THE EFFECTS OF SODIUM METASILICATE ON ANTIMICROBIAL, SENSORY, PHYSICAL AND CHEMICAL CHARACTERISTICS OF FRESH COMMERCIAL CHICKEN BREAST MEAT STORED AT FOUR DEGREES CELSIUS FOR NINE DAYS

By

HUISUO HUANG

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To my husband, Yongqiang Yang; my son, Allen Yang; and my parents, Fuxing Huang and Xiaoyu Wang.

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By

Huisuo Huang

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Marination for meat quality enhancement is an increasingly popular trend in the meat industry. The purpose of this study was to investigate the effectiveness of sodium metasilicate at the USDA approved level and at elevated levels with respect to antimicrobial effect, sensory, chemical and physical characteristics of fresh chicken breast meat stored at 4°C for 9 days. Breast fillets were marinated in a vacuum-tumbler (172.32 kPa) with tap water and 1%, 2%, 3% or 4% sodium metasilicate for 20 minutes. Marination yield, pH, water holding capacity, purge loss, cooking yield, total psychrotrophic counts, raw meat color, cooked meat color and texture were evaluated in this study. Sensory evaluation included juiciness, chicken flavor intensity, tenderness and off-flavor using a trained sensory panel. The evaluation of treated raw fillets for 9 days storage revealed that, fillets treated with 3% and 4% sodium metasilicate had higher ($P < 0.05$) pH and two additional days of shelf life, when compared to control fillets. The cooking yield percentage for fillets treated with 3% sodium metasilicate were higher ($P < 0.05$), when compared to control fillets. The control fillets and fillets treated with sodium metasilicate were similar ($P > 0.05$) for purge loss, cooked meat color,

instrumental texture, sensory evaluation, and water-holding capacity. When the sodium metasilicate solutions elevated levels up to 4%, the fillets treated with 3% and 4% sodium metasilicate could result in discoloration during the first 3 days of storage, when compared to control fillets. These results suggested that sodium metasilicate at USDA approved levels up to 2% could not sufficiently extend shelf life of raw chicken breast meat. If it were employed in practice, combination with other antimicrobial approaches or increasing the sodium metasilicate levels might be applicable to control microbial growth and extend shelf life.

CHAPTER 1
INTRODUCTION

Poultry meat and products are important components of diets in the United States. The annual per capita consumption continues to increase each year and has for decades. Chickens contribute seventy to 80% of the annual consumption, while turkeys contribute to only 19% (International Commission on Microbiological Specification for Foods, ICMSF, 1998). Total meat per capita consumption (red meat and poultry) in 2007 was 100.7 kilograms. Of these meat, 53.2 kilograms were contributed by red meat, whereas, 47.5 kilograms was from poultry. Meat consumption has significantly increased since 1975, where only 21.5 kilograms poultry meat was consumed per capita (Laux, 2009; USDA, 2009).

Consumers prefer purchasing skinless or boneless poultry parts and further processed products instead of the whole carcasses. For example, approximately 90% of poultry meat in the United States is sold as parts or further processed products (Young and Lyon, 1997). Consumers are especially interested in chicken parts due to the convenience and nutritional value, such as chicken breast meat (Seabra et al., 2001). Broiler breast meat is considered the premium part in the United States (Saha et al., 2009). Due to the uneven geographic distribution of poultry producers in the USA, most poultry plants are located in the southeast. Therefore, raw poultry products require transportation from the southeast of the U.S. to other districts in order to provide fresh poultry (Russell, 1998; Angella, 1999). A major problem with extensive transporting of raw poultry is that the natural properties of chicken provide an excellent substrate for microbial growth and raw poultry meat is a highly perishable commodity (Russell, 1998; White, 2000; Mead, 2004). The safety of poultry directly impacts the public health and

economy. Therefore, the requiring intervention strategies that could prolong shelf life of poultry and poultry products are of major concern to the government, corporation and consumers (Johny et al., 2008).

More than 1.4 million cases of nontyphoid salmonellosis and 2.4 million cases of *Campylobacter* infection were reported annually in the United States. The money spent for *Salmonella* and *Campylobacter* related illnesses associated with poultry were approximately $ 64 million to $ 114.6 million, and $ 362 million to $ 699 million, respectively (Altekruse et al., 1999; Johny et al., 2008). Inadequate cooking, time and temperature abuse, and cross-contamination obtained from raw poultry products are major contributors to the primary reasons of foodborne illness outbreak.

Cunningham and Cox (1987) stressed that “anything that contacts a single bird might lead to contamination and anything that contacts more than one bird might have cross-contamination”. Jay (1992) reported that intrinsic parameters and extrinsic parameters associated with poultry could determine microbial load and types. Any technologies that could modify these factors could extend shelf life of poultry products. Numerous approaches that have been investigated can be divided into chemical, physical and a combination of chemical and physical methods (Bolder, 1997). Each step in poultry processing, from farm to ready-to-cook product, may be factors that influence the microbial load and types.

Various antimicrobial chemicals have been employed into the poultry processing line. For instance, organic acids are used to wash, rinse and spray to clean carcasses and to reduce numbers of microorganisms. Other antimicrobial chemicals such as alternative chlorine and phosphate using in scalding water and spraying also have been

investigated to affect the shelf life and poultry quality. Another process that may be applied to introduce chemical antimicrobials is called marination which included vacuum tumbling, injection or combination methods. In this literature review, the source of contamination during poultry processing, control methods to reduce microbial load; factors that determine the microbial quality of poultry meat; the microorganisms associated with poultry; mechanisms of action and effect of chlorine, organic acids and salts, acidified sodium chlorite, and sodium tripolyphosphate on sensory characteristics and the functional possibilities of applying sodium metasilicate, which shares some similarities with sodium tripolyphosphate, will be discussed.

CHAPTER 2
LITERATURE REVIEW

Possible Contamination Sources during Broiler Chicken Breast Processing and Control Strategies

Sanitary Conditions

The numbers and types of microorganisms present in fresh chicken carcasses mainly contribute to four sources: (1) original flora of microorganisms in the raw chicken; (2) sanitary conditions around products such as wall surfaces, equipment, transfer machine, air and handlers; (3) control measures utilized during processing; and (4) sanitary conditions during packaging, handling and storage (Pearson and Dutson, 1994; Mead, 2007). Initial contamination generally results from live birds even healthy chickens. A healthy live bird carries several kinds of microorganisms on its skin, feathers, and in its intestinal tract. The microbial population of poultry carcasses could be generally divided into three types: the natural flora of skin; the transient flora, attached on the skin and feathers, which could be easily removed during slaughter processing; and obtained organisms during processing, it is generally called cross-contamination. Carcasses may be contaminated due to contact with equipment, tools, hands or gloves of workers and contaminated birds (Cunningham and Cox, 1987; ICMSF, 1998). However, most natural floras have no detrimental effect on consumers. But if control measurements are not used appropriately or efficiently, natural floras will decrease product quality (Russell, 1997).

The finished products that contained amounts and types of organisms were dependent on processing practices (Pearson and Dutson, 1994). Some microorganisms can be transmitted from the intestines of parent chicken to its offspring. Live healthy birds may get infected by contacting with the contaminated eggs, net materials and

incubators. Additionally, air current may spread microorganisms among hatcheries (ICMSF, 1998). Besides, the healthy chicken may be contaminated by the feeding food and drinking water. Feeding food may contain animal protein ingredients, and drinking water may be contaminated by dust, litter, feathers, feet and feces. Rodents and cockroaches may spread microorganisms within the poultry flock. Also workers may spread pathogens through their shoes within flocks as well (ICMSF, 1998). Hence, live birds may arrive at the processing plant with various bacteria from both the external and internal part of chicken bodies (Bolder, 1997; Russell, 1997). There are some possibilities that any of these microorganisms could be the sources of contamination of the final products (Mead, 2004).

Spoilage bacteria, mainly *Achromobacter (Acinetobacter), Corynebacterium,* and *Flavobacterium,* were detected in the respiratory systems of fresh broiler chickens. These microorganisms were detected on feathers, feet of live chickens, water and feed supply, and equipment in the processing plant (Russell, 1997; Russell, 1998). However, the number of spoilage organisms significantly declined after scalding. Cunningham and Cox (1987) reported that *Pseudomonas,* primarily detected in eviscerated spoiled chicken, could not be isolated in the respiratory system or in the intestinal tract after washing. The potential pathogens derived from the intestine of live chickens, which *Salmonella* spp., *Campylobacter* spp., *Listeria* spp., *E. coli* O157:H7 and *Staphylococcus* are of concern to processors (Bolder, 1997). If the processing plant practices do not efficiently manage the spread of microorganisms, then final meat quality and shelf life could be significantly affected (Russell, 1997). The presence of bacteria and spreading routes depend on plant hygiene conditions during harvest,

slaughter, processing, storage, distribution and preparation (Russell, 1997; Mead, 2004).

Primary Processing of Broiler Chicken Breast

Mead (2004) concluded that the processing flow, which involved from live broiler chicken to ready-to-cook chicken products, could be classified into four steps. The first step includes receiving and hanging the live broilers. The second step is considered the dirty processing (Mead, 2004), which includes stunning, slaughter, bleeding, and defeathering (scalding, picking and washing). The elements of the third step are evisceration (viscera removal, offal) and carcass washing. The fourth step involves chilling, grading, packaging, shipping, and may include further processing (Cunningham and Cox, 1987; ICMSF, 1998; Mead, 2004). Mead (2004) pointed out that the types and population of microorganisms on the final chicken products were chiefly dependent on the microbial state of the live broiler chicken. Since the plant producers cannot assure eradication of all pathogens during processing, it is important to control the pathogenic organisms on the farm. Vaccinating the birds and maintaining a clean environment are regarded as the best strategies to reduce the opportunity for vertical contamination of pathogenic microorganisms.

The principal genera of microorganisms could be detected in the intestinal system and respiratory system of the healthy broiler chicken. In the intestinal system, the organisms include *Lactobacillus, Corynebacterium, Escherichia coli, Streptococcus faecalis, and Clostridium perfringens*. The respiratory system of healthy birds contains *Streptococcus, Staphylococcus, Corynebacterium, Lactobacillus, Escherichia,* and *Bacillus.* The psychrotrophic bacteria that could be found on the feet, skin, and feathers of live chicken are *Flavobacterium, Achromobacter,* and *Corynebacterium*. However,

after scalding, the psychrotrophic organisms would be dramatically diminished. *Pseudomonas* is not commonly detected in scalding water since it does not exist on the live chicken (Cunningham and Cox, 1987)

After unloading birds to the processing plant, *E. coli* numbers were higher on the chicken breast surface compared with that prior to loading (Mead, 1989). Marin and Lainez (2009) reported that the colonization of *Salmonella* after transportation to the abattoirs was strikingly amplified. Some researchers concluded that stress during loading and transportation may accelerate the spread of bacteria (Mead, 1989; Richardson and Mead, 1999). During hanging chicken on the shackle, a majority of chickens may struggle and flap their wings causing dust, feathers and litter to fall down, which may lead to scatter dust and spread microorganisms. Mead (1989) also reported that *Salmonellas and Staphylococcus aureus* were easily detected in the air of the unloading compartment. So the effective method preventing spreading bacteria was to separate the unloading truck from the other following processing.

Traditional stunning birds with electrical shock and then bleeding carcasses have been reported to have an insignificantly influence on the final product regarding microbial quality (ICMSF, 1998). After stunning, the neck cutting machines, with one or two blades commonly used in the poultry industry, will detach the carotid vein and artery on each side of the neck. The advantage of this method is to remove the esophagus and trachea during evisceration processing (Mead, 2004). The next step is defeathering which contains scalding, picking and washing. Methods of scalding include hot water immersion, hot water spray, steam, and combination of hot water spray and defeathering (ICMSF, 1998). In general, hot water immersion scalding is the most

common in industry. The time and temperature of scalding water was determined by the appearance of the required product and chilling method (ICMSF, 1998). For example, turkeys are usually hard scalded to maintain the white skin appearance. In industry, chickens are soft scalded when meat is sold fresh due to the unappealing color developed when using hard scald.

The primary purpose of scalding is to readily remove feathers when plucking, but the microbial effect cannot be ignored during scalding process. After scalding, microorganisms are detected in the water tank. These microorganisms come from skin, feathers, and intestinal tracts of birds. Several bacteria could be isolated from the scalding water or from the carcass immediately after scalding, such as *Clostridium, Micrococcus, Proteus, Pseudomonas, Salmonella, Staphylococcus, and Streptococcus* (ICMSF, 1998). However, Mead (2007) stated that *Salmonella* was not frequently isolated from scalding water, and *Pseudomonas* was easily inactivated at any scalding temperature. When scalding water was maintained at 58°C to 60°C, it was not a major source of contamination (Pearson and Dutson, 1994). Furthermore, experimental evidence also proved the theory that a scalding water temperature of more than 60°C could reduce a larger number of bacteria than a lower temperature (Cunningham and Cox, 1987; Mead, 2004). ICMSF (1998) reported that salmonellae were not detected on chicken carcasses after scalding at 60 °C for 200 seconds, but at 55 °C for 105 seconds. Brotsky and Bender (1991) stressed that the external and internal *Salmonella* of carcasses could be reduced by adjusting the pH value of scalding hot water to approximately 9.0. Cross-contamination can be reduced by adjusting the scalding water temperature, scalding time and water pH (ICMSF, 1998; Mead, 2004).

Subsequent to the scalding step, psychrotrophic bacteria were dramatically diminished. *Pseudomonades* were not usually detected in scald water (Cunningham and Cox, 1987). Therefore, scalding was not the significant source of the contamination of spoilage microorganisms, nor the best step to control propagation of *Campylobacter jejuni* (ICMSF, 1998). Alternative interventions such as steam with hot water scalding and three tank systems with hyperchlorination solution could control cross-contamination. Nevertheless, it is not practical in industry because these methods could produce discoloration of carcasses (Mead, 2004; ICMSF, 1998; Davies and Board, 1992).

In contrast, cross-contamination was of most concern during the defeathering and evisceration processing (Pearson and Dutson, 1994). There are machines that employed rotating rubber fingers to release feathers from carcasses, however, if the rubber fingers fail to release the feathers, the feathers from the rubber fingers will harbor microorganisms and be difficult to clean. The rubber fingers deteriorate easily due to high line operating speed. Hence, the rubber fingers would become the source of spreading microbial to carcasses. In addition, aerobic plate counts and staphylococcal counts, rather than psychrotrophic spoilage bacteria counts, were higher after defeathering (ICMSF, 1998; Mead, 1989). Research reported that strains of *Staphylococcus aureus* attached to the machine became resistant to low concentrations of chlorine. Afterwards, bacteria became indigenous to the machines and were difficult to eliminate. The best method to control the contamination during defeathering and evisceration was cleaning with a higher level of chlorine before disinfecting, also frequently altering rubber fingers and preventing feathers from depositing into the

machine. Furthermore, the infection of *Salmonellae, Campylobacter* and *E.coli* O157: H7 organisms spread from few carcasses to many carcasses in the early step of feathering processing. In later stages, microorganisms may penetrate into muscles and are hard to get rid of. Therefore, defeathering was the major step to cause carcass contamination (Mead, 1989). The population of microorganisms after defeathering could predict microbial load, and quality of poultry carcass to some degree (ICMSF, 1998).

The third step included evisceration and washing the carcass. During evisceration, carcasses may become cross-contaminated from the hands of workers, carcasses to equipment or tools, then to the rest of the carcasses (ICMSF, 1998; Russell, 1997). Mead (2004) demonstrated that psychrotrophic bacteria contamination could take place during evisceration because Pseudomonades could spread from gloves to carcasses. The psychrotrophic pathogens, like Listeria monocytogenes, could attach to the evisceration apparatus (Mead, 2004). Spraying carcasses with water after defeathering and evisceration could get rid of organic substances and microorganisms gained during evisceration. Spraying carcasses many times after evisceration could decrease population of *Salmonella* and *Enterobacteriaceae* compared to spraying carcasses a single time (ICMSF, 1998). Eviscerated poultry may carry a high population of *Salmonella. Salmonella* attached on the carcasses surface involved multiplication sequence, transmitted to equipment, hands or other surfaces. In spite of this, water spraying could eliminate *Salmonella* (Brotsky and Bender, 1991) and also could reduce aerobic plate counts, *Enterobacteriaceae* and *coliforms* by 50 to 90%, respectively (ICMSF, 1998). However, some *Pseudomonas* spp. may disperse among carcasses during spraying. Studies concluded that spraying carcasses with organic acid or

chlorine did not inhibit the cross contamination, and it could not prolong the shelf life of fresh poultry meat (ICMSF, 1998), because the chlorine solutions immediately fell down from the carcasses, and this reduced the effectiveness of the chemical compounds (Mead, 2004; Northcutt et al., 2005).

The forth step included chilling, grading, packaging and transporting, as well as possibility of further processing. After evisceration, chilling was a valuable step to slow the growth rate of spoilage microorganisms and to manipulate pathogenic microbial growth (ICMSF, 1998; Mead, 2004). Most pathogenic organisms cannot generally grow below 6°C, but psychrotrophic bacteria could multiply at below 0°C. Common chilling processes were air chilling (dry chilling), wet chilling and combination chilling. Which chilling method used depended on how the meat was sold. It may be sold as a whole carcass, portioned or deboned meat like chicken breast meat. Raw chicken breast meat was sold wet fresh or frozen; therefore, wet chilling processing would be used. If raw broiler chicken breast meat was chilled by air, the discoloration would appear and impair the meat quality. Meat without normal surface color could not be accepted by producers and consumers. For raw chicken meat, the most common wet chilling methods were water-immersion chilling and spray chilling (ICMSF, 1998; Mead, 2004). After chilling processing, no further growth of mesophile organisms should be detected. However, a time delay in the transfer of carcasses to chill storage would tolerate growth of psychrotrophic organisms (Mead, 1989). Further cross-contamination could be related to handling, incising whole carcasses, deboning and circumstances related to packaging.

The long shelf life of meat can be determined by monitoring the growth of psychrotrophic microorganisms. Therefore, keeping hygienic conditions of equipment, carrying out sanitation specifications, maintaining the appropriate storage temperature and properly holding of products were of great importance to assure the quality of the chicken breast (ICMSF, 1998; Russell, 1998; Mead, 2004). Blackburn (2006) concluded that the current methods of controlling cross-contamination of microorganisms in slaughterhouses, during processing and package were contingent upon fulfilling the hygienic standards of Good Manufacturing Practices (GMP) at farms, Good Hygienic Practices (GHP), animal husbandry practices, and carrying out the HACCP system.

Factors that Affect Microbial Growth on Fresh Broiler Chicken Breast Meat

Intrinsic Factors

Raw fresh broiler chicken meat provides good substrate for bacteria growth due to the biological and chemical composition of chicken meat. Bacteria growth on broiler chicken is determined by inherent properties of chicken meat as well as external circumstances around chicken meat. Inherent parameters are moisture content, water activity or available water, pH or total acidity, oxidation-reduction potential (Eh), nutrient content, and the biological structure of raw chicken (George, 1989; Michael et al., 2001). Temperature and gas conditions during storage and distribution are considered to be the key extrinsic factors that affect the shelf life of raw fresh chicken meat (Pearson and Dutson, 1994). The combination of intrinsic factors and extrinsic factors could determine the shelf life and quality of fresh chicken breast meat.

The protein-rich poultry meat could provide a faster microbial growth environment than those with lower protein meat. The water content of raw broiler chicken meat is around 74%. Protein and fat content are approximately 23% and 2%, respectively

(Qiao, et al., 2002). Wattanachant et al. (2004) analyzed the biceps femoris and pectoralis muscles of Thailand broiler chicken meat and calculated protein content to be around 20%, fat content to be lower than 1%, moisture content to be around 75%, and pH to be 5.9 to 6.6 for muscle samples. The water activity for poultry meat is about 0.98 to 0.99 which is based on storage environment and storage time (ICMSF, 1998). Slaughter processing and other operations also could impinge on intrinsic factors, such as the pH of chicken breast meat would fall in the range of 5.7 to 5.9, and the PSE (pale, soft, exudative) chicken meat color, caused by the poor practice and high stress of bird, is darker than normal meat. The pH of the PSE is lower than that of normal chicken breasts, because of rapid lactic acid accumulation in a short time (Stringer and Colin, 2000). In additional, food ingredients added to meat could change the pH and water activity, such as acid flavoring seasonings. Pathogenic microorganisms require a slightly acidic pH level of 4.6-7.5. The pH value of chicken breast meat has an optimum acid tolerance level for the spoilage organisms and pathogen organisms to grow (ICMSF, 1998; White, 2000; ServSafe Essential 5th, 2006). For example, the minimum pH for *Salmonella* and *Pseudomonas* growth are 4.0 and 5.5, respectively. So if ingredients alter muscle pH to the optimum acidity condition, the type and rate of microbial proliferation would change. Environmental redox potential is an important determinant of microbial growth. Aerobic microorganisms required positive redox potential value, while anaerobes required negative redox value. The redox potential of poultry was reported to range from -150 mV to +250 mV and has similar level with beef, pork and lamb (ICMSF, 1998). Biological structure of poultry meat is also susceptible to microbial growth. Many microbes reside under the skin of poultry providing more

occasions to assault the muscle. Thus, skin and muscle tissue of poultry provide good substrates for bacteria growth (ICMSF, 1998).

Extrinsic Factors

In additional to intrinsic parameters that could affect the rate and extent of microbial growth, extrinsic factors influence growth of microorganisms as well. Therefore, the combination of factors could be determinants of the shelf life of meat. The extrinsic factors include storage environment such as storage temperature and time, relative humidity of the environment, and the presence and concentration of gas around chicken meat in package, and antimicrobials added (Stringer and Colin, 2000). Storage time could affect the population of microorganisms and the temperature could affect the multiplication and rate of microorganisms. For example, psychrotrophic bacteria have higher adaption under chill conditions. So, improper storage temperature is the most important factor affecting perishability of meat, especially in muscle meat. The rate of spoilage of fresh poultry at 10°C is about twice that at storage of 5°C, and that 15°C storage is about three times faster than the when the storage temperature is 5°C (Jay, 1992). Pearson and Dutson (1994) reported the same conclusion that the mean shelf life at 0°C is 14 days, and when the storage time increases to 5°C, storage days are reduced to 7 days, and so on. During the high humidity of refrigerator storage, the meat spoilage microorganism is mainly psychrotrophic bacteria. These organisms grow well under the chilled condition and cause meat spoilage. Studies also revealed that vacuum and gas atmosphere storage could delay the spoilage of poultry. When compared with raw poultry stored in oxygen permeable film, vacuum package, and carbon dioxide flushed high-barrier film, the shelf life was 9 days, 10 days and 17 days, respectively (Jay, 1992).

Spoilage and Pathogenic Microorganisms Associated with Fresh Broiler Chicken Meat

The bacteria harbored on poultry could be divided into pathogens (causing foodborne disease after food consumption) and non-pathogens (not associated with disease). Most nonpathogenic organisms, also called spoilage organisms, are still a concern of producers since spoilage organism could produce off flavor, discoloration and cause undesirable texture in the meat (Cunningham and Cox, 1987; White, 2000).

Pathogenic microorganisms associated with fresh poultry are *Salmonella, Campylobacter, Clostridium perfringens, Staphylococcus aureus, Listeria monocytogenes* and *Clostridium botulinum* (ICMSF, 1998; White, 2000; Mead, 2004). Controlling growth of *Salmonella* Enteritis and *Campylobacter jejuni* continue to be the major concerns for the poultry industry in the USA. The United States Department of Agriculture (USDA) made a regulation that the maximum level of *Salmonella* allowed in poultry carcasses is 10% (Bauermeister et al., 2008). More efforts should be performed to reduce cross-contamination during processing.

Spoilage Organisms Associated with Raw Chicken Breast Meat

The initial bacteria of raw poultry meat are mesophile microorganisms (Saucier et al., 2000). Immediately after processing, the isolated bacteria from fresh chicken carcasses were *Micrococcus* (50%), gram-positive rods (14%), *Flavobacteria* (14%), *Enterobacteriaceae* (8%), *Pseudomonas* (2%), *Acinetobacter* (7%), and unknown genera (5%). Of these, only *Pseudomonas and Acinetobacter* grow faster *at* refrigeration storage for 10 days, and 90% of the bacterial species were *Pseudomonas fluorescens* in the later storage time (Russell, 2000; Charles et al. 2006; Mead, 2007). Under refrigeration storage conditions, organisms generated fastest during refrigeration

conditions, are termed psychrotrophic. The psychrotrophic microorganisms grow well at below 7°C and produce visible colonies at 7°C for 10 days, and the optimum temperature growth is between 20°C and 30°C (Jay, 1992). The primary species of psychrotrophic microorganisms is *Pseudomonas* in fresh refrigerated poultry meat and mainly *Pseudomonas fluorescens*, *Pseudomonas putida* and *pseudomonas fragi* (White, 2000; Blackburn, 2006). *Pseudomonas* organisms cannot grow under vacuum and adequate carbon dioxide conditions. They can proliferate under aerobic and less than 20% carbon dioxide storage. Other characteristics of *Pseudomonas* are formation of off-flavor and surface stickiness.

At the beginning of spoilage, the microorganisms exhaust glucose till completely depleted, and then degrade the small compounds, like amino acids. Prior to slime formation, the metabolism of amino acids release off-flavor substances. Later, colonies appear on the surface of meat. Finally, colonies grow together and develop a coat on the meat. The off-flavor could be detected when counts are up to 7- 8 $\log_{10}$CFU/g, and the slime and sticky coat could be detected when the counts are over 8 $\log_{10}$CFU/g. Russell (1998) explained that the dominant bacteria that produced off-odor were *Shewanella putrefaciens, Pseudomonas fluorescens*, and *Pseudomonas putida.* Previous studies also demonstrated that majority of bacterial species on poultry meat in the later stage of storage were *Pseudomonas fluorescens*. Russell (1997) reported that the sulfur compound from off flavor in poultry meat was mainly produced by *Pseudomonas* and *Shewanella* spoilage bacterial.

Methods that measure spoilage in poultry include chemical methods (such as discoloration, release of gas, or chemical contents), physical methods (such as pH

value change, surface tension), bacteriological and physiochemical methods. For example, Jay (1992) pointed out that the total *psychrotrophic* counts and water holding capacity could be indicators of meat spoilage.

Pathogenic Organisms Associated with Raw Poultry Breast Meat.

Poultry products are a common media for foodborne illness outbreaks (ICMSF, 1998), because inappropriately cooling and heating, time and temperature abuse, undercooking, improper handling of raw poultry meat and cross contamination are fundamental factors that lead to outbreak of foodborne illness. Pathogenic bacteria associated with poultry meat are *Salmonella enteritidis, Campylobacter jejuni, Clostridium perfringens, Staphylococcus aureus, Listeria monocytogenes* (ICMSF, 1998; White, 2000; Mead, 2004). *Salmonella* Enteritidis may be found in the intestinal tracts of warm-blooded animals such as poultry meat and egg products. *Campylobacter* jejuni is one of the most common sources that cause diarrheal illness in humans. Monitoring cross-contamination and not consuming undercooked poultry meat could reduce infection of this disease. Food poisoning due to *Clostridium perfringens* is mainly associated with improper storage of cooked turkey. *Staphylococcus aureus* has been isolated on human hands*,* and ready to eat food such as chicken salad. “Live poultry can carry *Staphylococci* in bruised tissue, infected lesions, inside of nasal, arthritic joint, and on breast meat surface” (ICMSF, 1998). Most of the original staphylococci organisms on birds are damaged after scalding, however, the birds are infected by *Staphylococcus aureus* from defeathering machine. *Staphylococcus aureus* isolated from poultry are never been reported causing the serious foodborne outbreak, and under low temperature storage conditions, *Staphylococcus aureus* is a poor competitor with other spoilage organisms on raw meat and poultry. The majority of *Staphylococcus*

aureus foodborne illness associated with poultry is due to the improper handling of the cooked poultry product. Therefore, *Staphylococcus aureus* is not a concern for public health (ICMSF, 1998). *Listeria monocytogenes* is often present on raw meat, and can be destroyed by cooking, but poor hygiene practices still can cause consumer foodborne illness. However, there is no evidence shown that *Listeria monocytogenes* multiplication on raw meat is the primary causative of listeriosis foodborne illness outbreak. Therefore, *Listeria monocytogenes* is generally associated with cooked and ready to eat poultry products. By far, Salmonellae and Campylobacter are the most important pathogens associated with raw poultry product (ICMSF, 1998).

Salmonella

Salmonella is a gram-negative, facultative anaerobic, non-spore forming, and rod-shaped bacteria. The majority of *Salmonella* species can move by peritrichous flagella. USDA (2009) reported that "*Salmonella* is a member of the family Enterobacteriaceae, many of them can cause human illness and they are catalase positive, oxidase negative, and hemoorganotrophic. *Salmonella* has the ability to metabolize nutrients by both respiratory and fermentative routes". It comprises two species: *Salmonella bongori* and *Salmonella enterica. Salmonella enterica* causes intestinal disease, and could be isolated from human and warm-blooded animals. *Salmonella enterica* account for more than 99.5% of serotypes. *S. typhi, S. typhimurium* and *S. enteritidis* are three main serovars of *S. enterica. S. enteritidis* is the most common sources of foodborne illness in the United States. Vertical and horizontal transmissions of Salmonella are the primary pathways of cross-contamination in poultry plants. Scientists have identified more than 2,400 serotypes of the genes *Salmonella* bacteria. Of these, two serotypes are specific poultry pathogens (*S. gallinarum and S. pullorum)* (Breytenbach, 2004; Revolledo et al.,

2009). Paratyphoid *Salmonella* (*S. enteritidis, S. typhimurium, and S. typhi*) have a wide host range and could not lead to poultry disease, but these serotype pathogens are of major concern for public health. *Salmonella* outbreaks cost an estimated $3 billion annually in the United States.

Salmonella is named after Dr. D. E. Salmon in 1900. He, along with his coworkers, was the first person to observe and report the characteristics of *Salmonella* Choleraesuis*.* Since 1933*,* the term *Salmonella* has prevailed (Cunningham and Cox, 1987). *Salmonella* growth range is 7°C to 47°C, the optimum growth temperature range being 35°C to 37°C, which is close to body temperature. If the temperature is below 6.7°C, the growth of *Salmonella* could be prevented. Temperature over 70°C could kill *Salmonella*, and refrigeration temperature prevents the growth of *Salmonella* but will not kill them (ICMSF, 1998; White, 2000). *Salmonella* can grow between pH values from 4.0 to 9.0 and the optimum pH range is 6.5 to 7.5 (White, 2000). Jay (1992) reported that the best pH for S*almonella* growth is between 6.6 and 8.2. The minimal water activity for growth of *Salmonella* was about 0.94 (White, 2000).

Live poultry are the primary reservoir of *Salmonella* bacteria. Some organisms on the carcasses surface may spread to other carcasses during processing, packing, distribution and holding and further processing. There are mainly three routes of *Salmonella* cross-contamination*:* first, feed and drinking water; second, birds get infected by vertical transmission, namely, from contaminated eggs to their offsprings; and the third vehicle is called horizontal transmission, which means that healthy poultry is contaminated by other carcasses, or equipment, tools, workers and other animals (Mead, 2004). Researchers concluded that *Salmonella* horizontal transmission could be

the major determinant of the final microbial load and types on meat products. However, the initial source associated with poultry is feeding contaminated water and food (Cunningham and Cox, 1987; Mead, 2004). One unique characteristic of some *Salmonella* strains is the ability to penetrate from chicken skin to inside organs of chicken (Mead, 2004). An infectious dose of Salmonella on poultry carcass is small, probably from 15 to 20 cells, but sometimes more than 14 log $_{10}$CFU/g of skin occurred (ICMSF, 1998). However, a low dose level of *Salmonella* ingesting contaminated meat might be lethal.

Control methods employed in industry are to avoid cross-contamination between flocks and to provide poultry vaccination on farm. The control recommendation methods for producers are to keep carcass *Salmonella* free, avoid feeding contaminated food and water, and prevent cross-contamination between carcasses. For consumers and retailers, improper cooling, holding, reheating, and undercooking contribute to Salmonellosis outbreaks (Cunningham and Cox, 1987).

Campylobacter

The *Campylobacter* species has been considered the main common sources of human bacterial gastroenteritis in the United States (Isohanni and Lyhs, 2009). Egg and poultry products are the primary sources of *C. jejuni* (ICMSF, 1998; Mead, 2004). The most important risk of Campylobacteriosis is to consume undercooked poultry meat or to mishandle raw poultry meat (Isohanni and Lyhs, 2009; Nather et al., 2009). Once birds get infected, *Campylobacter* spp. spread fast (Nather et al., 2009). Horizontal transmission is the major route to spread organisms. Vertical transmission of *campylobacter* rarely occurs since only a few bacteria could survive on eggs. In contrast to *Salmonella, Campylobacter* cannot survive under long dry conditions of feeding food,

so the food is not the source for transmission of *Campylobacter* (Mead, 2004). Bacteria counts on carcasses are likely to increase during defeathering and evisceration (Nather et al., 2009).

Campylobacter are gram-negative, very slender curved to spiral shaped rods, 0.2-0.4 µm in width and length is 1.5-3.5 µm. Most *Campylobacter* are motile by a single flagellum. Campylobacter can survive well at microaerophilic conditions. The atmosphere that contains 5% oxygen and 10% carbon dioxide is optimum growth for *Campylobacter* (Cunningham and Cox, 1987; Simmons et al., 2008). Keener et al. (2004) stated that *Campylobacter jejuni* is unusually sensitive to oxygen and dehydration. Jay (1992) also stressed that *Campylobacter* requires low oxygen, approximately 6% to 8% to grow, and if oxygen is more than 21%, the growth of Campylobacter *jejuni* is inhibited. *Campylobacter* has a higher optimum growth temperature than *Salmonellae* (Mead, 2004). Studies reported that when the internal temperature of ground beef reached 70°C, *Campylobacter* counts were reduced 7 log cfu/g, when tested after 10 minutes. When placing chicken carcass into -18 °C storage condition, Campylobacter counts were reduced by 5 log cfu/g (Jay, 1992).

Antimicrobials Used in Chicken Breast Meat to Control Pathogenic and Spoilage Bacteria

ICMSF (1998) listed three mechanisms that could contribute to attachment of bacterial regarding poultry carcasses surface, there are retention, entrapment and adhesion mechanisms. “Retention” occurs when poultry carcasses contact the contaminated water. The bacteria coming from the contaminated water is residual and develops film on the surface of carcasses. Therefore, the microbial load on the surface of carcasses has positive effect with bacteria in the water. “Entrapment” occurs when

the muscle tissues are swollen by absorbed water, followed by bacterial penetration into the deep channel or crevices from the outer poultry carcass surface. This processing occurs easily in broken skin, meat and cut meat, such as chicken breast meat. Also as time increased, bacteria retained on the surface of carcass, might change to entrapped situation. Under the circumstances, spraying carcass with water cannot remove contaminants. Antimicrobials are added into spraying water and remove these entrapped bacteria. “Adhesion” occurs in the soft tissue and loosed connective tissue, but not all bacteria are capable of adhesion to these tissues. Adhesion bacteria function when the optimal conditions such as neutral pH, low ionic strength, and immersion in water for some time occur. When adhesion occurs, spraying, rinsing, and immersion are not good methods to reduce microbial load. Researchers reported that adding salts into immersion water could decrease the degree of adhesion and increase ionic strength. The effectiveness of chemical compounds depends on bacteria retained, entrapped or adhered to the tissue.

Fresh broiler chicken meat is prone to microbiological spoilage due to providing excellent substrate for microbial growth. If fresh meat is stored under inappropriate conditions or is not treated with preservatives, it becomes very perishable (Mead, 2004). The purpose of chemical intervention strategies in chicken carcasses is to prevent contaminants, remove contaminants, and extend lag phase of pathogenic and spoilage organisms, or destroy contaminants completely (George, 1989). Many Intervention decontaminants are described and grouped into physical, chemical and combination chemical and physical methods. Physical methods include rinsing, spraying, steaming with hot or cold water, Ultra high pressure, irradiation, Pulsed Electric Field, Ultrasonic

energy, and UV light. Chemical approaches include but not limited to chlorine (chlorine dioxide, cetylpyridinium chloride, sodium hypochlorite, stannous chloride, timsen, acidified sodium chlorite, sodium chlorite), organic acids (lactic acid, acetic acid, citric acid, propionic acid) and organic acid salt preservatives (sodium lactate, sodium sorbate, sodium citrate, potassium lactate; inorganic phosphates (trisodium phosphate, sodium tripolyphosphate, acid sodium pyrophosphate); bacteriocins (nisin, magainin; EDTA-nisin); oxidizers (hydrogen peroxide, ozone, quaternary ammonium) and other chemical compounds such as sodium metasilicate (Dicken and Whittemore, 1997; Kristen et al., 1997; Bolder, 1997; Bilgili et al., 1998; Russell, 1998; Russell, 2000; Aktas and Kaya, 2001; Jimenez-Villarreal et al., 2003; Northcutt et al., 2005; Ricke et al., 2005; Economou et al., 2009; Quilo et al., 2009). In this literature review, the effectiveness of these chemical compounds in poultry processing plants and their mechanisms of action will be described in detail.

The suitable chemical agents should have effective ability with low concentration, fast working, without residual on the surface of the carcass, and no detrimental effect to consumers. The agents should not produce undesirable appearance, texture, color, odor and favor. Some of the chemical compounds listed above are suited for one process, but might fail in another. Some chemical compounds have been verified to control microbial growth on lab level but can fail when applied under commercial plant conditions. For example, the problems could be meat color change, off-flavor development, equipment and tools erosive. In this literature review, the advantages or disadvantages of these interventions and their chemical actions and mode action will be explained.

Chloride

European Food Safety Authority (EFSA, 2005) reported antimicrobials that can be used in poultry carcasses include sodium tripolyphosphate, acidified sodium chlorite, chlorine dioxide, and peroxyacetic acid. In the United States, Chlorinated water was employed for carcass washing, spraying carcass or equipment and chiller water for on-line reprocessing to reduce microbial growth and cross-contamination (EFSA, 2005; Northcutt et al, 2005). Chlorine solution prohibited the *Salmonella* growth in water, but failed to reduce the bacteria on the surface of carcasses (Brotsky and Bender, 1991). The most common antimicrobial product used in carcass spraying is acidified sodium chlorite (Bauermeister et al., 2008). However, in chiller processing, chlorine dioxide is being used instead of acidified sodium chlorite because of stability of chlorine dioxide; however, the effectiveness of chlorine dioxide is influenced by the organic matters from water and chicken. Chlorine and organic matter could react and produce trihalomethane, a mutagenic compound. The compound might cause cancer (Cooper, 2009). Recently, researchers pointed out that chlorine solutions could react with organic matter from high protein food such as chicken breast meat and produce semicarbazide (EFSA, 2005). In the light of the limited evaluation information, whether the compounds could threaten public health still needs further researches. Pearson and Dutson (1994) reported that chlorine or acid spaying could corrode equipment and tools when used to spray the poultry carcass. Bauermeister et al. (2008) also reported that chlorine significantly lost its efficacy when the water contained high amount of organic matter and pH over 7.0.

Acidified sodium chlorite (ASC) is FDA (U.S. Food and Drug Administration) and USDA approved for use as an antimicrobial intervention on post-evisceration poultry

products. ASC is the formation of sodium chloride with any acid that is generally recognized to be safe in food. The chemical formula of ASC is $NaClO_2$. The pH range is 2.3 to 2.9 at concentration of 500-1200 mg/L sodium chloride dip. This solution can be applied either as a 15 second spraying or a 5-8 second. This treatment could result in 2 log reductions in *Escherichia coli, Campylobacter spp., and Salmonella spp.* For immersion chilled water, the concentration increases to 150 mg/L at a pH between 2.8 and 3.2 (EFSA, 2005). ASC provides an average 2.28 log reductions in *E. coli* and 2.56 log reductions in *Campylobacter* spp. The antimicrobial properties come from chlorous acid, which has stronger oxidation than either chlorine dioxide or chlorine. Chlorous acid oxidizes cellular constituents and disrupts protein synthesis (EFSA, 2005).

Organic Acids and Their Salts

Various organic acids could prohibit gram-negative spoilage microbial growth attaching on surface of meat (Bolder, 1997). They could effectively reduce the microbial load in the scalding water but have no significantly effect on the carcasses (Dickens and Whittemore, 1997). Two common organic acids, acetic acid and lactic acid, have been investigated for possible utilization in the meat and poultry industry. This is because they are effective for reducing specific organisms and are generally recognized as safe (GRAS) (Pearson and Dutson, 1998). The organic acid treatment may impact meat color and flavor which are determined by the concentration and application of acid. Aktas and Kaya (2001) reported that concentration of lactic and citric acid over 1.0% could cause meat sourness. Bauermeister et al. (2008) reported that organic acids, including acetic, formic, citric, and lactic and propionic acid, could control microbial proliferation but could also bring about an undesirable flavor and color. He also pointed out that 0.022% peracetic acid and 0.012 % hydrogen peroxide in solution could

maintain or increase the acceptability of flavor and color in poultry, in addition to its antimicrobial function. He drew the conclusion that low levels of propionic acid employed as antimicrobial in poultry chillers could reduce the population of *Salmonella Typhimurium* and *Campylobacter jejuni* on the final product without a change in organoleptic characteristics.

Bilgili et al. (1998) reported that organic acid (acetic, citric, lactic, malic, mandelic and tartaric acid) stimulated chiller condition, decreased lightness and increased yellowness values, as levels of concentration increased. In addition, lactic acid with sodium benzoate could control proliferation of Salmonella on chicken skin when refrigerated. A combination of 1% lactic acid and 0.5% hydrogen peroxide has 4 log reductions of Salmonella. Bauermeister et al. (2008) indicated that when carcasses inoculated with *Salmonella* (10^6 cfu) or *Campylobacter* (10^6 cfu), peracetic acid at concentration as low as 0.0025% was effective in reducing *Salmonella* spp. and at concentration as low as 0.002% was effective in reducing *Campylobacter* spp., when placed into poultry chiller. They also reported that the combination of 1% acetic acid and 3% hydrogen peroxide could significantly decrease the load of *Escherichia coli, Salmonella*, and *Listeria innocua* when sprayed on a previously inoculated beef carcass. Russell (1998) reported that 5% or more lactic acid eradicated all spoilage organisms isolated from broiler chicken. Bolder (1997) reported that poultry carcasses treated with 1-2% lactic acid solution after slaughter and during storage reduced bacteria population without a change in color or flavor. Brotsky and bender (1991) reported that using lactic or acetic acid above the specified level would control bacteria but was unacceptable with regards to sensory change. Organic acid antimicrobial

efficacy is determined by the level of acid and the pH value of the solution. Lactic acid removed bacteria attached to lean pork faster than bacteria attached to fatty parts. A combination of lactic acid and sodium benzoate could extend the shelf life and maintain meat quality. Therefore, organic acids, especially lactic acid, have the potential to be promising meat and poultry surface decontaminants.

The addition of organic acid and their salt compounds as preservatives in poultry and meat products has been utilized in commercial meat plants (Alvarado and Mckee, 2007). These chemical antimicrobials include sodium lactate, potassium lactate, sodium citrate, and combinations of these compounds. Jimenez-Villarreal et al. (2003) determined that cetylepyridinium chloride, chlorine dioxide, lactic acid and trisodium phosphate could be effective in reducing the numbers of bacteria. Also, cetylepyridinium chloride and trisodium phosphate could maintain the meat color and improve sensory characteristics and decrease the lipid oxidation rate compared to the untreated ground beef. Researchers also concluded that potassium lactate could be effective in reducing *Listeria monocytogenes* on various meats. Previous studies pointed out that sodium lactate, sodium acetate, sodium diacetate, potassium lactate, sodium citrate, the combination of sodium lactate and sodium diacetate, and the combination of sodium lactate and potassium were able to prevent the microbial population and increase the sensory evaluation of meat product (Shafit, 2000; White, 2000; Alvarado and Mckee, 2007). Shafit (2000) reported that 1.25 % lactic acid could lead to the discoloration of meat, and concentration of more than 2.0 % could cause flavor problems. Sodium lactate also has these problems. Williams and Phillips (1998) determined that increasing the concentration of sodium lactate reduced the population of psychrotrophic counts on

chicken breast meat. However, over 2% of sodium lactates could result in the cooked chicken meat having a bitter taste, so sensory problems limit the concentration level of chemicals use (Williams and Phillips, 1998). The effect of salt of organic acid has been attributed to cross molecular membranes and acid crosses the membrane barrier to acidify the cell interior.

Sodium Tripolyphosphate

The most commonly used poultry marinade is sodium tripolyphosphate, which had been shown to increase meat yield and water-holding capacity, as well as improve color and texture. Phosphate salt could prevent bacterial growth on carcass skin and not influence color or texture. Sodium tripolyphosphate as an intervention strategy could control the growth of *Salmonella, Campylobacter* and *E. coli* O157:H7 (Weber et al., 2004).

The chemical mode of action of sodium tripolyphosphate differs from chlorine, ozone, chlorine dioxide and acidified sodium chlorite, which could react and quickly remove unsaturated bonds from solution, and reduce the antimicrobial effect. Sodium tripolyphosphate is an alkaline salt. The high pH value of sodium tripolyphosphate (pH 12.1) could destroy cell membrane and damage the fat film of meat. The hydroxyl radical, remaining on meat surface, continues to function as an antimicrobial and retard the growth of bacterial after treatment (Ricke et al., 2005). It can be applied to remove “retention” and “entrapment” microorganisms. Brotsky and Bender (1991) reported that the death rate of *Salmonella* increased during scalding if the pH value of scald warm water was adjusted to around pH 9.0. The pH adjusting agents were sodium hydroxide, potassium hydroxide, sodium carbonate, and alkaline tripolyphosphate. He also concluded that trisodium phosphate dodecahydrate had the most powerful lytic action to

Salmonella typhosa, compared with monosodium disodium, and dipotassium orthophosphate. In addition, treating poultry carcasses or parts with 4% to 12% trisodium or tripotassium phosphate dodecahydrate was equally effective as sodium hydroxide, or phosphoric acid and sodium hydroxide. Alvarado and McKee (2007) mentioned that acid pH phosphates will lower water holding capacity, while alkaline phosphates had the reverse trend, which means that meat samples had a higher cooking yield, higher water-holding capacity, more juicer and tender, longer shelf life, higher color stable capacity, lower purge lost, and lower oxidation acidity after treated with alkaline phosphate.

Sodium Metasilicate

Sodium metasilicate (SMS) share some common with sodium tripolyphosphate. It is an alkaline salt with a high pH the ability to buffer. The pH value of a 1% aqueous solution is about 12.3, and the pH value of 5% aqueous solution is approximate 12.7. Sodium metasilicate has strong corrosive and penetrating ability. When sodium metasilicate reacted with protein and collagen, the saponifying effect occurs on lipid and dehydrates the tissue and cells. It can maintain pH stability when reacted with muscle tissue (Temple and Smith, 1997).

Sodium metasilicate as antimicrobial has been of interest in for years. Sodium metasilicate is considered GRAS (Generally Recognized as Safe) under 21CFR173.310 and is permitted to be added directly to food for human consumption (FDA, Code Federal Register, 2006). The USDA approved the application of sodium metasilicate on raw beef carcasses as an anti-microbial processing aid (USDA, 2009). Up to 4% (plus or minus 2%) of a solution could be used in the raw beef carcasses.

Quilo et al. (2009) applied the 4% SMS (w/v) to beef trimming and observed that the SMS treated sample was much juicier, had lower shear force, had less cooking loss than the control, and had no difference in sensory characteristics compared to the control product. Bender (2006) reported that the protein containing products contacted with alkali silicate solution for a period of time could sufficient to saturate the food products and absorbed the solution into product. He also concluded that SMS had lower cooked loss than untreated samples. Additionally, sodium metasilicate at concentration of 0.35% had slightly higher cooking yield than 0.35% phosphate treated samples. Weber et al. (2004) indicated that exposure of *E. coli* O157:H7 to 0.4% SMS solution for 20 minutes had same effectives with exposure to 0.6% SMS solution for 5-10 seconds which caused 100% inhibition without recoverable.

Recently, USDA approved sodium metasilicate for injection into raw meat and poultry as a 2% marinade solution by weight (UDSA, 2009). However, there is no documentation of the affect of sodium metasilicate in poultry products and little documentation recording the mechanisms of using sodium metasilicate to inhibit the growth of microorganisms. Therefore, SMS may have the same effectiveness in control growth of *Salmonella* and *Campylobacter* and may have the same mechanical action as sodium tripolyphosphate. Moreover, it may also improve the physical and chemical properties without sensory undesirable detectable. Also it may have no side effect to environment residue which may be different with sodium tripolyphosphate. Also it may also be more effective at extending shelf life when combined with other technologies.

CHAPTER 3
MATERIALS AND METHODS

This study was conducted in three phases. Phase I included preliminary studies to determine application method and to evaluate the effectiveness of sodium metasilicate (SMS) at the USDA approved level for poultry meat. Phase II included preliminary studies to determine the effectiveness of sodium metasilicate at approved and elevated levels and a shelf life study. Phase III included to investigate the effectiveness of sodium metasilicate at the USDA approved level and elevated levels on antimicrobial, sensory, chemical and physical characteristics of fresh chicken breast meat and a shelf life study. Marination processing was conducted at the University of Florida Meat Processing facility, and all analyses were performed in the Meat Research Laboratories.

Phase I. Preliminary Study: Application Method and Evaluation of Sodium Metasilicate at Approved Level for Poultry Meat

Sample Preparation

USDA GRADE A 97% fat free boneless skinless chicken breast fillets with rib meat and with expiration date of at least 7 days were purchased from a local supermarket. In order to insure the freshest fillets were used in the study, the fillets were purchased on the day of arrival to the store and immediately transported to the Meat Research Laboratory, and stored at 4°C in a walk-in cooler.

Sample Treatment and Marination Yield

Experiment one

Experiment one was conducted in a 4°C walk-in cooler. The fillets were randomly and evenly divided into three groups. A still-marinating process was used wherein the fillets were weighed and immersed into solutions containing either 0, 1 or 2% sodium metasilicate (AVGARD®XR, Lot. U012106, Danisco USA Inc., New century, KS) for 30

minutes (15 minutes for each side). The treated fillets were drained for 2 minutes, weighed and two fillets were packaged in a Cryovac 2.0" tray (Type CS978, Mulinix package Inc., Fort Wayne, IN), overwrapped with 18"X2000'plastic foodservice film (Companions^{TM}, Unipro Foodservice Inc., Atlanta, GA) and stored at 4°C for analysis. All samples were analyzed for marination yield, pH, total psychrotrophic counts, cooking yield, color, shear force and sensory evaluation on day 0.

Experiment two

Experiment two was conducted in the Meat Processing facility under simulated plant conditions in a 2°C processing room. Eighteen fillets were randomly and evenly divided into three groups. The fillets were weighed and placed into a vacuum tumbler (Lyco vacuum tumbler, model 40, Columbus, WI) with marinade solutions containing either 0, 1 or 2% sodium metasilicate solutions and tumbled under vacuum for 20 minutes at approximate 172.32 kPa (kilopascal) of pressure. The objective was to use the marinade solution to yield 10% increase in the total fillet original batch weight for each treatment. A vacuum tumbling processing was performed in a 2°C cold room to prevent fillets from increasing in temperature during marination. Control treatment samples were marinated with tap water (2°C). For 1% and 2% treatments, the sodium metasilicate compound was completely dissolved in tap water before marinated with samples. Except for tap water and sodium metasilicate, no other ingredients were added to the fillets in this study. The treated fillets were weighed and packaged in trays as previously discussed. Two fillets were placed into each tray and stored at 4°C for 6 days. For each treatment, two packages were randomly collected on 0, 1, 3 and 6 days and analyzed for marination yield, pH, total psychrotrophic counts, cooking yield color,

Instron and sensory evaluation. The marination yield (%) was calculated using the following equation:

Marination Yield (%) =100* W1/W2 (3-1)

W2 represents weight of fillets pre-marination, g

W1 represents weight of fillets post-marination, g

pH Analysis

The pH analysis was the same for experiments one and two. The pH value was determined immediately after completing microbiology analysis. The pH value was measured using a pH Meter (Accumet Basic AB15, Fisher Scientific, Fair Lawn, NJ). Prior to analysis of pH for each treatment, the pH meter was calibrated using pH buffers 4.00 (SB101-500, Fisher Scientific, Fair Lawn, NJ) and 7.00 (SB 107-500, Fisher Scientific, Fair Lawn, NJ). The probe was placed into the sample homogenate and allowed to equilibrate for one minute before the pH reading was recorded. All pH readings were performed in duplicates.

Cooking Yield Analyses

Experiment one: Grill reconstitution method

The grills (Hamilton beach, proctor-silex, Inc., Southern Pines, NC) were heated to 176.7 °C approximately 15 minutes. The fillets from the same treatment were placed on the same grill, and were heated for approximately 30 to 40 minutes. The fillets were turn over when the grill line occurred on the surface during grilling. The copper-constantan thermocouples were inserted the thickest part of fillets before grilling. The fillets were stopped cooking when the internal temperature reached 74 °C monitored with thermocouples attached to a potentiometer. The weights (Mettler Toledo scales, Mettler

instrumental corp., Model: MS 3001S 103, Hightstown. NJ) of before and after cooked fillets were recorded and cooking yield (%) was calculated using the following equation:

Cooking yield % = 100* W2/W1 (3-2)

W1 represents the weight before grilling, g

W2 represents the weight after grilling, g

Experiment two: Oven reconstitution method

Four fillets of each treatment were placed in a roasting pan. The roasting pan was covered with aluminum foil (Handi-Foil; 18”x 500’, Wheeling, IL,) to avoid moisture lost from fillets. The fillets were baked in a conventional gas oven (Model: JGRS14 GE Built In Gas Oven) at 176.7 °C, until internal temperature reached 74 °C which was monitored with copper-constantan thermocouples attached to a potentiometer. The copper-constantan thermocouples were inserted into the thickest part of the fillets before baking. The oven was preheated approximately 20 minutes until the oven temperature reached 176.7 °C. The weights (Mettler Toledo scales, Mettler instrumental corp., Model: MS 3001S 103, Hightstown. NJ) of the fillets were recorded before and after cooking, and cooking yield (%) was calculated using the following equation:

Cooking yield % = 100* W2/W1 (3-3)

W1 represents the weight before cooking, g

W2 represents the weight after cooking, g

Microbiological Analyses

Experiment one

The treated fillets were analyzed for total psychrotrophic counts on each assigned sampling days. Twenty-five gram fillets were aseptically cut and placed into a sterile stomacher bag (400ml, Fisher Scientific, Pittsburgh, PA). The 225 ml sterile 0.1%

peptone water (Cat. No. DFO1897-17-4, Detroit, MI) was poured into the stomacher bag. The stomacher bag was manually massaged for two minutes to loose surface bacteria. One milliliter of homogenate aliquot from stomacher bag was transferred into a test tube, which containing 9 ml sterile 0.1% peptone water. Two tubes were employed for each treatment from 10^{-1} to 10^{-2} serial dilution. The contents of tubes were mixed using vortex (Votex Geniz 2^{TM} Cat. No. 12-812 Model G 250, Fisher scientific, McGaw, IL) for 15 seconds to insure the bacterial evenly distributed. 3M Petrifilm Aerobic count plate (Cat. No. 6406, Fisher Scientific, Pittsburgh, PA) was placed on a level surface. The top film was lifted, and 1 milliliter aliquot from each tube was ascetically transferred into the plate, and a plastics squared spread was placed on the top center of plate and dispersed the aliquot on plate. The 3M Petrifilm Aerobic Plate Count was held at room temperature for15 minutes. Plates were incubated at 7°C refrigerator for 48 hours in a horizontal position for the total psychrotrophic count (Hamm, 2001). Microbiological counts were expressed as Logarithmic Colony Forming Units per grams (log cfu/g). The counts were recorded when containing 25-250 colonies on plate. All samples were plated in duplicates.

Experiment two

The sample homogenate and serial dilutions were prepared as discussed in Experiment One. Approximately 0.1 mL aliquot of the diluted sample homogenate from each serial dilution was aseptically transferred into sterile disposable 100 x 20mm Petri plates (Cat. No. 08-757-103C, Fisher Scientific, Suwanee, GA) that contained prepoured hardened Tryptic Soy Agar (No.1010617, MP Biomedicals, Inc., Solon, OH). The homogenate was spreaded on the plates using a sterile glass hockey stick. The stick was sterilized with 70% ethanol and flamed before spreading. The plates were

incubated aerobically at 7°C for 10 days to determine the total psychrotrophic counts (Hamm, 2001). Microbiological counts were expressed as Logarithmic Colony Forming Units per grams (log cfu/g). The counts were recorded when 25-250 colonies were on the plate. All plates were done in duplicates.

Objective Color Measurement

The color of raw and cooked fillets was measured with the Hunter MiniScan XE plus colorimeter (Hunter Associates Laboratory, Inc, Reston, VA) in the same manner for experiments one and two. The colorimeter was calibrated with a standard black tile and white tile as recommended by manufacturer. Fillets (two fillets per package) were measured at a total of four different locations for L*, a* and b* values. The instrumental color of L* a* b * color spectrum were recorded, where L* represents the total light reflected on a scale ranging from 0 = black to 100 = white, a* represents the amount of red (positive values) and green (negative values), and b * value represents the amount of yellow (positive values) and blue (negative values).

Warner-Bratzler Shear Force Analysis

The 1.0 cm cooked strips were employed for shear force measurement. The cooked 1.0 cm strips were covered with aluminum foil and stored at 4°C for 18 hours prior to shear force measurements. Texture measurements were conducted as described by Lyon and Lyon (1991). Each strip was oriented in the Warner-Bratzler shear attachment, which was attached to the Model 1011 Instron Texture machine (Model 1011 Instron, Instron Corporation, Norwood, MH). The speed of cross-head was 200 mm/min with a 50 kg load cell. The full scale range was 10 kg (Williams and Phillips, 1998). The Warner-Bratzler shear force values were recorded in kilograms. Five values were obtained from each treatment. All treatments were done in duplicates.

Sensory Evaluation Analyses

Experiment one: Grilled fillets

The fillets were cut into two 1.9 cm wide strips paralleled with the direction of the fibers. One strip was separated into three or four cubic cm for sensory evaluation, and another strip was used to determine instrumental texture. The cubes were trimmed into uniform size. Two cubes of each treatment were placed into a pre-warmed container to keep the serving temperature at approximate 55°C. The serving containers were labeled with one digit numbers. The sensory evaluation was performed in the Meat Laboratory sensory room equipped with eleven separated booths. Each booth was equipped with a ceiling lighting system with red, white, blue, or yellow lighting as needed (Williams and Phillips, 1998). The eight-point hedonic scoring scales were employed for Juiciness, chicken flavor intensity, overall tenderness and a six-point hedonic scoring scale was employed for off-flavor. The samples were evaluated in an informal taste test by two experienced panelists.

Experiment two: Baked fillets

The panelists were recruited from faculty, undergraduate and graduate students and staff in the Department of Animal Sciences who had participated in previous poultry sensory evaluations. The panelists were trained to comprehend the conception of Juiciness, tenderness, and chicken flavor intensity and to describe off-flavor. Juiciness evaluation included two treatments. Samples were baked in a conventional gas oven and covered with aluminum film to retain maximum moisture, and another group of samples were grilled to produce samples with lower moisture content than the baked samples. Tenderness evaluation included two treatments of chicken tenderloin. One group of samples were baked in a conventional gas oven and covered with aluminum

film to retain maximum moisture, and another group of samples were grilled, allowed to cool at 4°C for 15 minutes, and reheated in the microwave (Microwave Oven, Model: NN-S961, Panasonic, San Francisco, CA) for 3 minutes to produce a tough texture. Chicken flavor intensity evaluation included using different marinade solution and time. One treatment was soaked into chicken broth overnight, the weight of chicken broth marinade accounted for 30% total weight of fillets, this treatment had stronger chicken flavor. Another treatment was marinated with tap water and employed still-marinated for 30 minutes, the amount of tap water was 10% of fillets weight, and baked the samples at 176.7 °C. The marination processing was performed at 4°C cooler. Off-flavor evaluation included four treatments. Panelists were trained to indentify the off-flavor descriptors, such as salty, metallic, and bitter. The samples were marinated with tap water, 2% sodium chloride (salty), 2% of potassium chloride (bitter) and 0.5% sodium tripolyphosphate (metallic), and then baked in a conventional oven at 176.7°C, until internal temperature reach 74°C. The panelists were also trained to fill in the sensory sheet.

The eight-point hedonic scoring scales were employed for juiciness, chicken flavor intensity, and tenderness evaluation, where 8 represents extremely juicy, extremely intense and extremely tender, 7 represents very juicy, very intense, and very tender, 6 represents moderately juicy, moderately intense, and moderately tender, 5 represents slightly juicy, slight intense and slight tender, 4 represents slightly dry, slight bland and slight tough, 3 represents moderately dry, moderately bland and moderately tough, 2 represents very dry, very bland and very tough, and 1 represents extremely dry, extremely bland and extremely tough. A six-point scale was utilized for off-flavor

evaluation. 6 represents none detected, 5 represents threshold; barely detected, 4 represents slight off-flavor, 3 represents moderate off-flavor, 2 represents strong off-flavor and 1 represents extreme off-flavor.

Cooked meat was sectioned for sensory and instrumental texture measurements as described by Lyon et al. (2005) with some minor changes. The fillets were cut into 2 to 3 cubic cm wide strips paralleled with the direction of fiber. On strip was employed for instrumental texture, and another strips were employed for sensory evaluation. The cubes were discarded when the fibers from strips were not paralleled. The cubes were trimmed into uniform sizes. Two cubes of each treatment were placed into a pre-warmed container to keep the serving temperature at approximate 55°C. The serving container was labeled with one digit number. All treatments for sensory evaluation were served at the same time.

Phase II. Preliminary Study: Determination of the Effectiveness of Sodium Metasilicate at Approved and Elevated Levels and a Shelf Life Study.

In phase II, the sampling days included 0, 1, 3, 5, 7, 9 days. The fillets were marinated with tap water that contains 1, 2, 3 or 4% sodium metasilicate. The materials and methods for sampling preparation, sampling treatment, marination yield, pH analysis, microbiology analysis, color, cooking yield and sensory evaluation were the same as phase I in experiment two.

This preliminary study not only determined the effectiveness of the USDA approved levels, but also evaluated the effectiveness of elevated levels of sodium metasilicate on the shelf life of poultry meat. In addition to the parameters determined in experiment II in phase I, water-holding capacity values were determined.

Water-Holding Capacity Analyses

Water-holding capacity with sodium chloride. The water-holding capacity method described by zhuang et al. (2008) was conducted in this study. The treated fillets were minced with food processor (Braun Multiquick Hand Blender, Model: MR 400 HC, Type 4185, Lighthouse Point, FL). Ten gram minced samples were placed into a 50 ml tube containing 15 ml of 0.6 M sodium chlorine solution and vortexed (Votex Geniz 2^{TM} Cat. No. 12-812 Model G 250, Fisher scientific, McGaw, IL) for 1 minute per tube to ensure evenly distribution. The tubes were placed in a 4°C cooler for 15 minutes prior to centrifuge. The centrifuge machine (Superspeed Refrigerated Centrifuge, Sorvall RC-5B, Beverly, MA) was turned on approximate one hour before measuring. The tubes were centrifuged at 3000 rpm at 4°C for 15 minutes. The liquid was decanted, and the solid material was maintained in the tube. The weights of before and after centrifuged meat were recorded.

Water-holding capacity with distilled water. The water holding capacity percentage values also were determined by distilled water method. The purpose of measuring these values with distilled water were to compare with fillets measured with sodium chloride. Except for addition of distilled water, the procedure to determine water-holding capacity was the same as using sodium chloride. Therefore, the 15 ml distilled water in place of sodium chloride was added into tubes that contained ten grams minced samples. The samples were analyzed in duplicate. The data for this method were collected through day 3 to day 9. The same equation was used for these two methods.

WHC (%) was determined by using the following equation:

$$WHC\ \% = 100 * (W1-W2)/W3 \qquad (3\text{-}4)$$

Where W1 represents solution added into the sample, g

W2 represents solution removed, g

W3 represents the meat sample mass, g

Phase III. Investigation of the Effectiveness of Sodium Metasilicate at the USDA Approved Level and Elevated Level on Antimicrobial, Sensory, Chemical and Physical Characteristics of Fresh Chicken Breast Meat Stored at 4°C for 9 Days

In phase II test, the sampling days included day 0, 1, 3, 5, 7 and 9, and in phase III, the sampling days included days 0, 1, 3, 5, 6, 7, and 9, and purge loss was measured. The procedures of sampling preparation, sampling treatment, marination process, pH measurement, microbiology analysis, and water holding capacity were the same as phase II tests. The parameters of sensory evaluation, raw meat color, cooked meat color, cooking yield, Warner-Bratzler shear force were performed in duplicates in phase III. The treatments included 0 (control), 1, 2, 3, and 4% sodium metasilicate in marinade solution.

Sample Preparation

USDA GRADE A 97% fat free boneless skinless chicken breast fillets with rib meat and with expiration date of at least 7 days were purchased from a local supermarket. In order to insure the freshest fillets were used in the study, the fillets were purchased on the day of arrival to the store and immediately transported to the Meat Research Laboratory, and stored at 4°C in a walk-in cooler.

Sample Treatment and Marination Yield

Experiment was conducted in the Meat Processing facility under simulated plant conditions in a 2°C processing room. One hundred forty fillets were randomly and evenly divided into five groups. The fillets were weighed and placed into a vacuum tumbler (Lyco vacuum tumbler, model 40, Columbus, WI) with marinade solutions

containing either 0, 1, 2, 3 or 4% sodium metasilicate solutions and tumbled under vacuum for 20 minutes at approximate 172.32 kPa of pressure. The objective was to use the marinade solution to yield 10% increase in the total fillet original batch weight for each treatment. Vacuum tumbling processing was performed in a 2°C cold room to prevent fillets from increasing in temperature during marination. Control treatment samples were marinated with tap water (2°C). For sodium metasilicate treatments, the sodium metasilicate compound was completely dissolved in tap water before marinated with samples. Except for tap water and sodium metasilicate, no other ingredients were added to the fillets in this study. The treated fillets were weighed and packaged in Cryovac 2.0" trays (Type CS978, Mulinix package Inc., Fort Wayne, IN). Two fillets were placed into each tray and stored at 4°C for 9 days. For each treatment, two packages were randomly collected on 0, 1, 3, 5, 6, 7 and 9 days and the samples were analyzed the marination yield, pH, the total psychrotrophic counts, water holding capacity, purge loss, cooking yield, color, shear force and sensory evaluation. The marination yield (%) was calculated using the following equation:

Marination Yield (%) =100* W1/W2 (3-5)

W2 represents weight of fillets pre-marination, g

W1 represents weight of fillets post-marination, g

pH Analysis

The pH value was determined immediately after completing microbiology analysis. pH value was measured using pH Meter (Accumet Basic AB15 pH Meter, Model no. SA 520, Fisher Scientific, Fair Lawn, NJ). Prior to analysis of pH for each treatment, the pH meter was calibrated using pH buffers 4.00 (SB101-500, Fisher Scientific, Fair Lawn, NJ) and 7.00 (SB 107-500, Fisher Scientific, Fair Lawn, NJ). The probe was placed into

the sample homogenate and allowed to equilibrate for one minute before the pH reading was recorded. All pH readings were performed in duplicates.

Water-Holding Capacity Analyses

Water-holding capacity with sodium chloride. The water-holding capacity method described by zhuang et al. (2008) was conducted in this study. The treated fillets were minced with a food processor (Braun Multiquick Hand Blender, Model: Mr400 HC, Type 4185, Lighthouse Point, FL). Ten gram minced samples were placed into a 50 ml tube containing 15 ml 0.6 M sodium chlorine solution and vortexed (Votex Geniz 2^{TM} Cat. No. 12-812 Model G 250, Fisher scientific, McGaw, IL) for 1 minute per tube to insure even distribution. The tubes were placed in a 4°C cooler for 15 minutes prior to centrifuge. The centrifuge machine (Superspeed Refrigerated Centrifuge, Sorvall RC-5B, Beverly, MA) was turned on approximate one hour before measuring. The tubes were centrifuged at 3000 rpm at 4°C for 15 minutes. The liquid was decanted, and the solid material was maintained in the tube. The weights of before and after centrifuged meat were recorded (Zhuang et al., 2008). The samples were analyzed in duplicate.

WHC (%) was determined by using the following equation:

$$WHC\ \% = 100 * (W1-W2)/W3 \qquad (3\text{-}6)$$

Where W1 represents solution added into the sample, g

W2 represents solution removed after, g

W3 represents the meat sample mass, g

Water-holding capacity with distilled water. Except for addition of distilled water, the method was the same as described by zhuang et al. (2008). The treated fillets were minced with a food processor (Braun Multiquick Hand Blender, Model:

Mr400 HC, Type 4185, Lighthouse Point, FL). Ten gram minced samples were placed into a 50 ml tube containing 15 ml distilled water and vortexted (Votex Geniz 2^{TM} Cat. No. 12-812 Model G 250, Fisher scientific, McGaw, IL) for 1 minute per tube to insure even distribution. The tubes were placed in a 4°C cooler for 15 minutes prior to centrifuge. The centrifuge machine (Superspeed Refrigerated Centrifuge, Sorvall RC-5B, Beverly, MA) was turned on approximate one hour before measuring. The tubes were centrifuged at 3000 rpm at 4°C for 15 minutes. The liquid was decanted, and the solid material was maintained in the tube. The weights of before and after centrifuged meat were recorded. The samples were analyzed in duplicate.

WHC (%) was determined by using the following equation:

$$WHC\ \% = 100 * (W1-W2)/W3 \quad (3\text{-}7)$$

Where W1 represents solution added into the sample, g

W2 represents solution removed after, g

W3 represents the meat sample mass, g

Purge Loss Analysis

Purge loss included any liquid that was collected from the package tray. The weights (Mettler Toledo scales, Model: MS 3001S 103, Switzerland) of liquid released from fillets were recorded. Purge loss (%) was calculated by using the following equation:

$$\text{Purge loss (\%)} = 100*W1/W2 \quad (3\text{-}8)$$

W1 represents liquid released from fillets, g

W2 represents original fillet weight, g

Cooking Yield Analysis

Four fillets of each treatment were placed in a roasting pan. The roasting pan was covered with aluminum foil (Handi-Foil; 18”x 500’, Wheeling, IL) to avoid moisture lost from fillets. The fillets were baked in a conventional gas oven (Model: JGRS14 GE Built In Gas Oven) at 176.7°C until internal temperature reached 74°C, which was monitored with copper-constantan thermocouples attached to a potentiometer. The copper-constantan thermocouples were inserted into the thickest part of the fillets before baking. The oven was preheated approximately 20 minutes until the oven temperature reached 176.7°C. The weights (Mettler Toledo scales, Model: MS 3001S 103, Switzerland) of the fillets were recorded before and after cooking, and cooking yield (%) was calculated using the following equation:

Cooking yield % = 100* W2/W1 (3-9)

W1 represents the weight before cooking, g

W2 represents the weight after cooking, g

Microbiological Analysis

The treated fillets were analyzed for total psychrotrophic counts on each of the assigned sampling days. Twenty-five gram fillets were aseptically cut and placed into a sterile stomacher bag (Cat. NO. 400ml, Fisher Scientific, Pittsburgh, PA). The 225 ml sterile 0.1% peptone water (Cat. No. DFO1897-17-4, Detroit, MI) was poured into the stomacher bag. The stomacher bag was manually massaged for two minutes to loose surface bacteria. One milliliter of homogenate aliquot from stomacher bag was transferred into a test tube containing 9 ml sterile 0.1% peptone water. Five tubes were employed for each treatment from 10^{-2} to 10^{-6} serial dilutions. The contents of tubes were mixed using vortex (Votex Geniz 2^{TM} Cat. No. 12-812 Model G 250, Fisher

scientific, McGaw, IL) for 15 seconds to insure that the bacteria were evenly distributed. Approximately 0.1 mL aliquot of the diluted sample homogenate from each serial dilution was aseptically transferred into sterile disposable 100 x 20mm Petri plates (Cat. No. 08-757-103C, Fisher Scientific, Suwanee, GA) that contained prepoured hardened Tryptic Soy Agar (No.1010617, MP Biomedicals, Inc., Solon, OH). The homogenate was spread on the plates using a sterile glass hockey stick. The stick was sterilized with 70% ethanol and flamed before spreading. The plates were incubated aerobically at 7°C for 10 days for total psychrotrophic counts (Hamm, 2001). Microbiological counts were expressed as Logarithmic Colony Forming Units per grams (Log CFU/g). The counts were recorded when 25-250 colonies were on the plate. All plates were done in duplicates.

Objective Color Measurement

The color of raw and cooked fillets was measured with the Hunter MiniScan XE plus colorimeter (Hunter Associates Laboratory Inc., Reston, VA). The colorimeter was calibrated with a standard black tile and white tile as recommended by manufacturer. Fillets (two fillets per package) were measured at a total of four different locations for L*, a* and b* values. The instrumental color of L* a* b * color spectrum was recorded, where L* represents the total light reflected on a scale ranging from 0 = black to 100 = white, a* represents the amount of red (positive values) and green (negative values), and b * value represents the amount of yellow (positive values) and blue (negative values). All color measurements were performed in duplicates.

Warner-Bratzler Shear Force Analysis

The 1.0 cm cooked strips were employed for Instron shear force. The cooked 1.0 cm strips were covered with aluminum foil, and stored at 4°C for 18 hours prior to

Instron measurements. Texture measurements were conducted as described by Lyon and Lyon (1991). Each strip was oriented in the Warner-Bratzler shear attachment (Type D. D., Catalog no. 2830-002), which was attached to the Model 1011 Instron Texture machine (Model 1011, Instron Corporation, Norwood, MH). The speed of cross-head was 200 mm/min with a 50 kg load cell. The full scale range was 10 kg (Williams and Phillips, 1998). The Warner-Bratzler shear force values were recorded in kilograms. Five values were obtained from each treatment. All treatments were done in duplicates.

Sensory Evaluation

Cooked meat was sectioned for sensory and instrumental texture measurements as described by Lyon et al., (2005) with some minor changes. The fillets were cut into 2 to 3 cubic cm wide strips paralleled with the direction of fiber. One strip was separated into three or four cubic cm for sensory evaluation, and another strip was used to determine instrumental texture. The cubes were trimmed into uniform size. Two cubes of each treatment were placed into a pre-warmed container to keep the serving temperature at approximate 55°C. The serving containers were labeled with one digit numbers. The sensory evaluation was performed in the Meat Laboratory sensory room equipped with eleven separated booths. Each booth was equipped with a ceiling lighting system with red, white, blue, or yellow lighting as needed (Williams and Phillips, 1998).

The eight-point hedonic scoring scales were employed for juiciness, chicken flavor intensity, and tenderness evaluation, where 8 represents extremely juicy, extremely intense and extremely tender, 7 represents very juicy, very intense, and very tender, 6 represents moderately juicy, moderately intense, and moderately tender, 5 represents slightly juicy, slight intense and slight tender, 4 represents slightly dry, slight bland and slight tough, 3 represents moderately dry, moderately bland and moderately tough, 2

represents very dry, very bland and very tough, and 1 represents extremely dry, extremely bland and extremely tough. A six-point scale was utilized for off-flavor evaluation. 6 represents none detected, 5 represents threshold; barely detected, 4 represents slight off-flavor, 3 represents moderate off-flavor, 2 represents strong off-flavor and 1 represents extreme off-flavor.

Statistical Analysis

The experiment was arranged in a complete randomized 5 (treatments) x7 (sampling days) factorial design and was replicated two times. Data were analyzed using the GLM procedure of SAS (SAS Institute, 2002) by generating an analysis of variance (ANOVA). The model included the main effects of antimicrobial treatment, storage day, and treatment by day interaction. Data were re-analyzed within a day and within a treatment. Comparisons among means were performed using SAS Duncan Multiple Range test of the Statistical Analysis System. Treatments effects and differences were considered significantly when $P < 0.05$. The MEANS procedure was employed to analyze day and treatment.

CHAPTER 4
RESULTS AND DISCUSSION

Phase I. Preliminary Study: Application Method and Evaluation of Sodium Metasilicate at Approved Level for Poultry Meat

Experiment 1

Marination yield analysis

The fillets treated with 1% and 2% sodium metasilicate had slightly higher observed marination yields than control treatment (Figure 4-1). The data suggested that sodium metasilicate had ability to bind more water under still-marination conditions.

pH and cooking yield analyses

The data demonstrated that meat pH values increased as the concentration of sodium metasilicate levels increased. The pH value of control fillets and fillets treated with 1% and 2% sodium metasilicate were 6.05, 6.65 and 6.85, respectively (Figure 4-2). This is also true for the marinade solutions wherein pH increased with increased sodium metasilicate levels (Figure 4-3).

Control fillets and fillets treated with 2% sodium metasilicate had higher cooking yields than fillets treated with 1% sodium metasilicate (Figure 4-4). The higher cooking yield for 2% may due to the water binding capacity of sodium metasilicate.

Microbiological analysis

The total psychrotrophic counts (TPC) for all treatments had too numerous to count (TNTC) for dilution of 10^{-1} and 10^{-2} on day 0 (Table 4-1). The results indicated that fillets treated with 2% sodium metasilicate had less observed psychrotrophic counts, when compared to control fillets and fillets treated with 1% sodium metasilicate.

Objective color measurement

Raw fillet color. On day 0, the L* (lightness) values of raw fillets treated with 0% (Control, tap water), 1% and 2% sodium metasilicate solution were 58.48, 63.35, and 61.20, respectively (Table 4-2). Based on International Commission on Illumination (CIE) lightness values for chicken breast meat, normal L* values (lightness) of fillets are between 48 and 53, L* values of fillets less than 46 are considered dark, and L* values of fillets greater than 53 are considered light for chicken meat (Qiao et al., 2002). L* values higher than 60 are considered Pale, Soft, Exudative (PSE) (Van Laack et al., 2000). Qiao et al. (2002) also reported the color change of three groups of breast meat samples after overnight storage at 4°C. The samples were chopped prior to measure, the L*, a* and b* values of dark ground meat were 57.83, 5.01, and 9.05, respectively. The L*, a* and b* values of normal ground meat were 62.07, 4.38 and 9.68, respectively. And the L*, a* and b* values of light ground meat were 64.34, 3.75 and 9.55, respectively.

In this preliminary study, the sodium metasilicate treated samples were lighter ($P > 0.05$) than the control treatment. The control fillets were redder ($P > 0.05$) than sodium metasilicate treatments on day 0 (Table 4-2). The control fillets were less yellow ($P > 0.05$) than fillets treated with sodium metasilicate on day 0. These results revealed that sodium metasilicate treatments had higher L*, less a*, and higher b* values ($P > 0.05$), when compared to the control fillets (Table 4-2).

Cooked fillet color. The data revealed that all treatments had similar ($P > 0.05$) a* and b* values (Table 4-2). The control fillets had lighter ($P < 0.05$) cooked meat color than fillets treated 2% sodium metasilicate, and darker ($P < 0.05$) than fillets treated with 1% sodium metasilicate.

Sensory evaluation and warner-bratzler shear force analyses

No significant differences ($P > 0.05$) were observed among treatments regarding juiciness, chicken flavor intensity, tenderness and off-flavor sensory characteristics (Table 4-3). All the treatments had similar ($P > 0.05$) Warner-Bratzler shear force (Table 4-3). The data revealed that these parameters were not influenced by the concentration of sodium metasilicate in this preliminary study.

Experiment 2

In this preliminary study, the sampling days were 0, 1, 3, and 6. However, Off-odor, slim formation and surface discoloration were detected in the samples on day 6, therefore, collecting data for sensory evaluation, instrumental texture, cooked meat color and cooking yield were discontinued after day 3.

Marination yield analysis

The control fillets and fillets treated with 2% sodium metasilicate had slightly higher marination yield when compared to fillets treated with 1% sodium metasilicate after marinated (Figure 4-5).

pH analysis

As concentration of sodium metasilicate increased, the pH of meat increased (Table 4-4). The pH value of 2% sodium metasilicate treatment was significantly higher ($P < 0.05$) than the control and 1% sodium metasilicate treatments over 6 days storage. As storage time increased, the meat pH values of control treatment were similar ($P > 0.05$) over storage periods. The pH values of 1% sodium metasilicate treatment decreased over storage time, and 2% sodium metasilicate treatment decreased on day 6 when compared to pH values of day 0.

Cooking yield analysis

Except for day 3, the cooking yield increased as the concentration of sodium metasilicate increased (Figure 4-6). The cooking yield for 2% sodium metasilicate treatment was higher than the control and 1% sodium metasilicate treatments through 3 days storage. The cooking yields for control and 2% sodium metasilicate treatments slightly fluctuated (first decreased then increased) over storage time.

Microbiological analysis

The total psychrotrophic counts increased for all treatments as storage time increased (Table 4-5). Except for day 3, the fillets treated with sodium metasilicate had significantly lower ($P < 0.05$) total psychrotrophic counts through 6 days storage, when compared to control treatment. No significant differences ($P > 0.05$) in total psychrotrophic counts were detected between fillets treated with 1% and 2% sodium metasilicate through 3 days storage. On day 6, the psychrotrophic counts for all treatments had reached or exceeded 7 log cfu/g, and all samples had produced slime formation and off-odor development.

Objective color measurement

Raw fillet color. The L* (lightness) values for control fillets were similar ($P > 0.05$) with fillets treated with 1% and 2% sodium metasilicate on day 0 and day 1 (Table 4-6). On day 3, the control fillets were significantly darker ($P < 0.05$) than fillets treated with sodium metasilicate. The fillets treated with 1% sodium metasilicate had lower ($P > 0.05$) L* values on day 0, when compared with day 1 and day 3.

The control fillets had lower ($P < 0.05$) a* (redness) values than fillets treated with 1% sodium metasilicate on day 0. The fillets for all treatments had similar ($P > 0.05$) a* values on day 1 and day 3.

The control fillets had lower ($P < 0.05$) b* (yellowness) values than fillets treated with 2% sodium metasilicate on day 1. The fillets for all treatments were similar ($P > 0.05$) on day 0 and day 3.

Cooked fillet color. The fillets treated with 1% sodium metasilicate were darker ($P < 0.05$) than control fillets on day 0 (Table 4-7). The fillets for all treatments were similar L* (lightness) on day 0 and day 3. The control fillets were less red ($P < 0.05$) than fillets treated with 1% and 2% sodium metasilicate on day 0. The control fillets were redder ($P < 0.05$) than fillets treated with 2% sodium metasilicate on day 1. On day 3, all fillets had similar ($P > 0.05$) redness. The fillets treated with 1% sodium metasilicate were yellower than control fillets and fillets treated with 2% sodium metasilicate. All fillets were similar ($P < 0.05$) yellowness on day 1 and day 3.

Warner-bratzler shear force analysis

The Warner-Bratzler shear force value for all treatments fillets were less than 3.62, which were indicative of very tender meat (Table 4-8). The Warner-Bratzler shear force values were similar ($P > 0.05$) on day 0 and day 1 for all treatments. The fillets treated with 2% sodium metasilicate had higher ($P < 0.05$) Warner-Bratzler shear force values, when compared to control fillets and fillets treated with 1% sodium metasilicate.

Sensory evaluation

On day 0, the fillets treated with 1% and 2% sodium metasilicate were significantly juicier ($P < 0.05$) than control fillets (Table 4-9). On day 1, all fillets had similar ($P > 0.05$) juiciness. On day 3, the fillets treated with 1% sodium metasilicate were significantly juicer ($P < 0.05$) than fillets treated with 2% sodium metasilicate. As storage time increased, only fillets treated with 2% sodium metasilicate decreased in juiciness

over 3 days storage, all other treatments fillets had similar ($P > 0.05$) juiciness through 3 days storage.

Chicken flavor intensity was similar ($P > 0.05$) for all treatments through 3 days storage. The control fillets on day 3 had significantly ($P < 0.05$) stronger chicken flavor intensity than day 1, all other treatment fillets had similar ($P > 0.05$) chicken flavor intensity through 3 days storage.

Based on the responses of the panelists, overall tenderness varied from moderately tender (6.14) to extremely tender (7.63). There was no significant difference ($P > 0.05$) among treatments on individual sampling days. The sensory data indicated that the panelists “barely” (score of 5) or “did not detect” (score of 6) off-flavor for all treatments.

The effectiveness of sodium metasilicate at USDA approved level up to 2% marinade solution did not extend shelf life, maintain the raw meat color discoloration, and increased cooking yield and marination yield. However, the data were inconsistent between the two preliminary experiments. Therefore, further investigation was necessary to determine the effectiveness of sodium metasilicate at the USDA approved levels and elevated levels on shelf life and meat quality.

Phase II. Preliminary Study: Determination of the Effectiveness of Sodium Metasilicate at USDA Approved and Elevated Levels in a Shelf Life Study

Marination Yield Analysis

The fillets treated with sodium metasilicate had higher marination yields than control fillets (Figure 4-7). Except for fillets treated with 2% sodium metasilicate, the marination yield for all treatments slightly increased, as the concentration of sodium metasilicate increased.

pH Analysis

In general, the pH of poultry meat increased, as the concentration levels of sodium metasilicate increased (Table 4-10). The pH values of fillets treated with 4% sodium metasilicate were significantly higher ($P < 0.05$) over 9 storage days, when compared with control fillets and fillets treated with 1% sodium metasilicate. The pH values for 1%, 2%, 3%, and 4% sodium metasilicate marinade solutions were 12.42, 12.58, 12.75, and 12.83, respectively, these values were approximate 5 pH units higher than control solution which was 7.71 (Figure 4-8). The fillets treated with sodium metasilicate were expected to be more alkaline than control fillets. However, there was no significant difference ($P > 0.05$) for pH values between control fillets and fillets treated with 1% sodium metasilicate through 7 days storage. Except for day 7, the pH values of fillets treated with 3% and 4% sodium metasilicate were similar ($P > 0.05$) over 9 days storage. Except for fillets treated with 4% sodium metasilicate, all pH values of fillets among treatments were similar ($P > 0.05$) on day 0.

Water-Holding Capacity Analyses

Water-holding capacity with sodium chloride

The results for water-holding capacity (WHC) measured with the standard method (sodium chloride) are shown in Table 4-11. There were no significant differences in WHC among treatments on days 0 through day 5. The WHC for all sodium metasilicate treatments were consistently higher ($P > 0.05$), when compared to control treatment. On day 7, the WHC of fillets treated with 1% and 4% sodium metasilicate were significantly higher ($P < 0.05$), when compared to control fillets, and no difference ($P > 0.05$) was detected among fillets treated with 1%, 2% and 3% sodium metasilicate. On day 9, the WHC of fillets treated with 1% and 2% sodium metasilicate were significantly higher (P

> 0.05), when compared to control fillets, and were similar (P > 0.05) with fillets treated with 3% and 4% sodium metasilicate. Except for the WHC of fillets treated with 3% sodium metasilicate decreasing over storage time, the WHC of fillets for all treatments were similar (P > 0.05) through 9 days storage.

Water-holding capacity with distilled water.

The WHC percentages for all treatments were similar (P > 0.05) on day 3 (Table 4-12). On day 5, the WHC values for fillets treated with 1% sodium metasilicate were significantly higher (P < 0.05), when compared to control fillets, and similar (P > 0.05) among all other treatments. On day 7, the WHC values for fillets treated with 2% sodium metasilicate were significantly lower (P < 0.05), when compared to control fillets. On day 9, the WHC values for fillets treated with 3% and 4% sodium metasilicate were significantly higher (P < 0.05), when compared to control fillets and fillets treated with 1% sodium metasilicate.

Various methods have been developed or used to estimate meat WHC. For example, drip loss, cooking yield, filter paper method and centrifugal method (Zhuang, et al., 2008). In this experiment, the centrifuge method was used. The data (Table 4-11 and Table 4-12) indicated the uptake of added water by meat. The results of water uptake in Table 4-11 indicated the effective of combination of sodium metasilicate and sodium chloride. The results of water uptake in Table 4-12 indicated the effectiveness of sodium metasilicate alone. The data suggested that sodium metasilicate had weaker WHC, when compared to sodium chloride.

Cooking Yield Analysis

Although there was no statistical analysis of the data, the cooking yield values for fillets treated with 4% sodium metasilicate were higher than the remaining fillets

treatments over 9 days storage (Figure 4-9). Except for fillets treated with 2% sodium metasilicate on day 1, all fillets treated with sodium metasilicate had higher cooking yield value than control fillets through 7 days storage. On day 9, only fillets treated with 1% sodium metasilicate had slightly lower cooking yields than control fillets. The cooking yield values for all treatments on day 5 were lower than other sampling days. The lower cooking yield values were attributed to the different storage method that was used on day 5. On day 5, all panelists were unavailable. Therefore, fillets were stored in the freezer overnight, and analyzed on the next day. Freezing treatment could alter the spatial arrangement of the fibrillar network of meat, and would decrease the water holding capacity. Therefore, much more liquid from meat would be released during cooking, when compared to unfrozen meat.

Microbiological Analysis

In general, as storage time increased, the total psychrotrophic counts increased for all treatments (Table 4-13). The fillets treated with 4% sodium metasilicate had significantly lower ($P < 0.05$) psychrotrophic counts through 9 days storage, when compared to control fillets and fillets treated with 1% and 2% sodium metasilicate. Except for day 3, the fillets treated with 3% sodium metasilicate had significantly lower ($P < 0.05$) psychrotrophic counts than control fillets over 9 days storage. The total psychrotrophic counts for control fillets and fillets treated with 1% sodium metasilicate had similar ($P > 0.05$) counts through 7 days storage. No microbial growth on plates were detected for fillets treated with 3% and 4% sodium metasilicate on day 0 and day 1 at highest dilution plated, which was 10^{-2}. In general, off-odor was detected when total psychrotrophic counts reached 7 to 8 log cfu/g on meat surface and slime formation was developed when total psychrotrophic counts were over 8 log cfu/g. On day 7, the

control fillets and fillets treated 1% and 2% sodium metasilicate were spoiled and the total psychrotrophic counts had reached 7 $\log_{10}$ cfu/g. On day 9, the fillets for all treatments were spoiled, and the total psychrotrophic counts for all treatments exceeded 8 log cfu/g. The data revealed that 1% and 2% sodium metasilicate treatments did no significantly retard the microbial growth. The fillets treated with 3% and 4% sodium metasilicate had significantly lower ($P < 0.05$) psychrotrophic counts through 7 days storage, when compared to control fillets. The data demonstrated that 3% and 4% sodium metasilicate treatment retarded the growth for psychrotrophs and increased the shelf life of the fillets at most to 2 additional days.

Objective Color Measurement

Raw fillet color

L* value. The fillets for most treatments became darker as storage time increased (Table 4-14). On day 0, the fillets treated with 3% sodium metasilicate treatment were significantly darker ($P < 0.05$) than control fillets and similar ($P > 0.05$) with all other sodium metasilicate treatments. On day 5, the fillets treated with 1% and 2% sodium metasilicate were significantly darker ($P < 0.05$) than control fillets and similar ($P > 0.05$) to all other sodium metasilicate treatments. This effect was not observed at any other storage intervals. As storage time increased, the L* values for fillets treated with 1% sodium metasilicate were significantly lower ($P < 0.05$), when compared to day 0 and day 9.

a* value. Except for day 0 and day 7, there was no significant difference ($P > 0.05$) for a* values (Table 4-15), when compared to control fillets and fillets treated with sodium metasilicate for other storage days. On day 0, the a* value for fillets treated with 1% sodium metasilicate were redder ($P < 0.05$) than fillets treated with 2% and 4%

sodium metasilicate. On day 7, the fillets treated with 3% sodium metasilicate were significantly redder ($P < 0.05$) than control fillets and similar ($P > 0.05$) with other fillets treated with sodium metasilicate. The a* values tend to increase as storage time increased for all treatments. Myoglobin is responsible for the majority of the red color, as storage time increased, the liquid released from the fillets increased, and the concentration of myoglobin on the surface of meat increased.

b* value. The data indicated that b* values became greater as storage time increased (Table 4-16). The b* values for control fillets and fillets treated with 4% sodium metasilicate had slightly changed as storage time increased. The fillets treated with 2%, 3% and 4% sodium metasilicate had similar ($P > 0.05$) b* values over 9 days storage. On day 0 and day 1, fillets treated with 1% sodium metasilicate had significantly higher ($P < 0.05$) b* value than fillets treated with 4% sodium metasilicate. On day 9, fillets treated with 2% sodium metasilicate had lower ($P < 0.05$) b* value than control fillets and similar ($P > 0.05$) with all other treatments.

Cooked fillet color

L* value. The fillets treated with 2%, 3% and 4% had similar ($P > 0.05$) L* values as storage time increased (Table 4-17). Except for day 5, the control fillets and fillets treated with 1% and 2% sodium metasilicate had similar L* values ($P > 0.05$) through 9 days storage. As storage time increased, the L* values for the control fillets and fillets treated with 1% sodium metasilicate decreased ($P < 0.05$) slightly on day 9.

a* value. On day 0, the fillets treated with 1% sodium metasilicate had higher a* value ($P < 0.05$), when compared to fillets treated with 2% and 4% sodium metasilicate (Table 4-18). On day 7, the fillets treated with 3% sodium metasilicate had significantly

higher ($P < 0.05$) a* value, when compared to control fillets. Other fillets among treatments were similar ($P > 0.05$) for all sampling days.

b* value. On day 0, control fillets and fillets treated with 1% sodium metasilicate had higher ($P < 0.05$) b* values than fillets treated with 2% and 4% sodium metasilicate (Table 4-19). On day 1, the fillets treated with 1% sodium metasilicate had greater ($P < 0.05$) b* value, when compared to fillets treated with 4% sodium metasilicate. On day 9, the fillets treated with 2% sodium metasilicate had lower b* values than control fillets. Fillets were similar ($P > 0.05$) for all other sampling days.

Warner-Bratzler Shear Force Analysis

Except for day 1, shear force values were similar ($P > 0.05$) for all treatments. On day 1, the control fillets and fillets treated with 3% sodium metasilicate had lower ($P < 0.05$) shear force values than fillets treated with 1% sodium metasilicate. The shear force values ranged from 1.18 kg to 2.03 kg for all treatments (Table 4-20). All samples in this study were very tender based on the tenderness descriptions of Lyon and Lyon (1991).

Sensory Evaluation

The panelists rated all samples slightly juicy (5.17) to very juicy (7.00) (Table 4-21). Except for day 0, there was no significant difference in juiciness ($P > 0.05$) among all treatments through 7 days storage. On day 0, the fillets treated with 3% sodium metasilicate were juicier ($P < 0.05$), when compared to all fillets treated with 2% and 4% sodium metasilicate. On day 9, the control fillets had similar ($P >0.05$) juiciness, when compared to sodium metasilicate treated fillets, and the fillets treated with 2% and 3% sodium metasilicate were juicier ($P < 0.05$) than fillets treated with 1% sodium metasilicate.

Except for day 0, the panelists rated the chicken flavor intensity for all treatments similar ($P > 0.05$) for all storage days (Table 4-21). On day 0, the fillets treated with 3% sodium metasilicate had greater ($P < 0.05$) chicken flavor intensity, when compared to all other treatments.

Except for day 0, the panelists rated the tenderness of all treatments similar ($P > 0.05$) through 9 days storage (Table 4-22). The panelists rated all samples moderately tender (6.33) to extremely tender (8.00). On day 0, the tenderness of fillets treated with 3% sodium metasilicate were significantly higher ($P < 0.05$) than all other treatments. The fillets treated with 3% sodium metasilicate had a higher tenderness score on day 0 than on all other sampling days.

The panelists rated all treatments similar for off-flavor ($P > 0.05$) through 9 days storage (Table 4-22). The data indicated that the panelists barely detected (score of 5) or “did not detected” (score of 6) off-flavor development for all treatments.

Phase III. Investigation the Effectiveness of Sodium Metasilicate at the USDA Approved and Elevated Levels on Antimicrobial, Sensory, Chemical and Physical Characteristics of Fresh Chicken Breast Meat and Stored at 4°C for 9 Days

Marination yield Analysis

In general, the marination yield increased, as the concentration levels increased (Figure 4-10). The fillets treated with 1% sodium metasilicate had slightly higher marination yield than the other sodium metasilicate treatments. In this study, all sodium metasilicate treatments had slightly higher marination yield than control treatment.

pH Analysis

The fillets treated with 3% and 4% sodium metasilicate had significantly higher ($P < 0.05$) pH values than the control fillets and fillets treated with 1% sodium metasilicate over 9 days storage (Table 4-23). Except for day 3, the pH values were similar ($P >$

0.05) between the control fillets and fillets treated with 1% sodium metasilicate over 9 days storage. Except for day 7, the pH values were similar ($P > 0.05$) between fillets treated with 2% and 3% sodium metasilicate. There was a slight decrease in trends for treatments that contained sodium metasilicate over storage time. This may be due to the production of various acid compounds by spoilage bacteria (Ruiz, 2007). The microorganisms initially metabolized the glucose as energy, and later broke down small compounds, such as amino acid. The metabolic processes resulted in the muscle meat pH value decreasing. Liu et al. (2004) also reported that the pH values declined through storage times. The complex biochemical reactions could lead to decrease in pH values. Decreasing ($P < 0.05$) in pH values were observed for 2% sodium metasilicate treatment on days 6 and 7, and for 3% and 4% sodium metasilicate treatments on day 9, when compared to day 0 pH values.

Water-Holding Capacity Analyses

Water-holding capacity with sodium chloride.

The WHC values were expected to increase, as the pH values of fillets increased. In this study, the WHC of fillets measured with sodium chloride had no significant difference ($P > 0.05$) among treatments and over storage periods (Table 4-24).

Water-holding capacity with distilled water.

On day 1, the fillets treated with 3% sodium metasilicate had significantly higher ($P < 0.05$) WHC than fillets treated with 1% sodium metasilicate (Table 4-24). On day 3, the fillets treated with 1% and 3% sodium metasilicate had significantly higher ($P < 0.05$) WHC values than control fillets. On day 7, the fillets treated with 4% sodium metasilicate had significantly higher ($P < 0.05$) values than other fillets treated with sodium

metasilicate. Except for day 3, the values for fillets treated with 1% sodium metasilicate treatments had similar ($P > 0.05$) with control fillets.

Purge Loss Analysis

In general, as storage time increased, the purge loss percentages for all treatments increased (Table 4-25). The purge loss values were similar ($P > 0.05$) among all treatments for 7 days storage. On day 9, the purge loss of 3% and 4% sodium metasilicate treatments were significantly lower ($P < 0.05$) than all other treatments.

Cooking Yield Analysis

On day 0, the cooking yields for fillets treated with 3% sodium metasilicate were significantly higher ($P < 0.05$), when compared to all other treatments (Table 4-26). On day 1, the cooking yields for all treatments were similar ($P > 0.05$). On day 3, the cooking yields for fillets treated with 3% and 4% sodium metasilicate were higher ($P < 0.05$) than control fillets and fillets treated with 1% sodium metasilicate. On day 5, the cooking yield for fillets treated with 3% and 4% sodium metasilicate were higher ($P < 0.05$) than all other treatments. On day 6, the cooking yields for fillets treated with 3% were higher ($P < 0.05$) than control fillets and fillets treated with 4% sodium metasilicate. The results indicated that the cooking yields for fillets treated with 3% sodium metasilicate were higher through all storage days except for day 0.

Microbiological Analysis

In general, the total psychrotrophic counts increased as the storage time increased for all treatments (Table 4-27). When the concentrations of antimicrobials increased, the effectiveness of its properties increased. The total psychrotrophic counts for fillets treated with 4% sodium metasilicate treatment were significantly lower ($P < 0.05$) than

control fillets and fillets treated with 1% sodium metasilicate through 9 days storage. Except for day 0, there were no significant difference ($P > 0.05$) among control fillets and fillets treated with 1% and 2% sodium metasilicate through 9 days storage. Except for day 7, there was no significant difference ($P > 0.05$) among fillets treated with 3% and 4% sodium metasilicate over storage time. Except for fillets treated with 2% sodium metasilicate, the total psychrotrophic counts were similar ($P > 0.05$) for all treatments, when compared to the initial day and day 1. From day 1 to day 5, the growth rate of microbial accelerated for all treatments. On day 5, the control fillets and the fillets treated 1% and 2% sodium metasilicate reached 8 log cfu/g, therefore, the samples were spoiled. On day 6, the fillets for all treatments were spoiled. The results indicated that the 3% and 4% sodium metasilicate treatments were effective to extend two additional days for shelf life, when compared to control, 1% and 2% treatments.

When the means of the two trials were compared in phase III study, the total psychrotrophic counts for the two trials were similar ($P > 0.05$) on day 0, but after day 3, the total psychrotrophic counts for the two trials were higher by an average of 1- 2 log cfu/g units than preliminary study through 7 days storage. Results from this study suggested that the initial population of total psychrotrophic organisms was similar, but the storage condition, handling of samples and incubation conditions may have contributed to the acceleration of microbial growth.

Objective Color Measurement

Raw fillet color.

L* value. On the initial day, the color of fillets treated with 2% sodium metasilicate were darker ($P < 0.05$), when compared to control fillets, and similar with the remaining sodium metasilicate treatments (Table 4-28). On day 3, the color of fillets treated with

2% and 4% sodium metasilicate were darker ($P < 0.05$), when compared to control fillets, and similar ($P > 0.05$) to other fillets treated with sodium metasilicate. On day 6, the color of fillets treated with 3% sodium metasilicate were lighter ($P < 0.05$) than control fillets and no significant differences ($P > 0.05$) were observed among all other fillets treated with sodium metasilicate. On day 7, the fillets treated with 2%, 3% and 4% sodium metasilicate were lighter ($P < 0.05$) than control fillets and no significant differences ($P > 0.05$) were observed between control fillets and fillets treated with 1% sodium metasilicate. On day 9, the fillets treated with 4% sodium metasilicate had higher L* values ($P < 0.05$) than fillets treated with 1% sodium metasilicate. The control fillets and fillets treated with 1% sodium metasilicate had similar ($P > 0.05$) over 9 storage days. The remaining fillets treated with sodium metasilicate were similar color over 9 storage days.

The data indicated that the L* values for all treatments decreased as storage time increased, when compared with day 0 and day 9. However, the greatest difference in L* values change was observed in the control fillets. The L* values for control fillets were similar ($P > 0.05$) through 3 days storage. From day 1 to day 3, the fillets treated with 1% sodium metasilicate increased 3 log units for total psychrotrophic counts. The significantly L* values change for fillets treated with 1% sodium metasilicate may be due to the drastic microbial growth after day 3. It was possible that the onset of spoilage in the meat was on day 5 (control, 1%, and 2%) and on day 6 (3% and 4%). The bacteria may have produced pigments on the meat surface. The data indicated that the microbial counts increased 2 log units from day 3 to day 5, which might also explain the L* values of control fillets changing after day 3. Therefore, sodium metasilicate could cause color

of fillets to become darker on the first three days storage, and also could maintain the L* values for fillets treated with 3% and 4% sodium metasilicate treatments after day 3.

a* values: The fillets treated with sodium metasilicate had similar ($P > 0.05$) a* values, when compared to control fillets over 6 days storage (Table 4-29). After day 6, the control fillets were redder ($P < 0.05$) than all fillets treated with sodium metasilicate. As storage time increased, the control fillets became redder. This may be explained that as the storage time increased, the purge loss increased and the concentration of myoglobin on the surface of the meat increased.

b* values: As storage time increased, the b* values increased (Table 4-30). Except for day 0 and day 9, the b* values for fillets treated with 3% and 4% sodium metasilicate were lower than ($P < 0.05$) than control fillets through storage days. The results demonstrated that the sodium metasilicate could retard the yellowness development, when compared to control fillets.

Cooked fillet color

L* value. On day 0, the control fillets and fillets treated with 1% sodium metasilicate were lighter ($P < 0.05$), when compared to fillets treated with 4% sodium metasilicate, and were similar ($P > 0.05$) with remaining fillets (Table 4-31). On day 1, the control fillets and fillets treated with 1% sodium metasilicate were lighter ($P < 0.05$), when compared with remaining fillets treated with sodium metasilicate. On day 5, the control fillets and fillets treated with 4% sodium metasilicate were darker ($P < 0.05$), when compared to fillets treated with 3% sodium metasilicate.

a* value. The a* values were similar among control fillets and fillets treated with 1% sodium metasilicate through 6 days storage (Table 4-31). Also the a* values were similar ($P > 0.05$) among fillets treated with 2% ,3% and 4% sodium metasilicate

through 6 days storage. The fillets treated with 4% sodium metasilicate were redder ($P < 0.05$) than control fillets on day 0 and day 3.

b* values. Except for day 5, the b* values were similar ($P > 0.05$) for control fillets and fillets treated with 1% sodium metasilicate through 6 days storage (Table 4-31). Also the b* values were similar ($P > 0.05$) among fillets treated with 2%, 3% and 4% sodium metasilicate through 6 days storage.

Several studies reported that there was significantly negative correlation between the raw breast meat lightness (L*) and pH value (Allen et al., 1998). Allen et al. (1998) reported that samples marinated with a solution containing 3% sodium tripolyphosphate (STPP) and 7% sodium chloride had significantly higher L* (lightness) values and lower a* (redness) values and b* (yellowness) values ,when compared to control samples. Some researchers reported that samples marinated with 1% and 2% trisodium phosphate had lower L* and higher a* values. Some studies reported that no color differences were observed ($P > 0.05$) after meat was treated with sodium tripolyphosphate (STPP). Some results reported that still marination with sodium polyphosphate solution had higher L* (lightness) values for raw meat color. All of these studies reported that the color changed after the meat was marinated with an alkaline solution.

Warner-Bratzler Shear Force Analysis

Except day 1, no significant differences for Warner-Bratzler shear force values were detected among all treatments through 6 days storage (Table 4-32). On day 1, the control fillets and fillets treated with 4% sodium metasilicate were lower ($P < 0.05$), when compared to fillets treated with 1%, 2% and 3% sodium metasilicate. Lyon and Lyon (1991) reported that Warner-Bratzler shear force values less than 3.62 kg for

chicken breast meat were indicative of “very tender” meat. The Warner-Bratzler shear force values for all treatments ranged from 1.82 kg to 2.86 kg, which was indicative of very tender breast meat. The corresponding panelist scores were “moderately tender” to “extremely tender” meat.

Sensory Evaluation

Juiciness

On day 0, the fillets treated with 3% and 4% sodium metasilicate were juicier ($P < 0.05$) when compared to the other treatments (Table 4-33). Based on the responses of the panelists, on day 0, fillets treated with 1% sodium metasilicate were “slight dry” on day 0. The control fillets and fillets treated with1% and 2% sodium metasilicate were “slight dry” to “slight dry” “slight juicy”. The fillets treated with 3% and 4% sodium metasilicate were “moderately juicy”. Except for day 0, fillets for all treatments had similar ($P > 0.05$) juiciness over 6 day storage. As storage time increased, the fillets treated with 3% and 4% sodium metasilicate were similar ($P > 0.05$) over 6 days storage.

Chicken flavor intensity

Except for day 0, the chicken flavor intensity for all treatments was similar ($P > 0.05$) through 6 days storage (Table 4-34). On day 0, the chicken flavor intensity for fillets treated with 3% sodium metasilicate were higher ($P < 0.05$), when compared to fillets treated with 1% sodium metasilicate, and were similar ($P > 0.05$) with control fillets and other fillets treated with sodium metasilicate.

Tenderness

Except for day 1, the tenderness of fillets in all treatments was similar ($P > 0.05$) through 6 days storage (Table 4-34). On day 1, the fillets treated with 2% sodium

metasilicate were more tender ($P < 0.05$) when compared to control fillets. Lyon and Lyon (1991) reported that there is a relationship between the objective shear forces values and subjective sensory tests for tenderness in broiler chicken breast meat.

Off-flavor

None of the treatments developed off-flavor during 6 days of storage. All values were on the range of “barely detected” (score of 5) to “none detected” (score of 6).

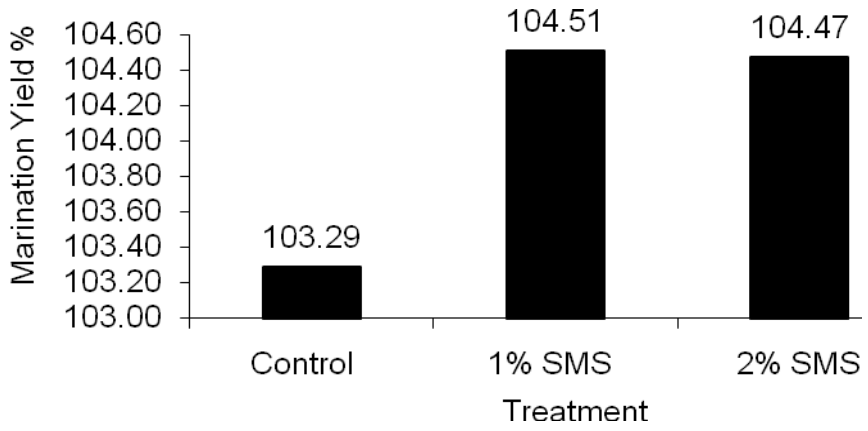

Figure 4-1. Marination yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

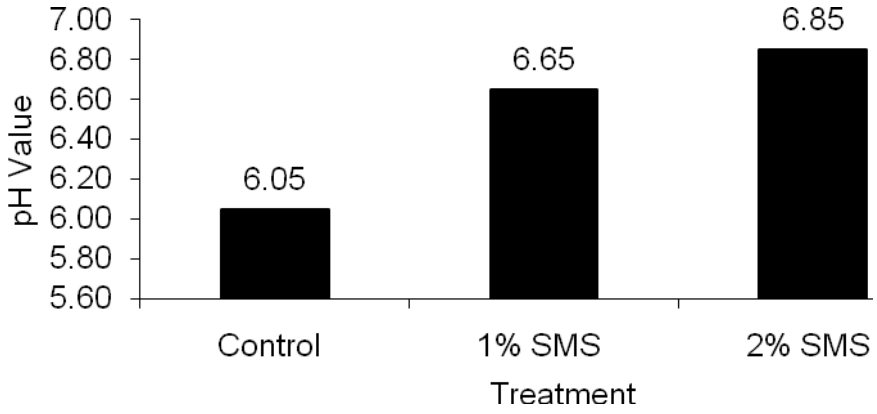

Figure 4-2. pH value for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

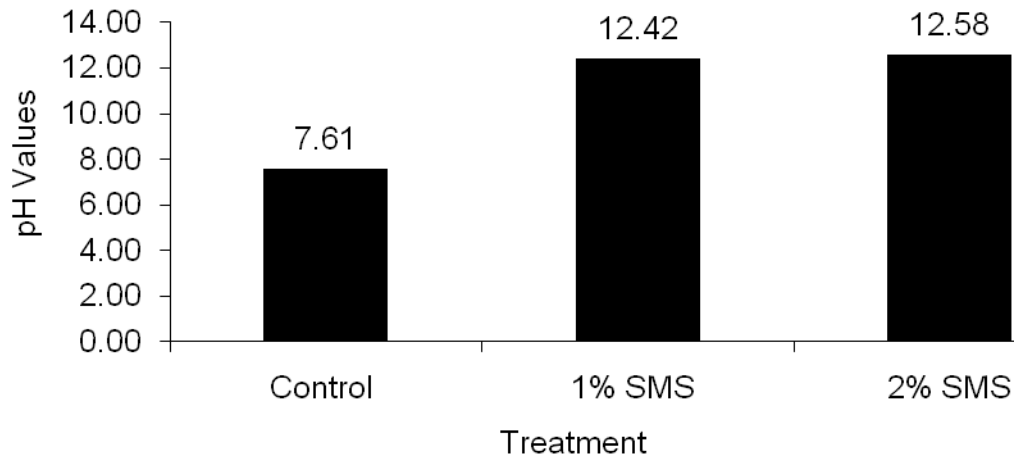

Figure 4-3. pH of marinade solutions for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

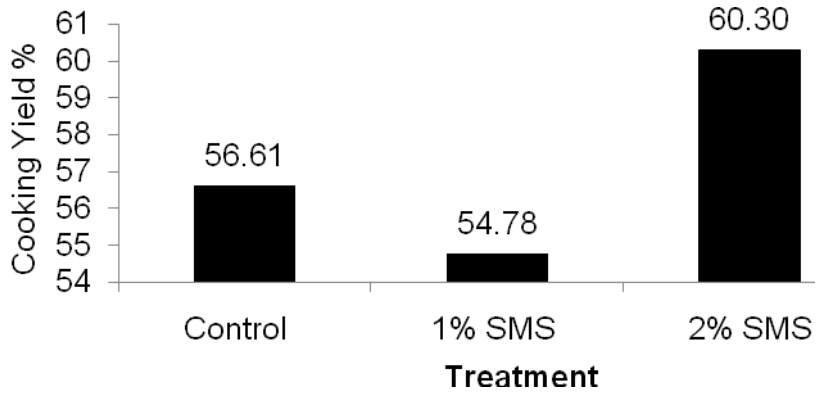

Figure 4-4. Cooking yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

Table 4-1. Total psychrotrophic counts for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

Treatment	Dilution	A1	A2	B1	B2
Control	0.10	TNTC	TNTC	TNTC	TNTC
	0.01	250	252	377	332
1% SMS	0.10	TNTC	TNTC	TNTC	TNTC
	0.01	291	TNTC	TNTC	TNTC
2% SMS	0.10	TNTC	TNTC	TNTC	TNTC
	0.01	TNTC	TNTC	84	86

Colony numbers between 25- 250 was counted;
TNTC = Colonies over 250 and it was too numerous to count;
SMS = Sodium metasilicate.

Table 4-2. Meat color measurement for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

	Attribute					
Treatment	Raw L*	Raw a*	Raw b*	Cooked L*	Cooked a*	Cooked b*
Control	58.48	7.27	14.62	82.15^{b}	2.03	17.20
1% SMS	63.35	5.73	16.03	84.45^{a}	1.62	16.61
2% SMS	61.20	6.51	17.22	79.59^{c}	2.03	16.34
SEM	2.52	2.32	1.73	1.06	0.50	1.21

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
n = 3 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-3. Sensory evaluation and Warner-Bratzler shear force for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

	Attribute				
Treatment	Juiciness	Chicken flavor Intensity	Tenderness	off-flavor	Warner-Bratzler shear force, Kg
Control	5.00	6.50	5.50	5.50	6.41
1% SMS	4.00	6.00	5.50	4.50	6.06
2% SMS	4.00	6.00	5.00	4.50	7.41
SEM	1.15	0.91	0.58	0.71	1.48

n = 7 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

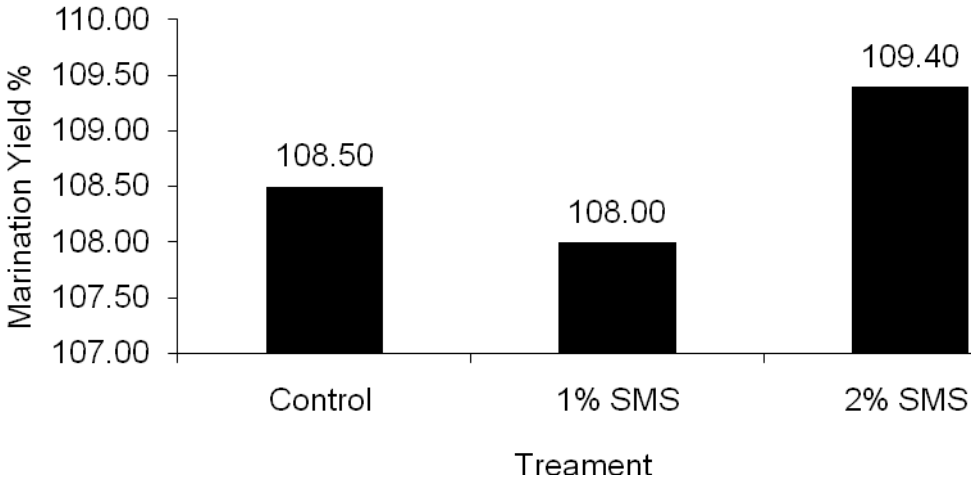

Figure 4-5. Marination yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

Table 4-4. pH measurement for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time				
Attribute	Treatment	d 0	d 1	d 3	d 6	SEM
pH	Control	$6.00^{c,x}$	$6.15^{b,x}$	$6.01^{c,x}$	$6.03^{b,x}$	0.10
	1% SMS	$6.46^{b,x}$	$6.38^{b,x}$	$6.38^{b,x}$	$5.98^{b,y}$	0.10
	2% SMS	$6.84^{a,xy}$	$7.04^{a,x}$	$6.62^{a,yz}$	$6.39^{a,z}$	0.11
	SEM	0.08	0.14	0.07	0.11	

[a-c] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-z] Means in same row with different superscripts differ significantly ($P < 0.05$);
n = 3 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

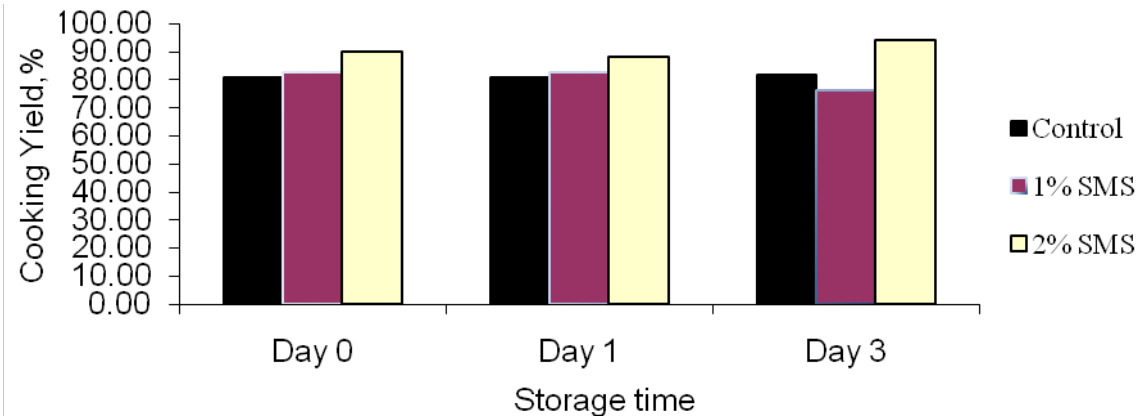

Figure 4-6. Cooking yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

Table 4-5. Total psychrotrophic counts for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time				
Attribute	Treatment	d 0	d 1	d 3	d 6	SEM
TPC, log cfu/g	Control	$6.55^{a,y}$	$6.43^{a,y}$	$6.77^{a,y}$	$8.82^{a,x}$	0.23
	1% SMS	$5.02^{b,z}$	$5.34^{b,z}$	$6.57^{a,y}$	$7.53^{c,w}$	0.29
	2% SMS	$4.51^{b,z}$	$5.35^{b,y}$	$6.73^{a,x}$	$8.24^{b,w}$	0.15
	SEM	0.17	0.21	0.32	0.18	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
n = 4 values per mean; TPC = Total psychrotrophic counts
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-6. Objective raw meat color for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 3 days

		Storage time			
Attribute	Treatment	d 0	d 1	d 3	SEM
L*	Control	$62.78^{a,x}$	$61.19^{a,x}$	$59.70^{b,x}$	2.85
	1% SMS	$55.60^{a,y}$	$65.00^{a,x}$	$61.62^{a,x}$	1.94
	2% SMS	$57.06^{a,x}$	$61.69^{a,x}$	$62.28^{a,x}$	3.66
	SEM	4.44	2.27	0.67	
a*	Control	$3.82^{b,x}$	$4.96^{a,x}$	$6.21^{a,x}$	1.18
	1% SMS	$11.01^{a,x}$	$5.66^{a,y}$	$6.79^{a,xy}$	2.09
	2% SMS	$6.99^{ab,x}$	$7.54^{a,x}$	$6.56^{a,x}$	0.85
	SEM	2.11	1.30	0.69	
b*	Control	$12.48^{a,y}$	$14.99^{b,y}$	$18.90^{a,x}$	1.55
	1% SMS	$16.70^{a,x}$	$15.31^{ab,x}$	$16.64^{a,x}$	2.31
	2% SMS	$14.67^{a,x}$	$17.79^{a,x}$	$16.06^{a,x}$	2.52
	SEM	2.55	1.26	2.46	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
n = 3 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-7. Objective cooked meat color for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 3 days

		Storage time			
Attribute	Treatment	d 0	d 1	d 3	SEM
Cooked L*	Control	$84.25^{a,x}$	$84.03^{a,x}$	$79.62^{a,y}$	1.61
	1% SMS	$80.76^{b,y}$	$84.13^{a,x}$	$79.95^{a,y}$	1.45
	2% SMS	$82.53^{ab,x}$	$84.09^{a,x}$	$79.15^{a,y}$	1.36
	SEM	1.30	1.28	1.79	
Cooked a*	Control	$1.15^{b,y}$	$2.03^{a,x}$	$1.85^{a,x}$	0.33
	1% SMS	$2.62^{a,x}$	$1.74^{ab,x}$	$1.73^{a,x}$	0.71
	2% SMS	$2.58^{a,x}$	$1.23^{b,y}$	$2.13^{a,x}$	0.31
	SEM	0.64	0.35	0.41	
Cooked b*	Control	$16.07^{b,x}$	$16.38^{a,x}$	$15.79^{a,x}$	0.68
	1% SMS	$18.96^{a,x}$	$17.04^{a,xy}$	$15.60^{a,y}$	1.03
	2% SMS	$16.17^{b,x}$	$15.85^{a,x}$	$17.74^{a,x}$	0.99
	SEM	0.94	0.71	1.05	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
n = 3 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-8. Warner-Bratzler shear force for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 3 days

		Storage time			
Attribute	Treatment	d 0	d 1	d 3	SEM
Warner-Bratzler shear force, Kg	Control	$1.65^{a,y}$	$2.07^{a,x}$	$1.68^{b,y}$	2.27
	1% SMS	$1.83^{a,x}$	$2.25^{a,x}$	$1.68^{b,x}$	0.47
	2% SMS	$1.63^{a,x}$	$2.20^{a,x}$	$2.12^{a,x}$	0.36
	SEM	0.33	0.51	0.24	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-9. Panelist rating for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 3 days

		Storage time			
Attribute	Treatment	d 0	d 1	d 3	SEM
Juiciness	Control	$5.88^{b,x}$	$5.29^{a,x}$	$5.20^{ab,x}$	1.27
	1% SMS	$6.88^{a,x}$	$5.86^{a,x}$	$5.80^{a,x}$	1.01
	2% SMS	$7.13^{a,x}$	$5.57^{a,y}$	$4.00^{b,z}$	1.12
	SEM	0.71	1.33	1.36	
Chicken Flavor	Control	$5.75^{a,xy}$	$4.71^{a,y}$	$6.40^{a,x}$	1.11
	1% SMS	$5.50^{a,x}$	$5.14^{a,x}$	$6.20^{a,x}$	1.28
	2% SMS	$5.38^{a,x}$	$4.71^{a,x}$	$6.00^{a,x}$	1.36
	SEM	1.40	1.45	0.63	
Tenderness	Control	$6.88^{a,xy}$	$6.14^{a,y}$	$7.20^{a,x}$	0.83
	1% SMS	$7.13^{a,x}$	$6.57^{a,x}$	$7.20^{a,x}$	0.98
	2% SMS	$7.63^{a,x}$	$6.86^{a,x}$	$7.60^{a,x}$	0.81
	SEM	0.86	1.04	0.67	
Off-flavor	Control	$5.75^{a,x}$	$5.29^{a,x}$	$6.00^{a,x}$	0.80
	1% SMS	$5.88^{a,x}$	$5.71^{a,x}$	$6.00^{a,x}$	0.36
	2% SMS	$5.63^{a,x}$	$5.57^{a,x}$	$6.00^{a,x}$	0.80
	SEM	0.70	0.90	0.00	

[a-b] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-y] Means in same row with different superscripts differ significantly ($P < 0.05$);
n=10 values per mean; Sensory scale: Eight-point sensory scale for juiciness, chicken flavor and tenderness where 8 = extremely juicy/intense/tender, 7 = very juicy/intense/tender, 6 = moderately juicy/intense/tender, 5 = slightly juicy/intense/tender, 4 = slightly dry/bland/tough, 3 = moderately dry/bland/tough, 2 = very dry/bland/tough, 1 = extremely dry/bland/tough. A six-point scale for off-flavor where 6 = none detected, 5 = threshold, barely detected, 4 = slight off-flavor, 3 = moderate off-flavor, 2 = strong off-flavor, 1 = extreme off-flavor;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

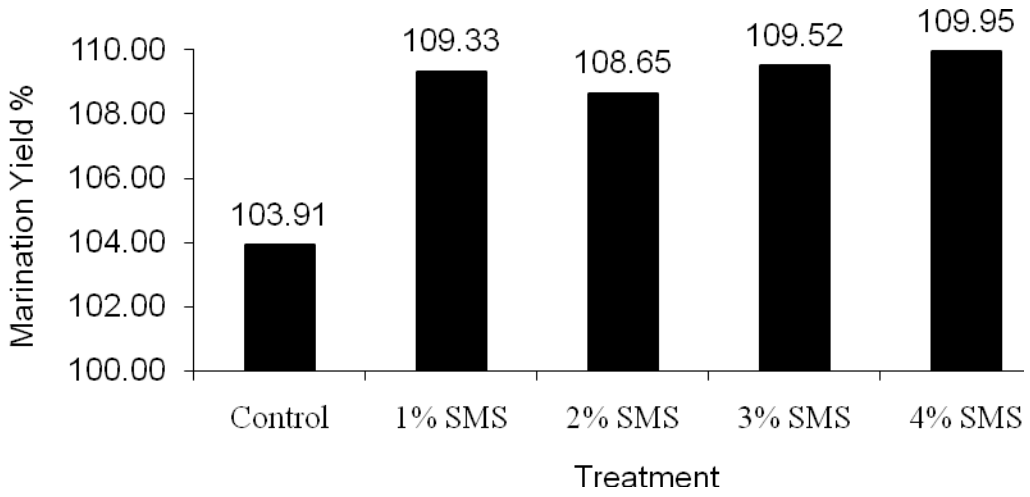

Figure 4-7. Marination yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

Table 4-10. pH measurement for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
pH	Control	$6.55^{b,x}$	$6.56^{c,x}$	$6.30^{c,z}$	$6.45^{c,y}$	$6.39^{d,y}$	$6.22^{c,z}$	0.11
	1% SMS	$6.86^{b,x}$	$6.69^{c,xy}$	$6.62^{c,xy}$	$6.65^{c,xy}$	$6.46^{d,y}$	$6.63^{b,xy}$	0.10
	2% SMS	$7.07^{b,x}$	$6.91^{b,x}$	$6.91^{ab,x}$	$6.78^{ab,x}$	$6.70^{c,x}$	$6.75^{b,x}$	0.16
	3% SMS	$7.36^{ab,x}$	$7.31^{a,x}$	$7.09^{a,x}$	$7.08^{ab,x}$	$6.89^{b,x}$	$6.90^{ab,x}$	0.22
	4% SMS	$8.00^{a,x}$	$7.43^{a,y}$	$7.06^{a,y}$	$7.16^{a,y}$	$7.30^{a,y}$	$7.11^{a,y}$	0.21
	SEM	0.31	0.08	0.13	0.13	0.03	0.12	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

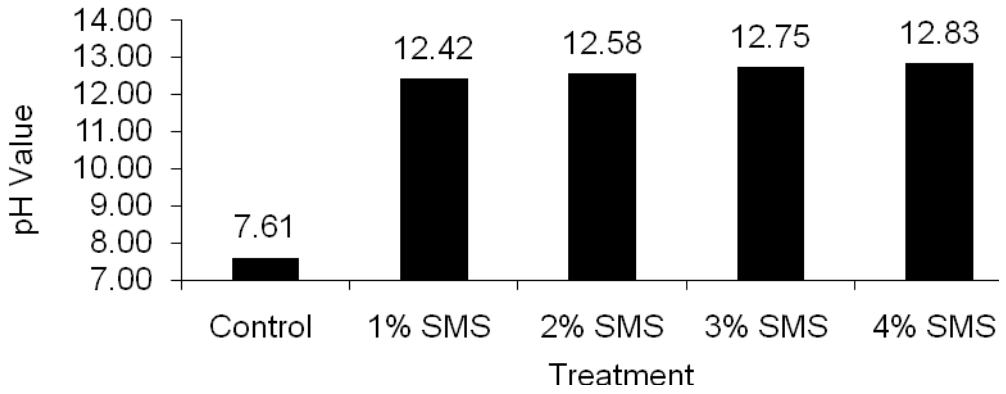

Figure 4-8. Marinade solution of pH for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C on day 0

Table 4-11. Water-holding capacity percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days: WHC with sodium chloride

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
WHC-NaCl, %	Control	117.14^{a,x}	131.52^{a,x}	92.77^{a,x}	142.99^{a,x}	134.99^{c,x}	119.02^{b,x}	32.69
	1% SMS	148.86^{a,x}	142.98^{a,x}	142.78^{a,x}	148.52^{a,x}	147.41^{ab,x}	145.57^{a,x}	2.55
	2% SMS	130.39^{a,x}	153.39^{a,x}	143.05^{a,x}	143.16^{a,x}	142.55^{abc,x}	142.13^{a,x}	13.43
	3% SMS	147.03^{a,w}	144.08^{a,xy}	146.65^{a,wx}	143.72^{a,y}	140.16^{bc,z}	140.10^{ab,z}	2.84
	4% SMS	144.55^{a,x}	149.82^{a,x}	148.51^{a,x}	152.33^{a,x}	152.19^{a,x}	139.33^{ab,x}	8.48
	SEM	19.83	13.25	29.40	8.56	4.12	8.14	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{w-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 2 values per mean;
WHC = Water-holding capacity; NaCl = Sodium chloride;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-12. Water-holding capacity percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days: WHC with distilled water only

		Storage time				
Attribute	Treatment	3 d[1]	5 d	7 d	9 d	SEM
WHC water, %	Control	$35.76^{a,xy}$	$29.94^{b,xy}$	$62.50^{a,x}$	$17.74^{c,y}$	12.76
	1% SMS	$33.25^{a,yz}$	$56.37^{a,x}$	$48.79^{ab,xy}$	$18.44^{c,z}$	6.65
	2% SMS	$39.72^{a,x}$	$52.97^{ab,x}$	$31.09^{b,x}$	$25.28^{bc,x}$	13.21
	3% SMS	$28.75^{a,y}$	$52.97^{ab,x}$	$57.88^{ab,x}$	$36.44^{ab,y}$	2.84
	4% SMS	$58.39^{a,x}$	$36.85^{ab,x}$	$58.63^{ab,x}$	$42.35^{a,x}$	10.32
	SEM	12.45	8.96	11.43	5.56	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
1 the data were available from day 3; n = 2 values per mean;
WHC = Water-holding capacity; NaCl = Sodium chloride;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

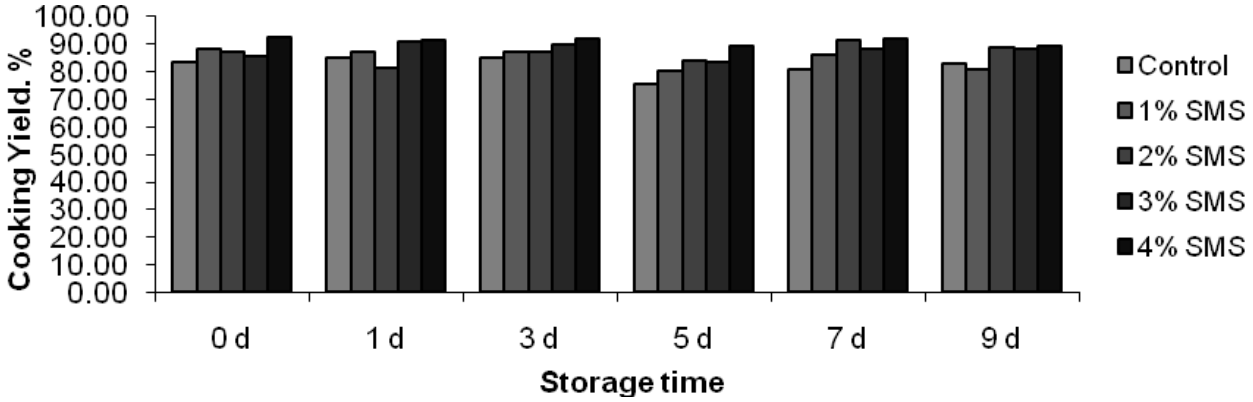

Figure 4-9. Cooking yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

Table 4-13. Total psychrotrophic counts for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
TPC, log cfu/g	Control	$3.91^{a,z}$	$4.21^{a,yz}$	$4.59^{ab,y}$	$6.48^{a,x}$	$7.93^{a,w}$	$8.74^{b,v}$	0.19
	1% SMS	$3.95^{a,z}$	$3.81^{ab,yz}$	$4.97^{a,y}$	$6.19^{ab,xy}$	$7.95^{a,wx}$	$9.11^{a,w}$	1.11
	2% SMS	$2.94^{b,z}$	$3.50^{a,y}$	$4.30^{ab,x}$	$5.53^{bc,w}$	$7.75^{a,v}$	$8.72^{b,u}$	0.22
	3% SMS	$^{1}0.00^{c,z}$	$0.00^{b,z}$	$3.93^{b,y}$	$5.15^{c,x}$	$6.51^{b,w}$	$8.12^{c,v}$	0.29
	4% SMS	$0.00^{c,z}$	$0.00^{b,z}$	$2.94^{c,y}$	$3.99^{d,x}$	$6.29^{b,w}$	$8.01^{c,v}$	0.19
	SEM	0.22	1.21	0.28	0.26	0.23	0.11	

$^{a-d}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{u-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
1 Means the plates counts fewer than 25 cfu, the counts from plates less than 2500/g.
TPC = Total psychrotrophic counts
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-14. Objective raw meat color L* values on boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
L*	Control	$62.65^{a,x}$	$61.27^{a,xy}$	$60.07^{a,xy}$	$58.44^{a,y}$	$61.45^{a,xy}$	$57.83^{a,y}$	1.99
	1% SMS	$62.23^{ab,x}$	$57.00^{a,yz}$	$63.04^{a,x}$	$55.39^{b,z}$	$60.43^{a,xy}$	$54.92^{a,z}$	2.38
	2% SMS	$60.94^{ab,x}$	$57.65^{a,x}$	$49.48^{a,x}$	$55.19^{b,x}$	$58.68^{a,x}$	$58.02^{a,x}$	7.25
	3% SMS	$58.98^{b,x}$	$56.64^{a,x}$	$58.69^{a,x}$	$56.56^{ab,x}$	$59.55^{a,x}$	$56.92^{a,x}$	2.21
	4% SMS	$60.75^{ab,x}$	$60.12^{a,x}$	$60.65^{a,x}$	$56.57^{ab,x}$	$57.42^{a,x}$	$57.28^{a,x}$	2.32
	SEM	1.85	2.48	7.83	1.49	2.77	2.50	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-15. Objective raw meat color a* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
a*	Control	$5.30^{ab,yz}$	$6.49^{a,xyz}$	$7.37^{a,x}$	$6.40^{a,xyz}$	$4.92^{b,z}$	$6.99^{a,xy}$	0.99
	1% SMS	$6.18^{a,x}$	$6.77^{a,x}$	$6.23^{a,x}$	$6.85^{a,x}$	$6.71^{ab,x}$	$7.51^{a,x}$	1.27
	2% SMS	$5.18^{b,x}$	$6.60^{a,x}$	$6.06^{a,x}$	$7.03^{a,x}$	5.94^{ab}	$5.27^{a,x}$	1.20
	3% SMS	$5.70^{ab,x}$	$6.93^{a,x}$	$6.52^{a,x}$	$6.65^{a,x}$	$7.52^{a,x}$	$7.10^{a,x}$	1.14
	4% SMS	$4.91^{b,z}$	$5.54^{a,yz}$	$5.40^{a,yz}$	$6.58^{a,xy}$	$7.34^{ab,x}$	$7.87^{a,x}$	0.80
	SEM	0.51	1.18	1.02	0.99	1.27	1.39	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-16. Objective raw meat color b* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
b*	Control	$15.79^{ab,y}$	$16.57^{ab,y}$	$16.68^{a,y}$	$18.68^{a,xy}$	$17.12^{a,y}$	$23.15^{a,x}$	2.14
	1% SMS	$16.96^{a,x}$	$18.40^{a,x}$	$17.45^{a,x}$	$17.1^{a,x}$	$18.94^{a,y}$	$19.43^{ab,x}$	1.79
	2% SMS	$13.42^{bc,x}$	$15.98^{ab,x}$	$14.81^{a,x}$	$16.21^{a,x}$	$17.51^{a,x}$	$13.92^{b,x}$	2.80
	3% SMS	$14.54^{abc,x}$	$13.84^{ab,x}$	$15.78^{a,x}$	$16.12^{a,x}$	$17.66^{a,x}$	$18.92^{ab,x}$	2.65
	4% SMS	$12.48^{c,y}$	$14.69^{b,xy}$	$14.47^{a,xy}$	$15.23^{a,xy}$	$16.20^{a,xy}$	$17.49^{ab,x}$	2.09
	SEM	1.69	2.22	1.93	1.79	2.78	3.13	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-17. Objective cooked meat color L* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
L*	Control	$62.65^{a,x}$	$61.27^{a,xy}$	$60.07^{a,xy}$	$58.44^{a,y}$	$61.45^{a,xy}$	$57.83^{a,y}$	1.99
	1% SMS	$62.23^{ab,x}$	$57.00^{a,yz}$	$63.04^{a,x}$	$55.39^{b,z}$	$60.43^{a,xy}$	$54.92^{a,z}$	2.38
	2% SMS	$60.94^{ab,x}$	$57.65^{a,x}$	$49.48^{a,x}$	$55.19^{b,x}$	$58.68^{a,x}$	$58.02^{a,x}$	7.25
	3% SMS	$58.98^{b,x}$	$56.64^{a,x}$	$58.69^{a,x}$	$56.56^{ab,x}$	$59.55^{a,x}$	$56.92^{a,x}$	2.21
	4% SMS	$60.75^{ab,x}$	$60.12^{a,x}$	$60.65^{a,x}$	$56.57^{ab,x}$	$57.42^{a,x}$	$57.28^{a,x}$	2.32
	SEM	1.85	2.48	7.83	1.49	2.77	2.50	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-18. Objective cooked meat color a* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
a*	Control	$5.30^{ab,yz}$	$6.49^{a,xyz}$	$7.37^{a,x}$	$6.40^{a,xyz}$	$4.92^{b,z}$	$6.99^{a,xy}$	0.99
	1% SMS	$6.18^{a,x}$	$6.77^{a,x}$	$6.23^{a,x}$	$6.85^{a,x}$	$6.71^{ab,x}$	$7.51^{a,x}$	1.27
	2% SMS	$5.18^{b,x}$	$6.60^{a,x}$	$6.06^{a,x}$	$7.03^{a,x}$	$5.94^{ab,x}$	$5.27^{a,x}$	1.2
	3% SMS	$5.70^{ab,x}$	$6.93^{a,x}$	$6.52^{a,x}$	$6.65^{a,x}$	$7.52^{a,x}$	$7.10^{a,x}$	1.14
	4% SMS	$4.91^{b,z}$	$5.54^{a,yz}$	$5.40^{a,yz}$	$6.58^{a,xy}$	$7.34^{ab,x}$	$7.87^{a,x}$	0.8
	SEM	0.51	1.18	1.02	0.99	1.27	1.39	

[a-c] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-z] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-19. Objective raw meat color b* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
b*	Control	$15.79^{ab,y}$	$16.57^{ab,y}$	$16.68^{a,y}$	$18.68^{a,xy}$	$17.12^{a,y}$	$23.15^{a,x}$	2.14
	1% SMS	$16.96^{a,x}$	$18.40^{a,x}$	$17.45^{a,x}$	$17.10^{a,x}$	$18.94^{a,x}$	$19.43^{ab,x}$	1.79
	2% SMS	$13.42^{bc,x}$	$15.98^{ab,x}$	$14.81^{a,x}$	$16.21^{a,x}$	$17.51^{a,x}$	$13.92^{b,x}$	2.8
	3% SMS	$14.54^{abc,x}$	$13.84^{ab,x}$	$15.78^{a,x}$	$16.12^{a,x}$	$17.66^{a,x}$	$18.92^{ab,x}$	2.65
	4% SMS	$12.48^{c,y}$	$14.69^{b,xy}$	$14.47^{a,xy}$	$15.23^{a,xy}$	$16.20^{a,xy}$	$17.49^{ab,x}$	2.09
	SEM	1.69	2.22	1.93	1.79	2.78	3.13	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-20. Warner-Bratzler shear force for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
Warner-Bratzler shear force, Kg	Control	$1.65^{a,x}$	$1.18^{c,y}$	$1.55^{a,xy}$	$1.83^{ab,x}$	$1.54^{a,xy}$	$1.40^{a,xy}$	0.35
	1% SMS	$1.82^{a,xy}$	$1.80^{a,xy}$	$1.70^{a,xy}$	$2.03^{a,x}$	$1.58^{a,xy}$	$1.50^{a,y}$	0.38
	2% SMS	$1.91^{a,x}$	$1.36^{abc,y}$	$1.51^{a,xy}$	$1.58^{b,xy}$	$1.55^{a,xy}$	$1.41^{a,y}$	0.35
	3% SMS	$1.78^{a,x}$	$1.32^{bc,y}$	$1.52^{a,xy}$	$1.69^{ab,xy}$	$1.49^{a,xy}$	$1.62^{a,xy}$	0.31
	4% SMS	$1.53^{a,xy}$	$1.66^{ab,xy}$	$1.53^{a,xy}$	$1.88^{ab,x}$	$1.41^{a,y}$	$1.54^{a,xy}$	0.29
	SEM	0.37	0.36	0.40	0.34	0.30	0.25	

[a-b] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-y] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 6 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-21. Panelist rating for juiciness and chicken flavor intensity for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
Juiciness	Control	$6.83^{ab,x}$	$6.43^{a,xy}$	$6.50^{a,xy}$	$5.29^{a,y}$	$6.33^{a,xy}$	$5.75^{ab,xy}$	1.26
	1% SMS	$6.83^{ab,x}$	$6.86^{a,x}$	$6.33^{a,xy}$	$6.00^{a,xy}$	$6.56^{a,x}$	$4.88^{b,y}$	1.32
	2% SMS	$5.50^{bc,x}$	$5.71^{a,x}$	$7.00^{a,x}$	$6.14^{a,x}$	$6.44^{a,x}$	$6.25^{a,x}$	1.29
	3% SMS	$8.00^{a,x}$	$6.43^{a,y}$	$6.00^{a,y}$	$5.43^{a,y}$	$5.89^{a,y}$	$6.38^{a,y}$	1.21
	4% SMS	$5.17^{c,x}$	$6.29^{a,x}$	$6.00^{a,x}$	$6.14^{a,x}$	$6.33^{a,x}$	$5.50^{ab,x}$	1.20
	SEM	1.20	1.52	1.15	1.40	1.09	1.17	
Chicken Flavor	Control	$6.50^{b,x}$	$6.43^{a,x}$	$6.00^{a,x}$	$5.71^{a,x}$	$5.67^{a,x}$	$5.75^{a,x}$	1.43
	1% SMS	$6.50^{b,x}$	$6.43^{a,x}$	$6.00^{a,x}$	$6.14^{a,x}$	$5.56^{a,x}$	$5.25^{a,x}$	1.43
	2% SMS	$6.33^{b,x}$	$5.86^{a,x}$	$6.00^{a,x}$	$6.14^{a,x}$	$5.22^{a,x}$	$5.38^{a,x}$	1.44
	3% SMS	$8.00^{a,x}$	$6.00^{a,y}$	$5.67^{a,y}$	$5.86^{a,y}$	$5.44^{a,y}$	$5.13^{a.x}$	1.57
	4% SMS	$6.00^{b,x}$	$6.00^{a,x}$	$5.50^{a,x}$	$6.00^{a,x}$	$5.56^{a,x}$	$5.00^{a,x}$	1.63
	SEM	1.03	0.94	0.96	1.59	1.60	2.16	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 10 values per mean;
Sensory scale: Eight-point sensory scale for juiciness, chicken flavor where 8 = extremely juicy/intense, 7 = very juicy/intense, 6 = moderately juicy/intense, 5 = slightly juicy/intense, 4 = slightly dry/bland, 3 = moderately dry/bland, 2 = very dry/bland, 1 = extremely dry/bland;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-22. Panelist rating for tenderness and off-flavor for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time						
Attribute	Treatment	0 d	1 d	3 d	5 d	7 d	9 d	SEM
Tenderness	Control	$7.17^{ab,x}$	$7.29^{a,x}$	$7.50^{a,x}$	$6.71^{a,x}$	$7.00^{a,x}$	$7.13^{a,x}$	1.01
	1% SMS	$6.83^{b,x}$	$7.29^{a,x}$	$7.17^{a,x}$	$7.00^{a,x}$	$7.00^{a,x}$	$6.75^{a,x}$	1.19
	2% SMS	$6.67^{b,x}$	$6.86^{a,x}$	$7.67^{a,x}$	$7.29^{a,x}$	$7.33^{a,x}$	$7.13^{a,x}$	1.01
	3% SMS	$8.00^{a,x}$	$7.14^{a,xy}$	$7.67^{a,xy}$	$6.86^{a,y}$	$7.00^{a,xy}$	$7.38^{a,xy}$	0.91
	4% SMS	$6.33^{b,x}$	$7.14^{a,x}$	$7.17^{a,x}$	$6.86^{a,x}$	$7.11^{a,x}$	$6.88^{a,x}$	1.06
	SEM	0.90	1.15	0.63	1.07	1.08	1.19	
Off-flavor	Control	$6.00^{a,x}$	$5.71^{a,x}$	$6.00^{a,x}$	$6.00^{a,x}$	$5.56^{a,x}$	$5.63^{a,x}$	0.65
	1% SMS	$6.00^{a,x}$	$5.71^{a,x}$	$6.00^{a,x}$	$5.86^{a,x}$	$5.56^{a,x}$	$5.75^{a,x}$	0.57
	2% SMS	$5.67^{a,x}$	$5.57^{a,x}$	$5.83^{a,x}$	$6.00^{a,x}$	$5.78^{a,x}$	$5.75^{a,x}$	0.54
	3% SMS	$6.00^{a,x}$	$5.57^{a,x}$	$5.33^{a,x}$	$6.00^{a,x}$	$5.78^{a,x}$	$5.75^{a,x}$	0.62
	4% SMS	$5.67^{a,x}$	$5.57^{a,x}$	$5.67^{a,x}$	$5.86^{a,x}$	$5.67^{a,x}$	$5.62^{a,x}$	0.64
	SEM	0.52	0.58	0.68	0.24	0.8	0.59	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 10 values per mean;
Sensory scale: Eight-point sensory scale for tenderness where 8 = extremely tender, 7 = very tender, 6 = moderately tender, 5 = slightly tender, 4 = slightly tough, 3 = moderately tough, 2 = very tough, 1 = extremely tough. A six-point scale for off-flavor where 6 = none detected, 5 = threshold, barely detected, 4 = slight off-flavor, 3 = moderate off-flavor, 2 = strong off-flavor, 1 = extreme off-flavor;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

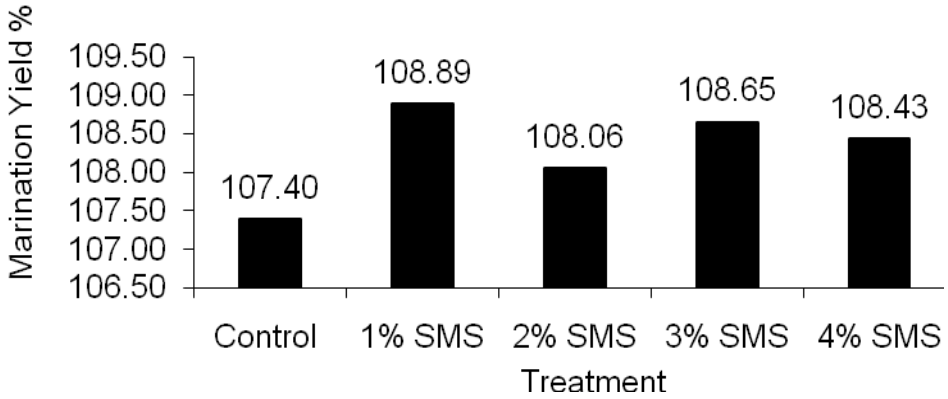

Figure 4-10. Marination yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

Table 4-23. Mean pH measurements for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
pH	Control	$6.29^{b,z}$	$6.57^{c,wxy}$	$6.29^{d,z}$	$6.42^{c,yz}$	$6.44^{c,xyz}$	$6.71^{b,w}$	$6.67^{b,wx}$	0.15
	1% SMS	$6.72^{b,x}$	$6.65^{c,x}$	$6.60^{c,x}$	$6.66^{bc,x}$	$6.57^{c,x}$	$6.75^{b,x}$	$6.70^{b,x}$	0.18
	2% SMS	$7.28^{a,x}$	$7.08^{b,xy}$	$6.99^{b,xy}$	$6.96^{ab,xy}$	$6.75^{bc,y}$	$6.79^{b,y}$	$7.03^{a,xy}$	0.29
	3% SMS	$7.40^{a,x}$	$7.40^{ab,x}$	$7.21^{b,xy}$	$7.08^{a,xy}$	$6.98^{ab,y}$	$7.03^{a,xy}$	$7.00^{a,y}$	0.24
	4% SMS	$7.61^{a,xy}$	$7.69^{a,x}$	$7.71^{a,x}$	$7.27^{a,xyz}$	$7.16^{a,yz}$	$7.22^{a,xyz}$	$6.99^{a,z}$	0.31
	SEM	0.37	0.88	0.16	0.25	0.25	0.14	0.18	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{w-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-24. Mean water-holding capacity percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days: WHC with sodium chloride and distilled water

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
WHC-Nacl, %	Control	144.98	137.17	135.66	146.55	147.17	144.67	146.94	12.30
	1% SMS	143.38	142.49	147.06	147.75	148.85	148.26	147.26	6.56
	2% SMS	149.06	148.25	146.47	146.58	145.11	148.52	146.57	3.66
	3% SMS	148.28	148.07	148.13	144.05	143.14	147.05	149.37	6.54
	4% SMS	147.42	148.24	143.50	144.81	145.78	148.32	147.91	4.64
	SEM	6.85	9.27	13.08	4.63	6.08	2.83	3.27	
WHC-Water,%	Control	$28.04^{a,xy}$	$33.37^{ab,xy}$	$18.44^{b,y}$	$25.78^{a,y}$	$19.50^{a,y}$	$31.57^{ab,xy}$	$42.37^{a,x}$	9.96
	1% SMS	$30.56^{a,xy}$	$24.84^{b,xy}$	$21.41^{a,xy}$	$26.97^{a,xy}$	$19.48^{a,y}$	$25.52^{b,xy}$	$32.29^{a,x}$	7.51
	2% SMS	$34.95^{a,x}$	$28.97^{ab,xy}$	$28.63^{ab,xy}$	$31.14^{a,x}$	$21.32^{a,y}$	$27.54^{b,x}$	$29.20^{a,xy}$	5.62
	3% SMS	$35.93^{a,x}$	$36.56^{a,x}$	$30.69^{a,x}$	$25.45^{a,x}$	$23.29^{a,x}$	$24.90^{b,x}$	$32.47^{a,x}$	8.66
	4% SMS	$40.06^{a,x}$	$35.00^{ab,xy}$	$25.57^{ab,y}$	$33.52^{a,xy}$	$25.25^{a,y}$	$39.60^{a,x}$	$34.24^{a,xy}$	8.27
	SEM	10.83	6.80	6.89	8.03	4.50	6.13	11.36	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
WHC = Water-holding capacity; NaCl = Sodium chloride
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-25. Mean purge loss percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
Purge loss, %	Control	$6.70^{a,x}$	$6.64^{a,x}$	$6.29^{a,x}$	$7.63^{a,x}$	$6.39^{a,x}$	$7.09^{a,x}$	$10.45^{ab,x}$	2.97
	1% SMS	$5.59^{a,x}$	$4.94^{a,x}$	$6.89^{a,x}$	$6.10^{a,x}$	$5.68^{a,x}$	$6.47^{a,x}$	$10.21^{b,x}$	3.55
	2% SMS	$4.75^{a,y}$	$6.20^{a,xy}$	$6.75^{a,xy}$	$6.68^{a,xy}$	$5.64^{a,y}$	$6.57^{a,xy}$	$11.25^{a,x}$	3.35
	3% SMS	$4.17^{a,x}$	$4.94^{a,x}$	$5.11^{a,x}$	$7.17^{a,x}$	$5.53^{a,x}$	$5.32^{a,x}$	$8.68^{c,x}$	3.64
	4% SMS	$4.97^{a,x}$	$4.33^{a,x}$	$4.50^{a,x}$	$5.70^{a,x}$	$4.13^{a,x}$	$5.56^{a,x}$	$8.29^{c,x}$	3.67
	SEM	3.19	3.59	4.20	3.40	3.66	4.14	0.53	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-26. Mean cooking yield percentages for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time					
Attribute	Treatment	0 d	1 d	3 d	[1]5 d	[1]6 d	SEM
Cooking yield, %	Control	$80.35^{bc,xy}$	$80.72^{a,x}$	$74.81^{b,z}$	$75.32^{b,yz}$	$81.24^{c,x}$	2.74
	1% SMS	$79.13^{c,xy}$	$80.77^{a,xy}$	$69.09^{c,z}$	$75.04^{b,yz}$	$85.01^{abc,x}$	4.83
	2% SMS	$86.41^{b,x}$	$80.43^{a,xy}$	$78.83^{ab,y}$	$73.60^{b,y}$	$88.24^{ab,x}$	3.90
	3% SMS	$93.03^{a,x}$	$85.25^{a,yz}$	$81.90^{a,z}$	$86.29^{a,xy}$	$85.93^{a,xy}$	3.28
	4% SMS	$85.66^{b,x}$	$86.96^{a,x}$	$82.38^{a,x}$	$85.22^{a,x}$	$86.81^{bc,x}$	3.13
	SEM	3.92	4.64	2.76	3.94	1.81	

[a-c] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-z] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
[1] on trial II, only 3% and 4% treatments were not spoiled on 5 d and 6 d;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-27. Mean total psychrotrophic counts for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
TPC, log cfu/g	Control	$4.27^{a,z}$	$4.20^{a,z}$	$6.54^{a,y}$	$8.56^{a,x}$	$8.97^{a,wx}$	$9.50^{a,w}$	$9.69^{a,w}$	0.52
	1% SMS	$3.80^{a,z}$	$3.93^{a,z}$	$6.40^{a,y}$	$8.23^{a,x}$	$8.91^{a,w}$	$9.41^{a,w}$	$9.33^{ab,w}$	0.46
	2% SMS	$0.68^{b,z}$	$2.89^{a,y}$	$5.76^{ab,x}$	$8.44^{a,w}$	$8.74^{ab,w}$	$9.44^{a,w}$	$9.38^{ab,w}$	0.96
	3% SMS	$^{1}0.00^{b,z}$	$0.00^{b,z}$	$4.78^{b,y}$	$6.81^{b,x}$	$7.84^{ab,x}$	$9.16^{a,w}$	$9.07^{bc,w}$	0.76
	4% SMS	$0.00^{b,z}$	$0.00^{b,z}$	$4.99^{b,y}$	$6.22^{b,x}$	$8.02^{b,w}$	$8.42^{b,w}$	$8.74^{c,w}$	0.69
	SEM	0.76	1.00	0.77	0.80	0.64	0.31	0.34	

[a-c] Means in same column with different superscripts differ significantly ($P < 0.05$);
[w-z] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
[1] means the plates counts fewer than 25 CFU, the counts from plates less than 2500/g;
TPC = Total psychrotrophic counts;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-28. Mean objective raw meat color L* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
L*	Control	$62.83^{a,w}$	$60.00^{a,wx}$	$59.97^{a,wx}$	$57.08^{a,xy}$	$55.54^{b,yz}$	$52.91^{c,z}$	$55.80^{ab,yz}$	2.11
	1% SMS	$61.57^{ab,w}$	$59.47^{a,wx}$	$57.81^{ab,xy}$	$57.46^{a,xy}$	$56.30^{ab,yz}$	$55.78^{bc,yz}$	$55.44^{b,z}$	1.65
	2% SMS	$59.38^{b,x}$	$58.32^{a,xy}$	$56.61^{b,xy}$	$58.63^{a,xy}$	$57.35^{ab,xy}$	$58.11^{ab,xy}$	$55.33^{ab,y}$	2.39
	3% SMS	$61.00^{ab,x}$	$59.15^{a,x}$	$58.90^{ab,x}$	$58.37^{a,x}$	$58.52^{a,x}$	$60.45^{a,x}$	$58.09^{ab,x}$	2.16
	4% SMS	$60.10^{ab,x}$	$58.42^{a,xy}$	$56.70^{b,y}$	$57.59^{a,xy}$	$56.15^{ab,y}$	$58.69^{ab,xy}$	$58.82^{a,xy}$	2.02
	SEM	1.83	2.20	1.78	2.29	1.75	2.12	2.47	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 16 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-29. Mean objective raw meat color a* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
a*	Control	$4.69^{a,z}$	$5.59^{a,yz}$	$5.82^{a,yz}$	$5.90^{a,yz}$	$6.42^{a,yz}$	$8.70^{a,x}$	$7.01^{a,xy}$	1.22
	1% SMS	$5.38^{a,x}$	$5.79^{a,x}$	$6.88^{a,x}$	$5.14^{a,x}$	$5.70^{a,x}$	$5.64^{b,x}$	$5.82^{ab,x}$	1.23
	2% SMS	$6.23^{a,x}$	$5.63^{a,x}$	$6.29^{a,x}$	$5.31^{a,x}$	$5.56^{a,x}$	$5.09^{b,x}$	$5.47^{ab,x}$	1.24
	3% SMS	$5.29^{a,xy}$	$4.98^{a,xy}$	$5.05^{a,xy}$	$5.89^{a,x}$	$4.79^{a,xy}$	$4.12^{b,y}$	$4.41^{b,xy}$	0.97
	4% SMS	$5.52^{a,x}$	$4.96^{a,xy}$	$6.21^{a,x}$	$5.70^{a,x}$	$5.04^{a,xy}$	$4.73^{b,xy}$	$3.94^{b,y}$	0.96
	SEM	0.98	0.83	1.24	1.14	1.12	1.15	1.38	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-y}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 16 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-30. Mean objective raw meat color b* values for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 9 days

		Storage time							
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	7 d	9 d	SEM
b*	Control	$18.97^{a,z}$	$22.40^{a,yz}$	$24.62^{a,y}$	$25.36^{a,y}$	$26.74^{a,y}$	$33.35^{a,x}$	$27.22^{a,y}$	3.19
	1% SMS	$19.95^{a,z}$	$20.71^{ab,yz}$	$24.16^{a,xyz}$	$22.95^{ab,yz}$	$24.42^{ab,xyz}$	$29.46^{ab,x}$	$25.96^{a,xy}$	3.40
	2% SMS	$20.06^{a,z}$	$19.42^{b,z}$	$21.95^{a,xyz}$	$22.28^{ab,xyz}$	$21.12^{bc,yz}$	$26.31^{ab,x}$	$26.08^{a,xy}$	3.19
	3% SMS	$19.16^{a,xy}$	$16.91^{c,y}$	$17.97^{b,xy}$	$21.06^{bc,xy}$	$18.43^{cd,xy}$	$22.74^{b,x}$	$22.07^{a,x}$	2.93
	4% SMS	$17.11^{a,xy}$	$14.88^{c,y}$	$17.81^{b,xy}$	$17.90^{c,xy}$	$16.77^{d.xy}$	$20.62^{b,x}$	$21.39^{a,x}$	3.12
	SEM	2.54	1.47	2.61	2.48	2.36	5.54	3.54	

$^{a-b}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$); n = 16 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-31. Mean cooked meat color for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time					
Attribute	Treatment	0 d	1 d	3 d	5 d	6 d	SEM
L*	Control	$81.29^{a,x}$	$82.42^{a,x}$	$77.21^{a,x}$	$76.79^{b,x}$	$78.66^{a,x}$	5.17
	1% SMS	$82.00^{a,x}$	$81.98^{a,x}$	$80.47^{a,xy}$	$78.09^{ab,y}$	$79.65^{a,xy}$	1.70
	2% SMS	$79.33^{ab,x}$	$80.58^{b,x}$	$80.70^{a,x}$	$79.13^{ab,x}$	$78.90^{a,x}$	1.68
	3% SMS	$79.58^{ab,x}$	$80.25^{b,x}$	$80.57^{a,x}$	$81.08^{a,x}$	$81.34^{a,x}$	2.21
	4% SMS	$77.73^{b,y}$	$80.11^{b,xy}$	$79.84^{a,xy}$	$79.09^{b,xy}$	$80.80^{a,x}$	1.49
	SEM	2.18	0.92	4.70	1.34	1.84	
a*	Control	$1.78^{b,yz}$	$2.25^{a,yz}$	$1.74^{b,z}$	$3.72^{a,x}$	$2.76^{a,y}$	0.51
	1% SMS	$1.96^{b,x}$	$2.09^{a,x}$	$2.06^{ab,x}$	$2.66^{a,x}$	$3.00^{a,x}$	0.55
	2% SMS	$2.55^{ab,x}$	$2.03^{a,x}$	$2.30^{ab,x}$	$2.84^{a,x}$	$2.69^{a,x}$	0.44
	3% SMS	$2.89^{a,x}$	$2.10^{a,y}$	$2.31^{ab,xy}$	$1.76^{a,y}$	$1.83^{a,y}$	0.44
	4% SMS	$3.00^{a,x}$	$2.13^{a,x}$	$2.59^{a,x}$	$2.16^{a,x}$	$2.30^{a,x}$	0.53
	SEM	0.58	0.46	0.42	0.45	0.55	
b*	Control	$17.61^{b,y}$	$18.45^{a,y}$	$18.09^{a,y}$	$20.73^{a,x}$	$18.08^{a,y}$	1.14
	1% SMS	$19.02^{b,x}$	$17.93^{a,x}$	$18.65^{a,x}$	$18.89^{b,x}$	$18.61^{a,x}$	1.84
	2% SMS	$21.71^{a,x}$	$19.43^{a,xy}$	$19.13^{a,xy}$	$19.91^{ab,xy}$	$18.76^{a,y}$	1.32
	3% SMS	$21.51^{a,x}$	$18.28^{a,yz}$	$19.40^{a,y}$	$19.80^{ab,xy}$	$17.07^{a,z}$	1.33
	4% SMS	$21.88^{a,x}$	$19.47^{a,yz}$	$20.06^{a,y}$	$20.70^{a,xy}$	$18.16^{a,z}$	1.00
	SEM	1.59	1.24	1.48	0.68	1.25	

$^{a-c}$ Means in same column with different superscripts differ significantly ($P < 0.05$);
$^{x-z}$ Means in same row with different superscripts differ significantly ($P < 0.05$);
[1]On trial II, only 3% and 4% treatments were not spoiled on 5 d and 6 d;
n = 24 values per mean;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-32. Mean Warner-Bratzler shear force for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time					
Attribute	Treatment	0 d	1 d	3 d	[1]5 d	[1]6 d	SEM
Warner-Bratzler shear force, Kg	Control	$2.08^{a,y}$	$2.03^{b,y}$	$1.95^{a,y}$	$1.82^{a,y}$	$2.81^{a,x}$	0.27
	1% SMS	$2.17^{a,xy}$	$2.59^{a,xy}$	$2.42^{a,xy}$	$1.96^{a,y}$	$2.86^{a,x}$	0.37
	2% SMS	$2.21^{a,xy}$	$2.66^{a,x}$	$2.31^{a,xy}$	$1.85^{a,y}$	$2.36^{a,xy}$	0.29
	3% SMS	$2.13^{a,x}$	$2.54^{a,x}$	$2.34^{a,x}$	$2.04^{a,x}$	$2.80^{a,x}$	0.57
	4% SMS	$2.25^{a,x}$	$2.15^{b,x}$	$2.28^{a,x}$	$2.20^{a,x}$	$2.26^{a,x}$	0.30
	SEM	0.29	0.20	0.29	0.40	0.73	

[a-b] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-y] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 4 values per mean;
[1]on trial II, only 3% and 4% treatments were not spoiled on 5 d and 6 d;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-33. Panelist rating for juiciness and chicken flavor intensity for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time					
Attribute	Treatment	0 d	1 d	3 d	[1]5 d	[1]6 d	SEM
Juiciness	Control	$4.60^{b,y}$	$5.38^{a,xy}$	$5.92^{a,x}$	$5.09^{a,xy}$	$5.50^{a,xy}$	0.65
	1% SMS	$4.11^{b,y}$	$4.69^{a,xy}$	$6.03^{a,x}$	$5.34^{a,xy}$	$5.63^{a,xy}$	0.80
	2% SMS	$4.51^{b,y}$	$5.02^{a,xy}$	$6.13^{a,x}$	$6.04^{a,x}$	$5.50^{a,xy}$	0.67
	3% SMS	$5.99^{a,x}$	$5.98^{a,x}$	$6.40^{a,x}$	$4.95^{a,x}$	$5.60^{a,x}$	1.05
	4% SMS	$5.69^{a,x}$	$5.08^{a,x}$	$5.92^{a,x}$	$6.36^{a,x}$	$6.50^{a,x}$	0.99
	SEM	0.65	0.96	0.76	1.13	0.90	
Chicken Flavor	Control	$5.08^{ab,x}$	$4.23^{a,x}$	$4.90^{a,x}$	$5.34^{a,x}$	$5.00^{a,x}$	0.98
	1% SMS	$3.90^{b,y}$	$4.88^{a,xy}$	$5.26^{a,xy}$	$5.79^{a,x}$	$5.13^{a,xy}$	0.85
	2% SMS	$4.53^{ab,x}$	$4.58^{a,x}$	$5.35^{a,x}$	$4.59^{a,x}$	$4.75^{a,x}$	0.88
	3% SMS	$6.04^{a,x}$	$5.88^{a,x}$	$5.97^{a,x}$	$5.21^{a,x}$	$4.68^{a,x}$	1.33
	4% SMS	$5.20^{ab,y}$	$5.19^{a,y}$	$5.53^{a,xy}$	$6.63^{a,x}$	$6.29^{a,xy}$	1.09
	SEM	0.42	1.15	0.80	1.10	1.23	

[a-b] Means in same column with different superscripts differ significantly ($P < 0.05$);
x-y means in same row with different superscripts differ significantly ($P < 0.05$); n = 20 values per mean;
Sensory scale: Eight-point sensory scale for juiciness, chicken flavor where 8 = extremely juicy/intense, 7 = very juicy/intense, 6 = moderately juicy/intense, 5 = slightly juicy/intense, 4 = slightly dry/bland, 3 = moderately dry/bland, 2 = very dry/bland, 1 = extremely dry/bland.
[1] on trial II, only 3% and 4% treatments were not spoiled on 5 d and 6 d;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

Table 4-34. Panelist rating for tenderness and off-flavor for boneless and skinless broiler chicken breast meat marinated with sodium metasilicate and stored at 4°C for 6 days

		Storage time					
Attribute	Treatment	0 d	1 d	3 d	[1]5 d	[1]6 d	SEM
Tenderness	Control	5.61^{a,x}	5.48^{b,x}	6.46^{a,x}	7.54^{a,x}	7.13^{a,x}	1.40
	1% SMS	7.84^{a,x}	5.81^{ab,x}	6.08^{a,x}	7.67^{a,x}	7.13^{a,x}	1.33
	2% SMS	7.16^{a,x}	7.33^{a,x}	7.49^{a,x}	7.67^{a,x}	7.13^{a,x}	0.33
	3% SMS	6.93^{a,xy}	7.19^{ab,x}	7.24^{a,x}	6.31^{a,xy}	5.71^{a,y}	0.78
	4% SMS	6.38^{a,x}	6.15^{ab,x}	6.65^{a,x}	6.71^{a,x}	6.40^{a,x}	0.77
	SEM	1.00	1.08	0.98	0.76	0.94	
Off-Flavor	Control	5.29^{a,y}	5.79^{a,x}	5.94^{a,x}	5.25^{b,y}	6.00^{a,x}	0.29
	1% SMS	5.75^{a,x}	5.86^{a,x}	5.69^{a,x}	5.88^{a,x}	5.75^{ab,x}	0.34
	2% SMS	5.70^{a,x}	5.73^{ab,x}	5.81^{a,x}	5.59^{ab,x}	5.38^{b,x}	0.22
	3% SMS	5.63^{a,x}	5.94^{a,x}	5.82^{a,x}	5.83^{a,x}	5.78^{ab,x}	0.29
	4% SMS	5.81^{a,x}	5.52^{b,x}	5.55^{a,x}	5.82^{a,x}	5.81^{ab,x}	0.27
	SEM	0.36	0.17	0.25	0.27	0.27	

[a-b] Means in same column with different superscripts differ significantly ($P < 0.05$);
[x-y] Means in same row with different superscripts differ significantly ($P < 0.05$); n = 20 values per mean;
Sensory scale: Eight-point sensory scale for tenderness where 8 = extremely tender, 7 = very tender, 6 = moderately tender, 5 = slightly tender, 4 = slightly tough, 3 = moderately tough, 2 = very tough, 1 = extremely tough. A six-point scale for off-flavor where 6 = none detected, 5 = threshold, barely detected, 4 = slight off-flavor, 3 = moderate off-flavor, 2 = strong off-flavor, 1 = extreme off-flavor;
[1] on trial II, only 3% and 4% treatments were not spoiled on 5 d and 6 d;
SMS = Sodium metasilicate; SEM = Standard error of the mean.

CHAPTER 5
SUMMARY AND CONCLUSION

Results from this study suggested that the fillets treated with sodium metasilicate had higher marination yield, when compared to control treatment. The pH values of meat after marination with sodium metasilicate increased, and the values of pH were close to neutral point (pH = 7). The water holding capacity measured with sodium chloride for fillets were similar among all treatments through 9 days storage. The water-holding capacity measured with distilled water for fillets treated with 3% and 4% sodium metasilicate were slightly higher than control fillets. The purge loss percentages for all treatments were similar through 7 days storage. The fillets treated with 3% sodium metasilicate had higher cooking yield than control fillets. The fillets treated with 3% and 4% sodium metasilicate had one additional day of shelf life, when compared to control fillets. Fillets treated with 3% sodium metasilicate were darker during the first 3 days of storage, when compared to control fillets. But after day 3, the fillets treated with 3% sodium metasilicate were lighter than control fillets. The fillets treated with 3% and 4% sodium metasilicate were less yellow than control fillets, and had similar red color for all treatments. Based on the panelist responses, the fillets treated with 3% and 4% sodium metasilicate were juicier than control fillets, and no significant differences were observed among all treatments for tenderness, chicken flavor intensity and off-flavor characteristics. No significantly differences were observed for shear force values for all treatments.

The results revealed that USDA approved levels were not effective to improve the meat quality and shelf life. The elevated levels of 3% and 4% sodium metasilicate could extend shelf life to two additional days. The disadvantages of sodium metasilicate

treatments included discoloration (darken) of the fillets, and provided suitable pH values for microbial growth. More work should be conducted to investigate the utilization of sodium metasilicate in hurdle technology to improve the meat quality and shelf life. Hurdle technology would include using sodium metasilicate in combination with other antimicrobials and at higher concentration levels (i.e.) for sodium metasilicate greater than approved level of 2% in marinade solutions.

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BIOGRAPHICAL SKETCH

Huisuo Huang was born in Hebei province in China, in 1981. She received her Bachelor of Science degree in Food Science and Technology with honors from Hebei Normal University of Science & Technology, Qinhuangdao, China in 2005. She worked in Hebei Food Additive Co., LTD. for one and half years after graduated. She started her master's degree in 2009 in Food Science and Human Nutrition at the University of Florida. She conducted her master's research in the Department of Animal Science since August 2009. Her current concentration was Food Safety and Food Microbiology. She earned her Master of Science degree in August 2010. Upon graduation, Huisuo plans to continue doing research in food industries or academy institutes. Her ultimate goal is to accelerate the exchanges and cooperation between China and the United States about economic and trade related with food.