

Chapter 2

Literature Review

2.1 Meat Tenderness

Consumer satisfaction with tenderness of a meat product will determine if the purchase is repeated in the future (Morgan et al., 1991). It is critical for food scientists and meat processors to consistently produce a tender meat product that meets or exceeds consumer expectations.

2.1.1 Factors affecting tenderness

The variation occurring in meat tenderness exists due to genetics, biological and physiological differences, changes during slaughter, differences created during post-mortem storage, or a combination of these factors (Koochmaraie, 1996). The percentage of protein, fat, moisture, and collagen composition of the meat product affect tenderness (Cross et al., 1973). Tenderness is affected by aging, type of rigor, sarcomere length, skeletal restraint and proteolytic activity (Pearson, 1987). In general, meat tenderness is affected by a variety of factors that occur during rigor mortis and post-rigor changes. Pre-rigor meat is tender but becomes progressively tougher as permanent crossbridges form between myosin and actin in the absence of adenosine triphosphate (Pearson, 1987). Temperature, pH, rate of temperature decline, genetics, and type of stunning affect the course of rigor (Fleming et al., 1991; McKee et al., 1997; Pearson, 1987; and Sams et al., 1990). Koochmaraie (1996) reported that prevention of sarcomere length shortening can prevent meat toughening. Marsh and Leet (1966) demonstrated a relationship between sarcomere length and tenderness such that maximum toughness occurs at 40% shortening

of excised beef muscles. Shortening of 40 to 60% was defined as a zone of “progressive rupturing” in which cell damage occurs from excessive shortening of the muscle (Marsh and Leet, 1966). Koohmaraie (1996) reported toughening during first 24 hours post-mortem attributed to rigor-induced sarcomere shortening. The authors also suggested that the greatest proportion of variation in sarcomere length is found from animal to animal. Sarcomere length has also been determined to be correlated with pH as a higher pH value is associated with longer sarcomere lengths in broiler breasts (Dunn et al., 1993). Shorter sarcomere lengths have been reported at the anterior (cranial) location of aged broiler *pectoralis* muscle (Papa and Fletcher, 1988). Additionally, sarcomeres are shortened at low temperatures (0 and 14°C) in aged broiler breasts (Bilgili et al., 1989).

In poultry, cold shortening is not normally a cause of toughening in normal industrial processing providing the breast meat is not pre-maturely excised or otherwise altered (Papinaho and Fletcher, 1996). Papinaho and Fletcher (1996) described temperature induced shortening in broiler breast muscle sampled as intact (on carcass), and excised muscle. Excised whole breast muscle incubated at 41°C demonstrated the greatest temperature induced shortening of 59% of the original breast length (Papinaho and Fletcher, 1996). The authors concluded that broiler breasts underwent cold and rigor shortening in intact and excised muscle, and the greatest muscle shortening in excised muscle occurred at 41°C. Similarly, Dunn et al. (1995) determined that type of chilling and temperature influenced the textural variability of broiler breasts. The risk of tenderness problems associated with rigor shortening may be diminished by chilling rapidly in 0°C water (Dunn et al., 1995). However, the rapid air-chilling method (-12°C) enhances the risk of cold shortening in carcasses with pH values greater than or equal to

6.7 at 15 minutes post-mortem. Papa and Fletcher (1988) reported that the least muscle shortening occurred at 16°C and the greatest shortening at 0 and 40°C at 2 hours post-mortem.

Sams and Janky (1986) reported that early de-boning (hot boned 45 minutes and chill boned 2 hours post-mortem) of broiler breast meat resulted in unacceptable tenderness, and the variability of tenderness in early de-boned samples increased between carcasses compared to delay de-boned breasts. In efforts to determine the cause of increased variation of tenderness, several coworkers have investigated location effects and aging on tenderness (Papa and Fletcher, 1988; Papa and Lyon, 1989; Lyon and Lyon, 1997). Papa and Lyon (1989) suggested that during cooking the thin caudal end of the breast would harden more than the cranial end. The authors further reported that sensory panelists rated aged intact caudal end of the samples as harder and chewier than the cranial location. The reverse situation was found for hot-boned groups (Smith et al., 1988; Papa and Lyon, 1989). Conversely, Papa and Fletcher (1988) reported no difference between the anterior, middle, or posterior sections of aged (24 hours) intact *pectoralis* muscle. Similarly, Lyon and Lyon (1997) noted that no differences in shear were observed due to location on the carcasses.

Lyon and Lyon (1996) determined that there were no differences in juiciness scores of the samples due to de-boning time and juiciness was not significantly correlated with instrumental measurements. Tenderness and overall texture acceptability scores were higher with increasing time between chilling and de-boning and these characteristics were significantly correlated (Lyon and Lyon, 1996). Additionally in this study, the trained panel determined that the 2-hour samples had a higher moisture release

than the 6 or 24-hour samples. These data agree with those of Lyon and Lyon (1993) who determined that intact samples de-boned prior to 24 hours post-mortem had a moisture that was characterized as free, less bound, and easily expressed.

2.1.2 Tenderness measurements

Tenderness measurements of meat include a variety of different techniques. Studies involving poultry mainly consist of the use of Warner-Bratzler and Lee-Kramer compression shear methods to evaluate instrumental tenderness. Sensory evaluation of tenderness can be accomplished with many different tests such as descriptive analysis, attribute tests, affective consumer tests and texture profile methods (Meilgaard et al., 1991).

Tenderness of meat is evaluated using instrumental determinations on intact pieces or cores that are large enough to ensure representative sampling of the muscle fibers (Lyon and Lyon, 1996). The Warner-Bratzler shear apparatus measures the force required to cut through the sample using a single blade. The Lee-Kramer system of shear measurement utilizes a multiple blade to objectively evaluate meat tenderness. Sams et al. (1990) evaluated the correlation between these two procedures for determination of early harvested broiler breast meat. These researchers evaluated hot-boned (immediately after picking), chill-boned (one hour post-mortem) and age-boned (24 hours post-mortem) with both shear techniques. Fillets were cooked to 80°C and two samples (35x20x7 mm) from the anterior portion of the right side fillet were evaluated by shear-compression with fiber orientation perpendicular to the blade. Warner-Bratzler shear was evaluated on strips (50x10x7mm) cut from the left fillet with the fiber-oriented

perpendicular to the blade. Each shear technique was able to differentiate between samples across a wide range of shear values. The overall correlation for all samples and two shear methods was high ($r=0.93$) (Sams et al., 1990). Additionally, the researchers reported a lower variance in shear values of the breasts harvested at 24 hours of aging compared to those hot-boned. Similar shear value variance differences were reported previously (Sams and Janky, 1986).

Lyon and Lyon (1993) investigated two cooking methods and post-mortem de-boning times for broiler breast meat using a diced sampling procedure. The cooked meat was ground through a food chopper and twenty grams of the diced sample placed in a Lee-Kramer shear cell. This diced method resulted in a random muscle fiber orientation. The shear values were reported as kilograms of force to shear twenty grams of meat. Samples de-boned at 2 or 24 hours required less than 109 kg/20g of shear force. However, the same treatments sheared as intact strips (1.9-cm wide) corresponded to the sensory scores for the 2 hour samples of moderately to slightly tough and for the 24 hour samples, very tender (Lyon and Lyon, 1990). This inconsistency in methods was also noted in a study of four de-boning times of broiler breasts measured with the strip and diced sampling methods (Smith and Fletcher, 1990). Smith and Fletcher (1990) reported lower shear values for the diced samples over the strip samples. Therefore, the authors concluded that the diced method of Lee-Kramer analysis was a less sensitive method than the strip method of sampling.

The sensory description of meat texture is a multi-faceted process involving considerations of meat sample degradation (particle size and shape, bolus size and wetness) and other attributes such as the amount of saliva produced, moisture released,

ease of swallowing, and mouth coating (Lyon and Lyon, 1997). Lyon and Lyon (1990) developed sensory descriptors that relate to Warner-Bratzler shear and Lee-Kramer shear values. The researchers determine that broiler breasts aged for 24 hours would be rated very tender. A Warner-Bratzler shear value of <3.62 kg of cooked (80°C) 1.9-cm wide strips of varying natural thickness corresponds to the very tender descriptor. The researchers developed a range of shear values to correspond to a six-category consumer sensory tenderness scale (very tough to very tender).

2.2 Tenderization Methods

2.2.1 Aging

Aging is a method often used to improve meat tenderness. The aging methods used in red meats include vacuum aging, dry aging, time course of aging, heat accelerated aging, and enzymatic aging (Pearson, 1987). Poultry aging (conditioning) is a term for the mechanical restraint of chilled broiler breast meat on intact carcasses. Red meats include both conditioning and aging. Aging in red meats is the process of holding the meat just above freezing (0 to 5°C) for days to weeks. This aging is due to inherent muscle enzymes and occurs in whole carcasses or primal meat cuts (Pearson, 1987). Koohmaraie (1994) also indicated that in red, meat post-mortem proteolysis is responsible for increasing the ease of fragmentation of Z-disks and other muscle proteins. In addition to proteolysis, the increase in post-mortem ionic strength due to decreased protein interactions and increased solubility of myofibrillar proteins contributes to aging induced tenderness (Wu and Smith, 1987).

The mechanism of poultry aging relies primarily on the mechanical restraint of the bones to prevent muscle shortening during rigor (Dunn et al., 1993; Papinaho and Fletcher, 1996; Sams et al., 1990; Uijttenboogaart and Fletcher, 1989). Harvesting broiler breasts pre-rigor results in shortened sarcomere lengths due to a loss of skeletal restraint (Dunn et al., 1993; Sams et al., 1990). *Pectoralis* muscle shortens approximately 18 to 20% within the first 15-min following excision (Papinaho and Fletcher, 1996). McKee et al. (1997) investigated physical and biochemical effects of broiler breast tenderness at 0, 23, 47 and 71 hours of aging. The researchers reported that aging for 71 hours reduced shear values and the enzyme, calpain, was active. Calpastatin was degraded by 47 hours post-mortem (McKee et al., 1997). Calpains are a type of endogenous enzyme which degrades myosin and associated proteins which are responsible for maintaining structural integrity of muscle myofibrils (Koohmaraie, 1996). Degradation of the structural proteins would cause weakening of the myofibrils and subsequent tenderization. Converse to the McKee et al. (1997), Koohmaraie (1996) suggested that since calpains are rapidly degraded, they are not entirely accountable for tenderization beyond 24 to 48 hours post-mortem. Additionally, the presence of calpastatin, which is an endogenous inhibitor to calpains, would eliminate calpain activity shortly post-mortem (Koohmaraie, 1996). In addition to enzyme activity, the aging from 47 to 71 hours was due to increased ionic strength (McKee et al., 1997). These findings suggest that additional poultry aging beyond the industry processing time of 4 to 6 hours occur due to proteolytic activity. Dunn et al. (1993) reported that the mean sarcomere lengths for pectoralis muscle were not changed in muscle aged 24 hours and 7 days. Electron microscopy of aged broiler breasts (greater than 24 hours) visually

demonstrated that extended aging does not affect mean sarcomere length (Dunn et al., 1993).

2.2.2 Electrical stimulation

Benjamin Franklin first used electrical stunning for meat animals in 1749 to kill turkeys (Lopez and Herbert, 1975). The meat from the electrocuted turkeys was reported to be uncommonly tender. Since then, electrical stimulation has been used to tenderize meats as well as a means to study biochemical function in muscles (Pearson, 1987). Since muscle contraction depends on electrical impulses from the nervous system, applying intermittent ES to a carcass immediately post-slaughter accelerates the natural course of contraction and relaxation of the muscles. The rate of glycolysis is increased so that rigor mortis develops more quickly than non-stimulated meat (Pearson, 1987).

In red meats, many studies have been conducted on improving meat tenderness primarily by preventing cold shortening and freeze shortening (thaw rigor). These studies have included altering carcass positions, post-mortem electrical stimulation and differing freezing rate and temperature (Sheridan, 1990). Cold shortening can occur in pre-rigor red meats and poultry. Rapid cooling of the muscle compromises the ability of the sarcoplasmic reticulum and mitochondria to retain calcium (Pearson, 1987). This phenomenon results in muscle fibers which are more contracted (shorter sarcomeres) when exposed to rapid chilling than muscle fibers exposed to a slower chilling process (Bilgili et al., 1989). Freeze shortening (thaw rigor) results in the same condition under freezing temperatures as previously frozen pre-rigor meat is thawed (Pearson, 1987).

ES has been used as a method to decrease post-mortem aging time of broiler breasts (Lyon et al., 1989; Maki and Froning, 1987; Sams et al., 1989). Early de-boned broiler breasts physically shorten as the muscle continues to undergo rigor changes. With proper handling and aging on the bone, the breasts are of acceptable tenderness. However, processors need to meet increasing consumer demand for boneless product. Thompson et al. (1987) reported that pulsed electrical stimulation with high voltage (820 V), short time (15 s) of chill-boned (de-boned 1 hour post-mortem) resulted in increased tenderness to acceptable levels of aged (24 hours) breast meat. The high voltage ES in hot-boned (10-min post-mortem), or age-boned (48 hours post-mortem) did not result in tenderness changes. Additionally, the authors did not find a relationship between changes in post-mortem muscle metabolism and tenderness changes in cooked muscle due to post-mortem ES. Sams et al. (1989) reported that cooked breast meat shear values decreased as time of de-boning increased for control and electrically stimulated carcasses. Additionally, the authors suggested that the ES meat produced significantly lower shear values than the controls when post-mortem aging times were equal to or greater than 100 minutes. This would be equated to a 60% decrease in holding time when electrical stimulation was used (Sams et al., 1989). Similarly, Maki and Froning (1987) reported a significant tenderization response in turkey breast muscle when carcasses were electrically stimulated immediately after bleeding for a total of 36-seconds of stimulation occurring in cycles of 4-seconds of stimulation and a 5-second rest with 820 V. Tenderness improvement with ES is also due to increased physical disruption of myofibrils and increased sarcomere lengths (Sams et al., 1989; Thompson et al., 1987).

The cooking loss of the turkey was not affected and the color was enhanced by ES (Maki and Froning, 1987).

In another study investigating the effectiveness of post-mortem ES of hot and cold de-boned broiler breast, electrical stimulation at 0 or 15 minutes post-mortem decreased tenderness as compared to non-stimulated and normally aged chicken (Froning and Uijttenboogaart, 1988). The authors reported further that ES increased the redness of the samples and cooking losses. A similar increase in cooking losses was noted by Lyon et al. (1989). Froning and Uijttenboogaart (1988) suggested that the increase in redness in chicken breasts would be undesirable to consumers. Hot de-boning decreased the sarcomere length, and Froning and Uijttenboogaart (1988) reported that ES has no significant effect on sarcomere length. Conversely, Thompson et al. (1987) reported an increase in sarcomere length in ES, early harvested broiler breasts. Sams et al. (1992) reported that anatomical location of electrical stimulation application affects the tenderness result of broiler breasts. Broilers were stimulated (840 V 340mA) in five pulses of 2 seconds of stimulation followed by 1 s rest at the breast or neck immediately after sticking, chilled and de-boned 1.25 hours post-mortem (Sams et al., 1992). The samples stimulated at the breast location were more tender (Lee-Kramer shear 6.3 kg/g) than both the controls (harvested 1.25 hours post-mortem, no stimulation; 8.3 kg/g shear) and the neck stimulated samples (8.6 kg/g shear) (Sams et al., 1992). Despite improvements in tenderness due to ES, the varied responses of stimulated broilers has prevented this technology from being used to replace the normal processing aging time of broiler breasts.

2.2.3 Ultrasonic techniques

Ultrasound occurs naturally and has been used in a variety of applications including but not restricted to medical surgeries, cleaning equipment, and location devices (Goldman, 1962). Additionally, ultrasound has been investigated as a method to tenderize meat. Cells are disrupted by a sonically maintained activity known as gaseous cavitation (Hughes and Nyborg, 1962). The ultrasound waves can cause two types of cavitation: stable cavitation and transient or collapse cavitation (Goldman, 1962; Smith et al., 1991). The first involves a bubble that grows to a resonant size and oscillates due to the ultrasound (Goldman, 1962). Hughes and Nyborg (1962) suggested that this bubble produces hydrodynamic forces which then rupture muscle structural components. The second force causes strong hydrodynamic forces through the collapse of the bubble and these forces rupture cells (Hughes and Nyborg, 1962).

Lyng et al. (1997) suggested that ultrasonic techniques may cause lysosomal rupture as well as myofibrillar protein and connective tissue disruption to result in tenderization of the meat. More specifically, tenderization occurs through the release of lysosomal cathepsins and calpains enzyme systems (Koochmaraie 1992). Lyng et al. (1997) also suggested that ultrasonic waves cause the degradation of collagen. In a study of low frequency (range of 30 to 47 kHz), high intensity (range of 0.29 to 0.62 W/cm²) ultrasound baths on beef steaks, Lyng et al. (1997) reported that the ultrasound treatments were not effective in improving tenderness of intact beef steaks. Additionally, the collagen solubility and the SDS PAGE of myofibrillar proteins of the ultrasonicated beef were not different from untreated controls. Conversely, Smith et al. (1991) determined a significant decrease in shear force values for beef *Semitendinosus* which were sonicated

for 2 and 4 minutes with low frequency (26 kHz), high intensity (value not provided) ultrasound (Smith et al., 1991). However, in the same study an increase in shear values was noted after 8 minutes of ultrasonic exposure at the same level. This contrast was not further discussed.

2.2.4 Hydrostatic Pressure

Hydrostatics is the study of characteristics of liquids at rest or the force that a liquid imposes on a submerged object (Zobell and Kim, 1972). MacFarlane (1973) researched the effects of hydrostatic pressure on beef and lamb. An improvement in tenderness was determined when the meat was treated with hydrostatic pressure of $1.05 \times 10^7 \text{ kg/m}^2$ (14,903 psi) at 30 to 35°C for a two-minute duration. Kennick et al. (1980) also determined that hydrostatic pressure accelerates meat aging and improves tenderness. The tenderness incurred by hydrostatic pressure was due to the disruptive nature of the pressure causing a dissociation of the myofibrillar proteins (Kennick et al., 1980).

Zobell and Kim (1972) reported that pressures of 3000 to 15,000 atm inactivate or denature virtually all enzymes. The degree of inactivation is dependent on the duration of pressure treatment (Zobell and Kim, 1972). In a study on the effects of pressure on protease (isolated from *Bacillus subtilis*) activity, a 50% reduction of activity was determined after 72 hours at 1000 atm of pressure (Zobell and Kim, 1972).

2.2.5 Hydrodynamic Pressure

In 1970, Godfrey patented (U.S. Patent # 3,492,688) a method and apparatus for

tenderizing meat with the use of an explosive charge that generates a shock wave pressure front. The wave was propagated through a liquid medium at velocities exceeding the speed of sound. The patent stated that the meat might be placed in a protective wrapping, such as a flexible bag made of rubber or plastic material, from which the air has been evacuated. While the principle behind Godfrey's patent was sound, the embodiments disclosed, with respect to the tank and position of the meat in relation to the tank and explosive charge, would present serious difficulties in a commercial tenderization situation. Thus the objective was to overcome the deficiencies in the prior art of tenderizing meat with an explosive charge and provide an improved system for tenderizing meat using a hydrodynamic shock wave.

The Hydrodyne process, redesigned by John Long, (U.S. Patent #5,273,766 and #5,328,403) is a technology being tested by the USDA's Agricultural Research Service Meat Science Research Laboratory, Beltsville, MD, to tenderize beef, pork, and lamb. Hydrodynamics are the study of fluid motion and forces on solids immersed in the fluids (Kolsky, 1980). The Hydrodyne process is an example of the hydrodynamic force of a shock wave on an object in a fluid. To date the explosive used to create a shock wave has been a combination of nitromethane (liquid) and ammonium nitrate (solid) (Solomon et al., 1997a). These components are not explosive until combined. The amount of explosive and the distance of the explosive to the surface of the packaged meat product determine the amount of pressure imposed on the meat. The explosive is hand packed in a spherical shape and then detonation of the explosive occurs with a high-energy electrical blasting cap. The shock waves produced move equidistant from an explosive source depending on the shape of the explosive (Batsonov, 1994). The shock wave

travels rapidly through the fluid (water) and any objects which are an acoustical match with the water (Kolsky, 1980). Since meat is composed of 75% of water (Pearson, 1987), the wave passes through the solid meat sample and tears muscle proteins during the Hydrodyne treatment (Zuckerman and Solomon, 1997). The shock wave indiscriminately ruptures sarcomeres, but has a tendency to affect the sarcomeres at the Z-line/A-band/I-band juncture (Zuckerman and Solomon, 1997; Solomon et al., 1997b).

Shock waves are found naturally produced from cosmic explosions, thunderstorms, volcanic eruptions, and meteoroid impacts. In general any shock wave is defined as a very sharp, thin wave front (Glass, 1974). Furthermore when a shock wave is generated, the wave raises the surrounding materials to a high pressure, then induces a flow velocity behind the wave and quickly subsides (Glass, 1974). A flow velocity is similar to an aftershock or reverberation of subsiding pressure waves (Glass, 1974). The shock wave is the largest single source of energy (Cole, 1948) and is the first front to reach the meat surface in the Hydrodyne process (Personal communication, Steven Renfro, Ensign-Bickford Co., 660 Hopmeadow St., P.O. Box 483, Simsbury, CT 06070). The secondary pressure pulses from gas sphere contractions are apparent in a longer duration than the shock wave, but the energy associated with the gas sphere is one third or less of the shock wave (Cole, 1948). Figure 1 depicts a schematic representation of the Hydrodyne tank. Figures 2 through 6 demonstrate the evolution of the wave front and gas sphere. The explosive is suspended in the tank with the broiler breast placed in the bottom center of the tank (Figure 2). Upon detonating the explosive (Figure 3), a primary

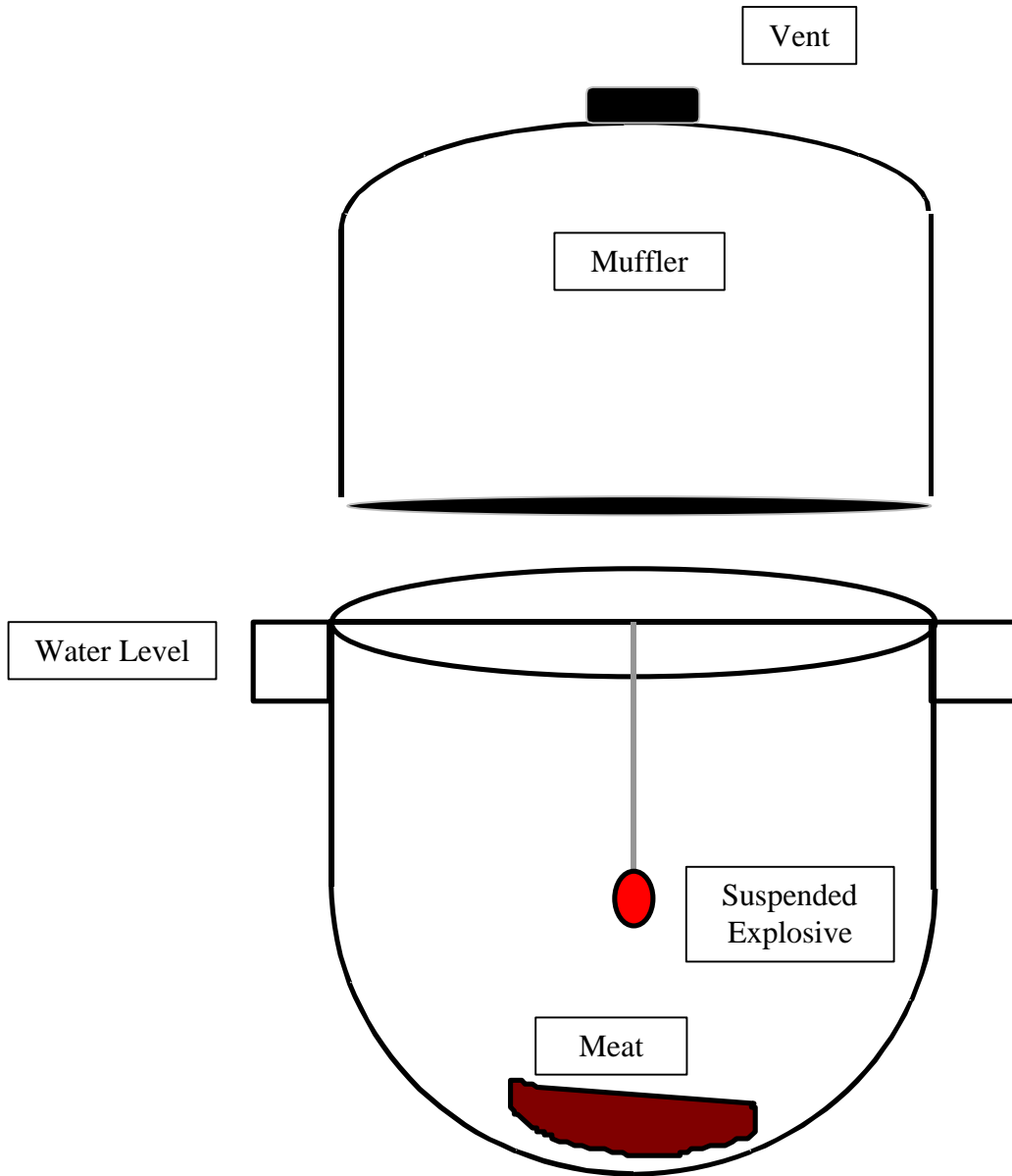


Figure 1: Schematic representation of the Hydrodyne tank.

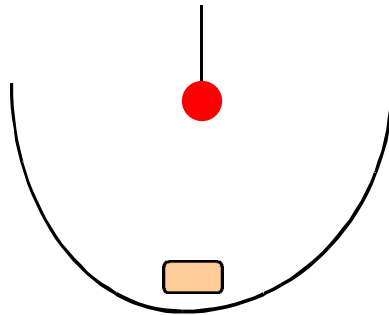


Figure 2: Explosive suspended in tank with broiler breast placed in the bottom center of the tank

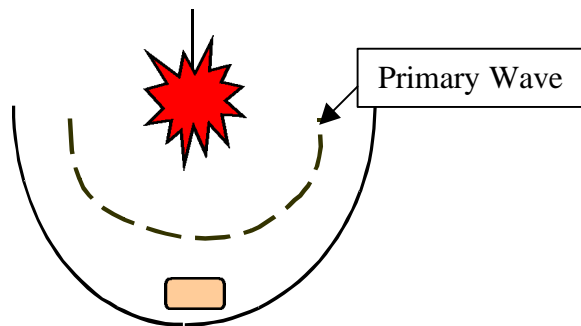


Figure 3: The explosive is detonated and the primary wave front formation occurs first.

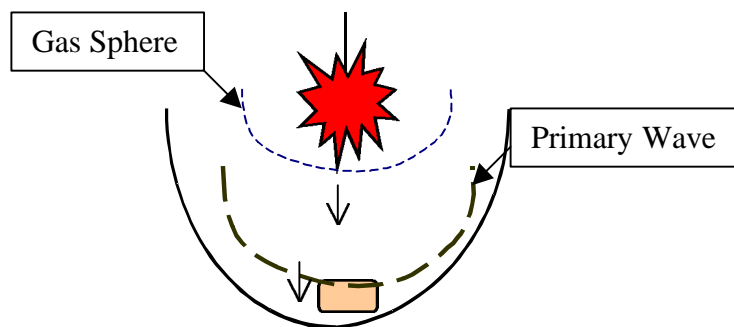


Figure 4: The gas sphere (secondary wave front) evolves.

wave front is radiated from the explosive epicenter in all directions and reaches the meat first. The secondary wave front, which is considered the gas sphere (Figure 4), follows the evolution of the wave front. Both pressure fronts radiate through the water until they contact an object that causes mechanical impedance mismatch such as the side or bottom of the steel tank. At this point, the pressure fronts are reverberated or reflected off of the sides of the tank (Figure 5). The wave velocity and wave period are related to the particular explosive utilized. In addition, as the wave front is reflected off of the bottom and sides of the Hydrodyne tank it intersects (Figure 6) the remaining portion of the incoming wave (Solomon et al., 1997a). The effects of the gas sphere generated energy (secondary wave) on the submerged object depends on the geometry of the explosive charge, target and shape of nearby surfaces (Cole, 1948). As the wave front initially passes through the meat and is reflected off the tank wall, a compression force occurs on the meat. The intersection of the reflected and remaining portion of the incoming wave ensures that the pressure within the meat is doubled compared to if only a singular wave passed through the sample (Solomon et al., 1997a). Additionally, there is a nearly uniform exposure of the pressure treatment from the top to bottom surface of the meat based on tenderization effects (Solomon et al., 1997c).

A study analyzing the effectiveness of Hydrodyne treatment on fresh beef muscle was conducted in a small-scale Hydrodyne unit consisting of a plastic container (208-L capacity and 51-cm diameter) fitted with a steel plate 2-cm thick (Solomon et al., 1997a). The container was situated below ground level and filled with water. Meat samples were treated with different amounts of explosive (50, 75, and 100 g) suspended at 30.5 cm from the meat surface. Solomon et al. (1997a) reported a reduction in Warner-Bratzler

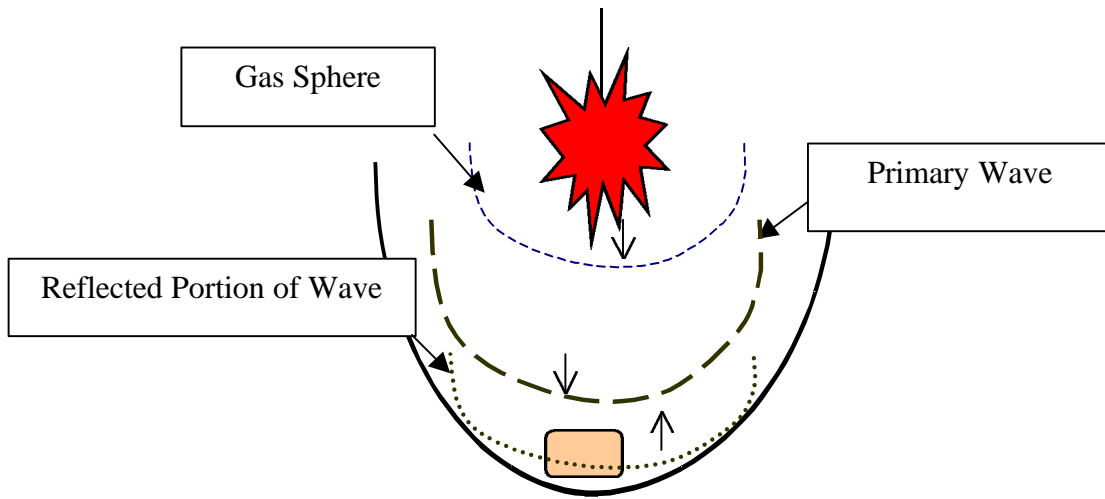


Figure 5: Reflection of wave front.

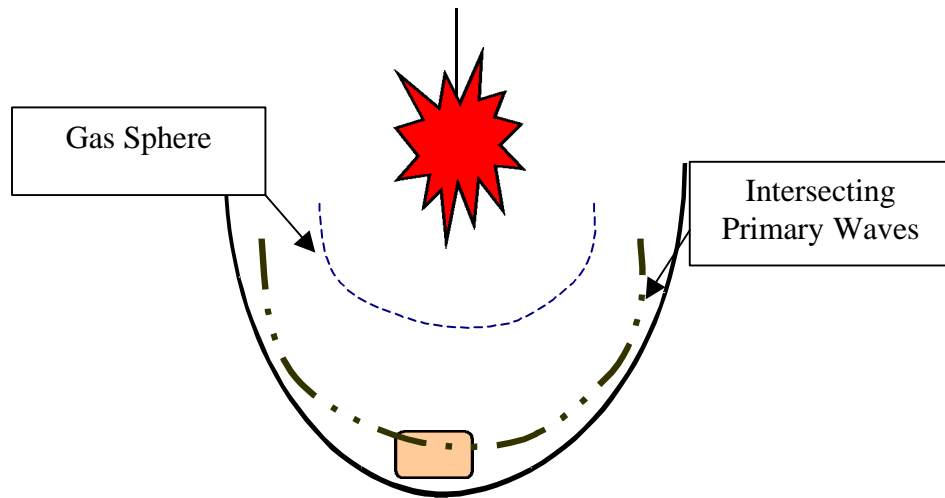


Figure 6: Intersection of reflected and remaining portion of incoming wave front.

shear force (cooked 1.27-cm diameter cores) of 49 to 72% for the fresh beef steaks (2.5-cm thickness). Hydrodyne treated pork LM chops (2.5-cm thickness) were also improved (lower shear force) by 17.2% (Solomon et al., 1996). Fresh beef biceps femoris treated with the Hydrodyne process (50, 75, and 100 g of explosive) that were considered initially tender resulted in a 19 to 30% reduction in shear values (Solomon et al., 1997a). Fresh beef LM steaks treated with two concurrent blasts (Hydrodyne treatment) resulted in the largest shear-force improvement (72%) of 7.8 kg (pre-treatment) versus 2.2 kg (post treatment) as compared to meat treated with one load blasts (shear force 7.8 kg versus 2.6 kg) (Solomon et al., 1997a).

In the same Hydrodyne study, selected loin and round muscles were hot-boned from 2-year-old Holstein cows and stored (1 day at 4°C), frozen (-34 °C), and then thawed before treatment. LM tenderness was improved by 66%, and the round muscles were improved as much as 53 to 59% using the Hydrodyne process (100 g of explosive; distance of 30.5 cm). The control group of muscles resulted in high shear values. The authors suggested that the high shear values were due to cold shortening of the muscles; therefore, the Hydrodyne treatment effectively tenderized cold-shortened meat (Solomon et al., 1997a).

The effectiveness of the Hydrodyne process has also been investigated with lamb and pork in comparison to conventional tenderization methods (Solomon et al., 1996). The callipyge gene provides an increase in muscle mass while also increasing toughness by 140% in lamb (Yaguchi, 1996). Improving the tenderness of callipyge lamb has been investigated with electrical stimulation, calcium chloride injections, and aging (Solomon et al., 1996). Solomon et al. (1996) compared electrically stimulated (60 Hz, 0.25 amps

of alternating current, duration not provided) and non-electrically stimulated callipyge lamb *longissimus* muscle (LM) treated with the Hydrodyne process (100 g explosive at 30.5 cm), aging time (8, 15 or 22 days) and injection with calcium chloride. Additionally, the *semitendinosus* (SM) from one side of the carcass was used for Hydrodyne treatment. These samples were compared to non-callipyge lamb samples. The Hydrodyne process improved tenderness by 33% in non-electrically stimulated LM and 49% in the electrically stimulated LM. The non-electrically stimulated, non-callipyge lamb resulted in a 67% improvement in tenderness when treated with the Hydrodyne process. Additionally the non-callipyge lamb treated with electrical stimulation and the Hydrodyne process resulted in a 55% improvement in tenderness (Solomon et al., 1996). The Hydrodyne treated lamb was comparable in tenderness to both the calcium chloride injected and aged (22 days) lamb (Solomon et al., 1996). Pork *longissimus* muscle (LM) chops (2.5-cm thickness) were treated with the Hydrodyne process and stored under refrigeration for 40 days (Solomon et al., 1996). An improvement of 17.2% was realized with the Hydrodyne whereas aging alone for 40 days resulted in a 13% tenderness improvement (Solomon et al., 1996). The Hydrodyne process tenderizes meat in fractions of a millisecond and is comparable to conventional tenderizing techniques for beef, lamb and pork.

Other quality characteristics of Hydrodyne treated meat are similar to non-treated meat (Solomon et al., 1997a). Berry et al. (1997) reported that no differences were found in appearance or color in the muscles (beef, pork, and lamb) treated with the Hydrodyne process. Additionally, the authors noted that the samples did not appear mushy or over-

tenderized regardless of intensity of Hydrodyne treatment. Solomon et al. (1996) reported a 14% decrease in purge loss from the Hydrodyne treatment.

Currently, there is no known published material utilizing the Hydrodyne technology on tenderizing early de-boned broiler breasts. The objective of this study was to determine the effects of explosive level and distance of explosive to meat surface for tenderizing early de-boned broiler breasts using the Hydrodyne process.

2.3 References

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