

## Introduction

The search for safe and wholesome whole-muscle meat products with a reduced aging time and acceptable tenderness has been an objective for the muscle foods industry for decades. The sensory characteristic of “tenderness” is considered the most important factor of consumer perception, ranking inadequate tenderness as the seventh concern among the top fifteen concerns of the beef industry. More tender cuts demand a much higher retail cost, therefore improving the tenderness of a less tender cut would increase its sale price. It is widely accepted that tenderness in meats is a result of multiple factors, among these being genetics (breed type), muscle type, the quality of tissue, amount of marbling, post-slaughter processing (including conditions before and after rigor-mortis), and cookery technique (Judge et al., 1989; Savell and Shackelford, 1992).

Researchers have explored the use of many non-thermal post-slaughter technologies for improving tenderness, including application of enzymes, acids, blade tenderization, hydrostatic pressure, and hydrodynamic shock wave treatment. During treatment by hydrodynamic shock waves, the rapid movement of an explosively (explosively-generated hydrodynamic shock wave [EHSW]) or electrically (high voltage arc discharge Hydrodyne™ [HVADH]) generated shock wave through a raw boneless skinless muscle food mechanically tenderizes the sample (Long, 1993; 1994; 2000a,b). The technique tenderizes beef, poultry, lamb, and pork (Berry et al., 1997; Meek et al., 2000; Moeller, et al., 1999; Solomon et al., 1997a,b,c) without producing discernable changes in such functional properties as color or protein functionality (Schilling et al.,

2002). The mode of action for the EHSW process has been determined as well as the overall effect on the structural integrity of muscle foods (Meek, 1997; 1999; Solomon et al., 1997a,b,c; Zuckerman and Solomon, 1998). By increasing the instrumental tenderness of a meat, treatment with hydrodynamic shock waves offers the potential for increasing the sale value of a previously less tender cut of beef, poultry, lamb, or pork.

Although the tenderizing properties of explosively or electrically generated hydrodynamic shock waves have been explored, the possible bacteriological effects have not been fully examined. Four peer reviewed studies reveal conflicting results on the affects of EHSW processing on the bacterial flora of treated raw muscle foods, with two studies citing bactericidal effects and two citing no effect (Gamble et al., 1998; Moeller et al., 1999; Williams-Campbell and Solomon, 2001; 2002). No data has been published on the bacteriological effects of electrically generated hydrodynamic shock waves with muscle foods, but there are reports for treated fluids.

Because consistent bacteriological results of the effects of EHSW and HVADH have not been published, further data must be collected in order to determine which, if any, processing parameters involved have the ability to reproducibly reduce the bacterial levels in treated samples. Treatment may reduce the microbial flora naturally present on the muscle or within the bulk of a treated ground product, possibly resulting in an extended shelf-life or producing a safer product as others have suggested (Williams-Campbell and Solomon, 2001; 2002). Effects resulting in a product with an extended shelf life or a broader safety margin would add to the tenderization effects for whole

treated muscle foods and help justify the added monetary cost (to both processor and consumer) of hydrodynamic shock wave treatment. If the hydrodynamic shock waves penetrate through a ground beef sample and reduce the bacterial flora in treated ground samples, the technique may be explored as a possible non-thermal treatment to produce a ground product with an increased shelf life and a broader safety margin. However, hydrodynamic shock wave treatment may offer bacteriological effects which could outweigh the tenderization benefits observed thus far. Treatment may spur the growth of the natural microflora, promoting spoilage and thus reducing the bacteriological shelf-life of the treated whole product. This may be the result of the outgrowth of certain segments of the microflora, resulting in off flavors, slime production, and degradation of muscle cell structure. If the technique spurs the growth of bacterial flora of ground product, its use as a non-thermal bactericidal treatment in ground products should be discouraged.

The mechanical action of the process may also induce the migration of surface bacteria into the interior of the muscle, where it may withstand thermal inactivation. If this occurred, treated whole muscle foods like chicken or steak may pose a bacterial safety hazard to consumers if the treated foods are undercooked prior to consumption. Bacterial migration has been observed in mechanically (via blade tenderization) tenderized beef steaks and beef roasts. Blade tenderization has been shown to transfer bacteria present on the surface of a whole meat product into the interior of the muscle where the bulk of the muscle may protect bacteria from thermal inactivation during traditional steak cookery techniques (Johnston et al., 1979; Phebus et al., 1999). Researchers have suggested the low levels of bacterial penetration induced by blade

tenderization do not pose an additional safety hazard to consumers since cooking to a target internal temperature of 54°C (rare) produced a 5.0 log reduction (CFU/g) in treated steaks as compared to a 5.6 log reduction (CFU/g) in non-blade tenderized steaks.

The following work begins with a review of the literature rooted in examining the nature, generation, and applications of hydrodynamic shock waves in raw whole and ground muscle foods. The review also covers recent publications discussing the bacteriological impacts of hydrodynamic shock waves as well as a discussion of the parallels which other researchers have drawn between hydrodynamic shock wave processing and the static process of high pressure processing. The laboratory research performed during the course of the study is presented in Chapters III through VI. Each chapter is written in journal article format for subsequent submission to several journals for publication as research notes; Chapter III to Applied and Environmental Microbiology, Chapter IV to the Journal of Food Protection, Chapter V to the Journal of Food Science, and Chapter VI to the Journal of Poultry Science. The purpose of the following research was to evaluate the affects that hydrodynamic shock waves generated by either chemical explosions (EHSW) or electricity (HVADH) had on the bacterial flora of multiple food model systems in terms of keeping quality and bacteriological safety. Since treatment by hydrodynamic shock waves has shown promise in tenderizing whole muscle foods (beef, poultry, pork, and lamb), it is important to scientifically determine whether the process impacts the bacterial flora of treated meats on both the surface and throughout the entire bulk of the meat.

The immediate lethality impact of EHSW processing was studied with ground beef, in a log phase culture of the marker microorganism *Listeria innocua*, and in a ground beef and water slurry. The impact of EHSW processing on the bacterial shelf life of treated ground beef was evaluated during a refrigerated storage study. In separate studies, whole eye of round beef steaks were used to determine if the process reduced bacterial populations on the surface of meats (psychrotrophs, lactics, and coliforms) and to determine whether the technique induced the dislocation of surface-inoculated bacteria into the interior of treated steaks. The immediate lethality effects of HVADH processing on the bacterial microflora of treated ground beef was evaluated during one study. Boneless skinless chicken breasts were used to determine if HVADH processing induced the dislocation of surface-inoculated bacteria into the bulk of the tissue. Many EHSW and HVADH processing parameters were examined during the course of the following work to determine if one in particular or if a combination of parameters produced a discernable effect on the bacterial flora of treated samples. Variables which would be expected to affect the nature, magnitude, or propagation of the shock wave during EHSW or HVADH treatment were the focus of the trials. Included in these were the composition and mass of explosive used to create the EHSW, the distance between the explosive and the top of the treated sample, and the density of the water within the treatment chamber. In addition, the affect of multiple successive treatments by EHSW or HVADH on the ability to significantly reduce psychrotrophic, lactic, and coliform populations was evaluated in order to determine if successive treatments increased the likelihood of bacterial inactivation.