigor treatment is to remain a viable option.

Cooking Loss and Fiber Diameter:

For this preliminary, limited data set, no differences (P>0.05) were found between the HSW treated and not HSW treated breasts in terms of fiber diameter and cooking loss within a boning time. Although not statistically different, HSW tended to have smaller fiber diameters than the non-HSW treated counterparts. This would suggest that the HSW treatment may have inhibited some of the muscle shortening as theorized. However, at the conditions tested for this experiment, this was not enough to inhibit the rigor related shortening associated with the pre-rigor excised muscle as the numerical shear force mean was higher for the HSW treated breast. Nevertheless, this is a positive indication and testing higher pressure fronts should proceed.
Conclusions
At the HSW conditions used in this experiment, there was only a tendency to decreased shear values in the postrigor and early deboned treatments. Shock wave tenderization of prerigor chicken appeared to be the least viable approach to eliminate the need for delayed deboning.

References


Appendix A

Table 1- Prerigor pH values at treatment and 24 h postmortem.

<table>
<thead>
<tr>
<th>Tank</th>
<th>Breast</th>
<th>Initial pH</th>
<th>Initial Temp (°C)</th>
<th>24 hr pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3R</td>
<td>6.55</td>
<td>19.1</td>
<td>5.69</td>
</tr>
<tr>
<td>B</td>
<td>5R</td>
<td>6.3</td>
<td>25.2</td>
<td>5.41</td>
</tr>
<tr>
<td>C</td>
<td>7R</td>
<td>6.49</td>
<td>24.2</td>
<td>5.77</td>
</tr>
<tr>
<td>D</td>
<td>10L</td>
<td>6.2</td>
<td>26.0</td>
<td>5.57</td>
</tr>
</tbody>
</table>

Table 2- Mean¹ Warner Bratzler shear values for spent hen cooked breasts

<table>
<thead>
<tr>
<th>Boning time</th>
<th>Non Treated</th>
<th>Hydrodynamic Shockwave treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postrigor</td>
<td>2.52</td>
<td>2.25</td>
</tr>
<tr>
<td>Early deboned</td>
<td>4.17</td>
<td>3.69</td>
</tr>
<tr>
<td>Prerigor</td>
<td>3.98</td>
<td>4.33</td>
</tr>
</tbody>
</table>

¹Means within an instrumental shear method and row without superscript letters are not different (P>0.05).
Table 3- Mean\(^1\) cooking loss and fiber diameter for spent hen breasts

<table>
<thead>
<tr>
<th>Boning time</th>
<th>Fiber Diameter (um)</th>
<th>Cooking Loss (%)</th>
<th>Dependent Variable</th>
<th>Hydrodynamic Treated</th>
<th>Hydrodynamic Treated</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non Treated</td>
<td>Shockwave Treated</td>
<td>MSE</td>
</tr>
<tr>
<td>Postrigor</td>
<td>68.0</td>
<td>79.7</td>
<td>-</td>
<td>13.09</td>
<td>12.07</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(1)</td>
<td>(5)</td>
<td>(5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early deboned</td>
<td>89.0</td>
<td>97.0</td>
<td>-</td>
<td>11.41</td>
<td>11.27</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(1)</td>
<td>(6)</td>
<td>(6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prerigor</td>
<td>98.6</td>
<td>79.3</td>
<td>9.41</td>
<td>8.58</td>
<td>9.37</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(4)</td>
<td>(6)</td>
<td>(6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Means within a dependent variable and row without superscript letters are not different (P>0.05). Numbers in parentheses are the number of breast breasts evaluated.
Appendix C

Preliminary Testing of Electrical Shockwave Technology

Objective: Rapidly evaluate various test parameters to determine objective and experimental design for a replicated study.

General* Materials and Methods:

*Although test parameters differed in various preliminary tests, chicken procurement and cookery remained the same.

Early deboned, butterflied broiler breasts were obtained from a local processor and transported to the commercial test facility. Breasts were separated and individually labeled. Breasts were placed into cotton netting for placement in the machine. Treated breasts were exposed to shockwave produced by various machine settings. Hydrodynamic shockwave was applied using a Pulsed Plasma Generator (600C Pulsed Power Technologies Inc. (Patents #4,345,650, #5,368,724, and # 5,397,961), Spring Valley, CA, 91976). Machine settings are reported as Percent Energy (E) and Pulse Firing Network (PFN).

Samples were water cooked in a jacketed steam kettle (model # KET-12-T, Cleveland Steam Cooking Specialists, Cleveland Range, Ltd., Toronto, Canada) maintained at 80°C. Samples were vacuum packaged (Model # Easypack, Koch Supplies, Inc., Kansas City, MO, 64108) in 6 by 8 bags (VAK 3 L #01BS1116-155205, Docket #148052-1, Koch Supplies, Inc., Kansas City, MO, 64108). Breast portions were cooked to an internal temperature of 78°C. Internal temperature was monitored with T-
type thermocouples (Model # 91100-20, Cole-Parmer Instrument Company, Vernon Hills, IL, 60061-1844).

Cooked breast portions were allowed to equilibrate to room temperature before Warner-Bratzler shear (WBS) determination. Breast portions were cut into 1 cm by 1 cm by 1 cm, variable length strips for shear force determination. Six to eight strips were taken from each breast portion and sheared once per strip. Samples were sheared with a tabletop Warner-Bratzler shear machine (G-R Electrical Manufacturing Co., Manhattan, KS 66502). A mean was calculated for each breast portion. Percent change was determined by the formula: 1 minus (treated WBS divided by control WBS) times 100.

Results:

Preliminary Test One (PR001):

Test Parameters: Machine settings 45 % E, PFN 1, N=4

Table 1: Warner-Bratzler shear force of treated versus control broiler breasts

<table>
<thead>
<tr>
<th>Bird Number</th>
<th>Control (n=4)</th>
<th>Hydrodynamic Shockwave (n=4)</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.66 (0.79)</td>
<td>1.12 (0.31)</td>
<td>32.5</td>
</tr>
<tr>
<td>2</td>
<td>5.25 (1.18)</td>
<td>3.32 (1.19)</td>
<td>36.8</td>
</tr>
<tr>
<td>3</td>
<td>3.8 (0.66)</td>
<td>2.27 (0.74)</td>
<td>40.4</td>
</tr>
<tr>
<td>4</td>
<td>2.12 (0.69)</td>
<td>3.02 (1.33)</td>
<td>-42.5</td>
</tr>
</tbody>
</table>
**Preliminary Test Two (PR002):**

Test Parameters: Machine settings 45 % E, PFN 1 & 2, N=4

Table 2: Warner-Bratzler shear force of treated verses control broiler breasts

<table>
<thead>
<tr>
<th>Bird Number</th>
<th>Control (n=4)</th>
<th>Hydrodynamic Shockwave (n=4)</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.72</td>
<td>1.64</td>
<td>55.9</td>
</tr>
<tr>
<td></td>
<td>(0.88)</td>
<td>(1.01)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.68</td>
<td>2.40</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td>(2.26)</td>
<td>(1.10)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.7</td>
<td>2.63</td>
<td>-59.6</td>
</tr>
<tr>
<td></td>
<td>(0.67)</td>
<td>(0.96)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.1</td>
<td>4.72</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>(1.33)</td>
<td>(0.87)</td>
<td></td>
</tr>
</tbody>
</table>

**Preliminary Test Three (PR004):**

Test Parameters: Machine settings 72 % E, PFN 1 & 2, N=4

Table 3: Warner-Bratzler shear force of treated verses control broiler breasts

<table>
<thead>
<tr>
<th>Bird Number</th>
<th>Control (n=8)</th>
<th>Hydrodynamic Shockwave (n=8)</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.18</td>
<td>1.65</td>
<td>24.31</td>
</tr>
<tr>
<td></td>
<td>(0.81)</td>
<td>(.44)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.93</td>
<td>5.32</td>
<td>-8.02</td>
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<tr>
<td></td>
<td>(1.29)</td>
<td>(3.21)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6.38</td>
<td>2.05</td>
<td>67.84</td>
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<tr>
<td></td>
<td>(3.08)</td>
<td>(0.92)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3.60</td>
<td>3.70</td>
<td>-2.8</td>
</tr>
<tr>
<td></td>
<td>(1.28)</td>
<td>(1.91)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.33</td>
<td>3.30</td>
<td>60.36</td>
</tr>
<tr>
<td></td>
<td>(2.10)</td>
<td>(0.85)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.57</td>
<td>5.50</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>(1.25)</td>
<td>(0.36)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>7.10</td>
<td>1.85</td>
<td>73.94</td>
</tr>
<tr>
<td></td>
<td>(1.06)</td>
<td>(0.42)</td>
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</tr>
<tr>
<td>8</td>
<td>6.58</td>
<td>3.00</td>
<td>54.37</td>
</tr>
<tr>
<td></td>
<td>(2.92)</td>
<td>(1.19)</td>
<td></td>
</tr>
</tbody>
</table>
Vita

Jennifer Knowles Schilling was born on November 24, 1975 in Cincinnati, Ohio and is the daughter of Jane Plyler Knowles and Jimmy Harold Knowles. She received her High School Diploma from Jefferson Forest High School in Forest, Virginia and her Bachelor of Science degree in Animal and Poultry Sciences on May 9, 1998 from Virginia Polytechnic Institute and State University. She married Mark Wesley Schilling on May 29, 1999. Upon completion of her Master’s degree in January, 2000, and after a short vacation, Jennifer began work as a Laboratory Specialist in the Department of Animal and Poultry Sciences at Virginia Tech. In addition to her career, Jennifer plans to continue riding her horses and have a family with Wes.