EFFECTS OF BROILER SLAUGHTER BYPRODUCTS, BLEED TIME AND SCALD TEMPERATURE ON POULTRY PROCESSING WASTEWATER

by

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ABSTRACT

The U.S. poultry industry uses an average of 26 L (7 gal) of potable water per broiler during processing. Each step in the process generates byproducts that combine with this water to form the facility's poultry processing wastewater (PPW) stream. While extensive research has been conducted on concentration (mg/L) of constituents in PPW since the 1950s, little data exists on the impact that the various processing byproducts have on PPW as measured by wastewater stream loading (g/kg^{lwt}). Also, little is known about the variation in impact that individual broilers have on PPW. Experiments were conducted to establish the variation in PPW loading, as well as determining which byproducts have the greatest PPW impact and at which points in the slaughter process the greatest impact occurs. Samples of scalder PPW, and feather and viscera rinse PPW were analyzed for common wastewater parameters (e.g., COD, TS, TSS, TVS, and TKN). Results demonstrated that bleeding time, external debris, and transport time of slaughter byproducts in offal flumes significantly increased the organics, solids and nutrient loading in PPW.

INDEX WORDS: Poultry processing, wastewater, blood loss, feathers, viscera, COD, TS, TSS

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B.S., University of Georgia, 2009

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2011

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August 2011

DEDICATION

To my Dad, Mom, Sister, and Fiancée. Thank You for your love and support.

ACKNOWLEDGEMENTS

I would like to thank everyone who contributed to this research. First and foremost is my major professor, Dr. Kiepper. Thank You for your knowledge, support and guidance that you gave me this past two years. Your effort and time is greatly appreciated. A special thanks to Dr. Ritz for helping out with conducting the experiments. I would also like to thank the rest of my committee members, Dr. McDougald, Dr. Ritz, and Dr. Russell for their guidance and support. I would like to thank my colleague and friend, Ebenezer Abboah-Afari, for his support. Another special thanks to Dr. Davis for guiding me in the right direction to Dr. Kiepper's laboratory. Lastly, I would like to thank my family and all my friends for their love and support.

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INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

In a poultry processing plant, water is primary used for scalding, bird washing before and after evisceration, chilling, cleaning, and sanitizing of equipment and facilities [1]. Water is also the primary means used to transport offal out of various processing areas, where it is subsequently screened and separated from the rest of the poultry processing wastewater (PPW) stream [2]. An average of 26 L (7 gal) of potable water per broiler is used during processing [3]; thus, U.S. broiler slaughter plants typically utilize over 5 million L (1.3 million gal) of water daily.

PPW consists of various constituents in the form of organics, particulates and nutrients [4-6]. Organic matter in PPW can be characterized by tests such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and oil and grease (O&G). The particulates present in PPW are measured using tests such as total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS). Nitrogen and phosphorus are the nutrients present in PPW that are of the highest interest [1]. With the steep rise in water usage by U.S. poultry processors, there has also been a corresponding rise in the concentration of organics, particulates and nutrients in (PPW) due to the increasing processing intensity (e.g., increasing number of birds processed per day, line speeds and carcass washing [7].

Extensive research has been conducted establishing the concentration (mg/L) of various pollutants in PPW in operating commercial plants both in isolated streams within plants as well as final effluents [7-9]. However, this research has focused on establishing just the concentration (mg/L) of pollutants in PPW. Very few researchers have attempted to establish the actual mass or 'load' of each pollutant contributed to the PPW stream by a broiler carcass during isolated slaughter operations, which would identify critical byproducts (e.g., blood, external debris, feathers and viscera) and processing operations that have the greatest impact on PPW.

To examine the effects of poultry slaughter byproducts (i.e., blood, external debris, feathers, and viscera) on PPW, two experiments were conducted. The first experiment was conducted to measure the effects of bleed time and scald temperature on individual broiler carcass impacts on PPW, while the second experiment measured the same effects by groups of carcasses. Chapter 2 is devoted to the effects of bleed time and scald temperature on scalder PPW by individual and groups of carcasses. Chapter 3 focuses on effects of bleed time and scald temperature on subsequent feather rinse and viscera rinse PPW by individual and groups of carcasses. The two experiments were also conducted to measure the variation among individual and groups of carcasses impacts on PPW based on bleed time and scald temperature. Effects on PPW were determined by first establishing the concentration (mg/L) of common wastewater analytical parameters (e.g., COD, TS, TSS, TVS and TKN) in experimental PPW samples, and then calculating PPW loadings (i.e., grams/kilogram of live weight) established for each concentration data point. Thesis conclusions are summarized in Chapter 4.

LITERATURE REVIEW

U.S. Poultry Industry

The term poultry refers to a group of avian species that are raised for the consumption of meat and eggs. Poultry includes chicken, turkey, geese, quail, pigeons, and pheasant [10]. However, for the purpose of this thesis, the term poultry is used synonymously with young chickens (i.e., broilers) as defined by the U.S. Department of Agriculture (USDA), which account for over 95% of the 9 billion poultry processed in the U.S. on an annual basis [11]. The poultry industry is one of the most successful sectors of agriculture in the U.S. In a little over 50 years, the broiler industry has changed from being a loose network of fragmented, locally oriented businesses to a highly productive system of vertically integrated companies [12]. The Georgia poultry industry, which began in the mid-1930s, is focused in the northeast section of the state. Today, Georgia has eight major broiler companies that annually process 1.3 to1.4 billion birds, with the largest plant processing 330,000 broilers daily [11, 13]. The vertically integrated operations in the poultry industry can be divided into two broad categories: production and processing. Poultry production involves raising a flock of live birds to a certain age, while processing is the conversion of live birds to food [14]

U.S Poultry Production

The capability of the poultry industry to grow in the U.S. as well as the rest of the world has been attributed to the ability of chickens to adapt to most places in the world, their economic value per unit, their rapid growth rates and generation times. Chicken is the primary source of meat that appears in the diet of people throughout the world. Because chickens can thrive in confinement, they can be hatched year-round and grown in large flocks, rather than as individual animal units. This has made it possible to have mega-poultry production companies [15].

In the 1800s and early 1900s, many U.S. households had backyard flocks of dual-purpose chickens [12]. Dual-purpose chickens are those raised for both meat and egg production [16]. These chickens supplied eggs on an everyday basis, but the meat supplied by processed culled birds was only consumed on weekends and holidays [12]. Backyard flocks were also used for some local retail egg sales and chicken meat was considered as a byproduct [10]. At this point, year-round production of chickens was limited because of two main reasons: 1) the discovery of vitamin D had yet not been made. Vitamin D functions in the development, growth, and maintenance of a healthy skeleton along with maintaining calcium homeostasis. Later vitamin D was used in the poultry diet which allowed for year-round poultry production and 2) the importance of the photoperiod (i.e., the cycle of sunlight and darkness) and how it affects egg production was not yet understood [12, 17].

During the 1920s and 1930s chicken meat production began with the introduction of the 'broiler' – a young immature chicken raised specifically for meat consumption. As a result, broiler production was initiated in places such as the Delmarva Peninsula, Georgia, Arkansas, and New England [12]. Since 1930, advancements made in the fields of management, disease control, genetics, technology, and marketing have made the poultry industry very efficient in producing meat [15].

In the 1940s, the poultry industry saw the inception of feed mills, hatcheries, farms and processors, although these operations were all separate business entities [12]. Chickens were typically sold as a New York dressed bird (i.e., blood and feather removed only). These birds were slaughtered a week to ten days before they were eviscerated. It was believed that the flavor of the meat would change if the bird was eviscerated too soon, and that opening the body cavity would cause bacterial contamination inside the carcass and cause it to spoil more rapidly [15].

In 1942, a broiler processing plant in Illinois was the first to receive approval from the U.S. government for 'online' evisceration. In 1949, the USDA created a voluntary program to grade carcasses to ensure that consumers received high quality meat [12]. During World War II, the demand for poultry within the military increased [18]. After World War II, advances in nutrition, genetics, and health continued to increase the productivity of broilers [19]. The introduction of new technology and better management of confined poultry gave farmers the ability to raise broilers for larger commercial consumption [10]. As an example, during World War II it took 16 weeks and 6 kg of feed to produce a 1.5 kg bird. Today, a bird of the same market weight can be produced in approximately 6 weeks on 3 kg of feed [20].

By the 1950s and 1960s, commercially grown broilers surpassed small flock farm chickens as the number one source of poultry meat in the U.S. In 1950, the introduction of the essential element for the successful modern poultry processing industry occurred – vertical integration [12]. This is a system where a single poultry firm owns several or all the steps of production from breeding through processing [21]. This means that an individual poultry company (i.e., integrator) owns the animals, hatchery, feed mill, slaughter plants and rendering operations in a local area. Traditionally, feed mixing, breeding, hatchery, and processing were done by independent companies. A major advantage of vertical integration is that it maximizes efficiency and uniformity. Vertical integration produces economies of scale by reducing the number of times a component of the production system (e.g., feed, chicks, labor) changes ownership, thereby eliminating the profit margin at each level of change [21]. Since the early 1960s, vertical integration has controlled as much as 90% of broiler production in the U.S [19].

By the mid-1970s, the poultry industry continued to grow with the implementation of nutritional discoveries, disease eradication programs, genetic improvements through traditional breeding, mechanization and automation technologies. By the early 1980s, consumers preferred cut-up and further processed chicken parts as opposed to the traditional whole carcass. In the U.S., chicken consumption surpassed pork consumption in 1985 and beef consumption in 1992 [12]. In 1992, a typical chicken plant produced five times more output than a plant in 1967 and instead of producing whole carcasses, a mixture of traypack, cut-up, deboned meat, nuggets and other further-processed products were produced [22]. In 1996, the USDA required HACCP (i.e., Hazard Analysis and Critical Control Points) be implemented in all large poultry slaughter plants. HACCP seeks to control, reduce or eliminate any biological, chemical or physical hazards that may occur at different points in processing [12]. Between 1935 and 1995, the average weight of a commercial broiler increased by 65%, while the time required to raise a bird to market weight decreased by more than 60% and the amount of feed required to produce a pound of broiler meat (i.e., feed efficiency) decreased by 57% [19].

U.S. Poultry Processing

The main goal of poultry processing is to produce meat for human consumption. Poultry processing is a combination of biology, chemistry, engineering, marketing and economics. Related fields also include waste management, pet food production, and non-food uses of poultry [21]. The average size of a U.S. poultry processing plant has increased dramatically over the years. In 1972 plants with over 400 employees accounted for about 25% of the chicken and turkey output, but by 1992 that number increased to 80%. This shift towards larger plant sizes suggest that economies of scale are important [22].

The basic automated slaughtering process in use in U.S. plants today began in the late 1960s [23]. Poultry processing varies in different countries with regards to both primary whole bird processing (i.e., slaughter, defeathering, evisceration, chilling) and secondary processing (e.g., cut-up, portioning, deboning). In countries where labor cost is high (e.g., U.S.) automation is very high in both primary and secondary processing. However, in countries that can afford labor at a low cost, automation is minimal. Today, a standard processing line handles 8000 birds an hour which is an increase from 7200 in the last few years. When manual evisceration was the norm, processing lines only handled 3600 birds per hour [24].

Primary Processing: Slaughter through Chilling

Primary processing begins when live birds are caught by hand and placed into dump coops that are placed on a truck for transport to a processing facility [16]. After the truck arrives at the plant, the birds are 'dumped' onto a conveyer belt that takes them to the hanging room. The hanging room is traditionally dark with 'black lights' or dim blue light to calm the birds. The birds are then manually hung by their feet onto a shackle line [25].

The first step in humane slaughter of poultry is stunning. Stunning is done prior to killing the bird and renders the bird unconscious to minimize movement in preparation for automated killing [26]. Stunning of poultry is currently accomplished through the use of electrical current or CO_2 gas. Electrical stunning is the most popular method utilized in U.S. plants. During stunning, the head of the bird comes in contact with saline solution (e.g., 1% NaCl) that is electrically charged so that the body of the bird forms an electrical circuit. Inadequate stunning can lead to carcass defects and damage because of poor blood loss and excessive movement, while over-stunning can cause electrocution, heart arrhythmia, and hemorrhage from ruptured arteries and capillaries. After stunning, birds move to an automated killing machine. The killing machine consists of a circular rotating blade that cuts the jugular vein and the carotid artery on one or both sides of the neck of the bird. Opening the veins and arteries causes the blood to drain for about 2 to 3 minutes, depending on the size of the bird.

During this bleed out period, the bird loses about 30 to 50% of its blood, which causes brain failure and death [15, 16, 25].

Once the carcass has been bled, it enters a scalder. The primary purpose of the scalder is to denature the protein structures that hold the feathers in place thereby aiding in the defeathering process. There are two types of scalding (i.e., hard scald and soft scald) that differ in time that the carcass stays submerged in the scalder and the temperature of the scalder water. ‘Soft scalding’ is typically accomplished at 53°C (127°F) for 120 s, while ‘hard scalding’ is done at 62 to 64°C (144 to 147°F) for 45 s. Soft scalding does not cause damage to the outer layer of the skin called the stratum corneum or ‘cuticle’. Hard scalding is a harsher procedure because it removes the cuticle. However, it allows easier feather removal than soft scalding. If a bird’s neck is not cut, then the bird can die by drowning in the scalder. The high temperature scald water causes the blood to rush to the skin and gives the bird a bright red color. This rare condition is known as ‘cadaver’. Next, the scalded carcasses pass through a series of automated pickers that defeathers the carcasses. This equipment uses rubber fingers on rotating discs that strike the carcass and remove the feathers [25].

Once the feathers are removed, the carcasses are transferred through a wall and onto a different shackle line to an evisceration room to prevent cross contamination. Evisceration has three main objectives: (1) the opening of the body cavity from the posterior tip of the breast bone to the cloaca; (2) the separation of the edible from the inedible portions of the carcass; and (3) the harvesting of edible viscera or ‘giblets’ (i.e., heart, liver and gizzard) from the extracted viscera [25]. Each carcass is passed by a USDA inspector who is trained to examine the carcass and viscera for any specific signs of disease, contamination and overall wholesomeness of the product [15]. Prior to chilling, the carcasses pass through a series of inside/outside bird washers (i.e., IOBW) that spray water that contain anti-microbial agent through nozzles. These spray nozzles are directed towards the interior and the exterior of the carcass to remove any external debris or blood clots.

Next, the carcasses go through a chiller with a counter-current flow of cold water that reduces carcass temperature and minimizes microbial contamination. It is required by U.S. regulations that a carcass temperature of 4^{o}C (39.2^{o}F) or less be achieved within 4 hours of slaughter. Many U.S. poultry processing plants use a prechiller that is 7 to 12^{o}C (45 to 55^{o}F) with a duration of 10 to 15 minutes. After prechilling, the carcasses enter the main chiller tank that is maintained at 4^{o}C at the entrance and 1^{o}C (33.8^{o}F) at the exit. This further reduces the temperature of the carcass during the 45 to 60 minutes the carcasses are in the main chiller [25]. To maintain high quality poultry chiller water, the Food Safety and Inspection Service (FSIS) of the USDA requires that the chiller water be replenished with fresh cold water maintaining an overflow rate of 1.9 L for each broiler carcass. Many plants will also use a disinfectant such as chlorine as a means to reduce microbial contamination within the chiller [27]. The USDA-FSIS oversees two major food safety programs in U.S. poultry processing plants: HACCP and Zero Tolerance. FSIS mandates that there be no fecal contamination on carcasses as they enter the chiller tank due to the risk of cross contamination [28]. Hence, one of the primary methods to remove fecal contamination is implementing cabinet washers, including IOBW, carcass sprays and brush washers [3].

Secondary Processing

Secondary processing is defined as the cutting of the carcass into parts, packaging of raw products, deboning and portioning [20]. In the late 1950s and early 1960s, consumer choices grew with more cut-up and further processed meat products. As popularity with these products increased, more parts such as breast quarters, drumsticks, thighs and wings, became available with advanced mechanical separation equipment. Deboning of poultry parts can be accomplished manually or by using mechanical equipment. Following deboning, the remaining meat and bones can be ground together and then passing it through a sieve under high pressure in a process known as mechanically-deboned meat (MDM) [29]. MDM is recovered meat after hand deboning or from poor quality poultry [30].

Third Processing

Third processing is the formulation of specific products from poultry meat and includes coating, shaping, marination, cooking and freezing. The terms second and third processing are often combined into the encompassing term of 'further processing'.

It should be noted that each plant is unique in terms of which further processing steps it utilizes. For example, one plant may process broilers all the way from slaughter to a fully cooked ready-to-eat (RTE) product; whereas, another plant may stop at primary processing and market their product as a raw whole chicken. Further processing ranges from cutting and portioning the carcass to sophisticated technologies to formulate food products. Some of these technologies include shaping, marinating, emulsifying, forming, coating and smoking [20]. Some products from MDM include bologna, salami, frankfurters, turkey rolls, restructured meat products and soup mixes [29].

For the past four decades, there has been a significant demand shift from whole birds to further processed products [22]. The demand for whole birds is less than 10% in the U.S. It is estimated that 50% of broilers are cut up for consumer sales, fast-food-restaurants and institutional markets, while the remaining 40% are deboned and used to make poultry-based further processed products [20].

Rendering

Consumer demand for increase portioned and further processed products has resulted in an increase in the amount of poultry byproducts (i.e., offal) and underutilized products generated in the U.S. [31]. Today, the rendering industry uses these byproducts to manufacture hundreds of useful edible and inedible products, chemicals, meat meals, and bone meals [32]. The purpose of a rendering plant is to convert poultry offal and waste products into animal feed and grease that is often unsuitable or unfit for human consumption [31, 33]. Rendered products have a greater value than raw offal because the rendering process increases the stability or 'shelf life' of the fat and protein by reducing the moisture content and killing any microbes present in the raw offal [34]. Rendering of offal involves two basic steps of first separating the fat from the protein and then drying the residues [31]. Separation of the fat is done by cooking offal at a high temperature for a period of several hours [31, 33]. The cooked material is then finally pressed to extract grease and the pressings are used for animal feed [33].

Rendering can be categorized as batch, continuous, or continuous at low-temperature. Batch dry rendering systems use a cooker that is steam jacketed and reduces the material to about 8% moisture. The material is loaded and unloaded in batches where heat is provided. The dehydrated material is then pressed to remove the extra fat so that the final product will have a fat content of 10%. Finally, the product is ground to a small size so that it can be screened [32, 35].

The continuous dry rendering system is very similar to the batch dry rendering system. The only difference is that in the continuous dry rendering system, the flow of material in and out of the cooker is uninterrupted [32]. Continuous and batch rendering systems are both referred to as 'dry rendering' that starts with an initial temperature of 100^{o}C (212^{o}F) and gradually increases to 125^{o}C (257^{o}F). Continuous wet rendering is another procedure for processing offal at a lower temperature. The material is heated to 60 to 90^{o}C (140 to 192^{o}F) for 10 to 30 minutes that allows the cells to break and release fat. After the removal of fat, the material is dried and ground [32].

Wastewater

In 2003, Sincero and Sincero defined wastewater as any remaining spent water that is used in households, commercial establishments, industries, public institutions, and other similar entities [36]. Prior to 1940, most municipal wastewater was generated from domestic (i.e., household) sources. However, after 1940, with the industrial development in the U.S, most of the wastewater discharged to municipal collection systems was generated from industrial sources [37].

Wastewater can be classified as sanitary or non-sanitary. Non-sanitary wastewater is commonly generated by commercial and industrial facilities and is produced in the process of manufacturing, whereas sanitary wastewaters are those generated in residences. Sanitary wastewater generated in households include spent water from restrooms, bathing, and washing dishes and clothes, it is also referred to as domestic wastewater [36].

Industrial Effluent Discharges

Following the enactment of the Clean Water Act (CWA) in 1972, the U.S. Environmental Protection Agency (EPA) began proposing industry-specific effluent limitation guidelines for food processing, metal manufacturing, electrical components manufacturing, inorganic and organic chemical manufacturing, plastics manufacturing and mining. These guidelines applied to both direct and indirect dischargers. Direct discharging facilities treat their water on site and directly discharge treated wastewater to surface waters (e.g., lake, river, ocean). Direct dischargers must have a permit under the National Pollutant Discharge Elimination System (NPDES) or a state equivalent NPDES permit. An indirect discharger sends their wastewater to a publicly owned treatment works (POTW) such as a municipal wastewater treatment plant.

Poultry Processing Wastewater (PPW)

In a poultry processing plant, water is primarily used for scalding, bird washing before and after evisceration, chilling, cleaning, and sanitizing of equipment and facilities [1]. Water is also used as a primary means to transport offal (e.g., feathers, heads, viscera) out of various processing areas where it is separated from the poultry wastewater stream using mechanical screens [2]. The collective stream of the water and byproducts remaining in the stream after initial offal screening is known as poultry processing wastewater (PPW) [38].

Studies have shown that the amount of water used and the wastewater generated by poultry slaughter varies substantially among processing plants [1]. A recent industry survey shows that the average amount of potable water used per bird in a U.S. broiler slaughter plant is 27 L (7 gal) [3]. This volume of water used per bird has increased rapidly in the past several years due mainly to the implementation of HACCP and other mandated food safety programs in the U.S. [7].

During processing, some of the major sources of byproducts and wastes are live bird holding and receiving, killing, defeathering, evisceration, carcass washing, chilling, cut-up, further processing, rendering, and cleanup operations. These byproducts and wastes include uncollected blood, feathers, viscera, external debris, bone, and various cleaning and sanitizing compounds. Thus, wastewater from poultry processing plants contains biodegradable organic matter including grease, fats, proteins, suspended solids, and inorganic matter such as phosphates, salt, nitrates and nitrites [1].

PPW consists of various constituents in the form of organic, particulates, and nutrients [4, 6]. The most common analytical parameters used to characterize PPW are BOD (biochemical oxygen demand), COD (chemical oxygen demand), O&G (oil and grease), TS (total solids), TSS (total suspended solids), TDS (total dissolved solids), TVS (total volatile solids), TKN (total Kjeldahl nitrogen) and P (phosphorus) [39]. Mechanical screens are the most popular form of primary physical treatment used in on-site poultry wastewater treatment systems [14]. Screening systems typically consist of primary and secondary rotary screens that can remove solids greater than 500 micron (μm) in size from PPW [14, 40]. Screens function to recover offal and prepare PPW for more advanced wastewater treatment systems [41]. Even after screening, PPW contains high concentrations of BOD, COD, TSS, nitrogen and phosphorus.

Organics

Poultry processers are required to remove the majority of soluble and particulate organic matter from their wastewater before it can be discharged from the plant [5]. Organic matter in PPW is characterized using the BOD, COD and O&G analytical tests [39].

BOD is a standardized empirical test used to determine the relative oxygen requirement of the microorganisms in a wastewater sample. This test measures the oxygen consumed by microbes that biochemically degrade the organic material in wastewater under aerobic conditions. BOD also measures the oxygen used to oxidize sulfides and ferrous iron. When PPW is discharged to surface water, microorganisms present in the surface water decompose the organic matter. In the process of decomposing this organic matter, microorganisms consume oxygen and reduce the amount available for aquatic animals. This reduction in dissolved oxygen (DO) concentration can lead to fish kills.

BOD is the measure of DO depletion in a wastewater sample incubated at 20^{o}C for a period of five days. The results of a five day BOD test can be reported as BOD_5. A BOD value from food processing waste will be higher (e.g., >1000 mg/L) compared to the BOD from domestic sewage, which will have a BOD of 200 to 400 mg/L [1, 39]. Significant factors in determining the BOD level of PPW are uncollected blood, solubilized fat, urine and feces [1].

COD is defined as the measure of the oxygen equivalent of the organic content in a sample that can be oxidized by a strong dichromate-sulfuric acid reagent. Because not all molecules can be oxidized by this method, COD is often conducted in conjunction with BOD [1, 39]. BOD and COD are both good indicators of organic 'strength' of wastewater, however COD has the distinct advantage of being a 3 hour test as opposed to the 5 day BOD test [39]. Thus, COD results can indicate a plant upset long before a BOD test can be completed [42]. COD generally has a higher value than BOD because COD includes slowly biodegradable and recalcitrant organic compounds that were not degraded by the microbes in the BOD test. COD can be used as a surrogate for BOD to estimate the impact of wastewater discharges on natural wastewaters only if the ratio between BOD and COD is constant for a type of wastewater [1]. COD can range from about 1.0 to 6.0 times the BOD in both the raw and treatment wastewater for a poultry processing plant, with typical ratios between 1.5 and 3.0 [42].

Another classification of organics in PPW includes O&G. Oil and grease is defined as any material that is soluble in a laboratory solvent (e.g., trichlorotrifluoroethane). In their 1975 industry survey, EPA reported that the concentration of O&G in PPW ranged from 100 to 400 mg/L. However, EPA reported O&G results of just 8 mg/L for final treated effluent PPW [42]. Research done in 1976 on PPW from Mississippi poultry processing plants reported that the O&G concentration was between 100 to 200 mg/L [43]

Grease creates a thin film on the surface of water which prevents the exchange of air and water, thereby decreasing the level of DO in natural waters. Oil emulsions can also adhere to the gills of a fish and cause death. It can also destroy algae or other plankton growth by depositing at the bottom sediment and interrupting the aquatic food chain [1, 37, 39, 42, 43].

Research on the organic strength of PPW from U.S. plants dates back to the 1950s. In 1950, Porges reported that the BOD concentration of PPW from multiple broiler processing plants were 997, 1475, 1070, 1560, and 290 mg/L [9]. In 1958 Roberts sampled a sewer next to a poultry processing plant in Gainesville, Georgia and reported poultry waste to have a BOD of 1100 mg/L [13].

In 1975, the EPA reported a wide fluctuation in the concentration of organics in PPW with a BOD range of 500 to 1300 mg/L [42]. Research conducted in 1976 at Cornell University on poultry manure wastewater that consisted of feces, urine, wasted feed, and feathers reported that the BOD range was 340 to 2900 mg/L and the COD range 720 to 10,400 mg/L [44]. Olson et al. (1968) studied the combined meat processing and domestic waste in North Dakota and reported the BOD of a poultry plant to be 810 mg/l [45]. In 1991, Merka reported that the PPW from a broiler processing plant (260,000 birds per day) had an average BOD of 2178 mg/L, COD of 3772 mg/L, TSS of 1446 mg/L, TVS of 1745 mg/L, TKN of 129 mg/L and O&G of 776 mg/L [46].

In 2005, Chavez et al. found that the mean BOD and COD for poultry slaughter wastewater was 5500 and 7333 mg/L [47]. Research done in Brazil in 2007 reported that the COD of PPW from a poultry slaughtering process was 3102 mg/L [48]. In 2009, research reported that the average COD of PPW from a poultry slaughterhouse was 6880 mg/L [49].

Discrete wastewater streams within the poultry processing plants have also been analyzed for organic strength. In 1972, Hamm conducted a study on specific sites within poultry processing plants to see which contributed most to the PPW stream. Wastewaters from the scalder, feather and viscera flume, chiller, eviscerating trough, and final bird washer were analyzed for wastewater parameters. Hamm reported that all sites displayed great variability in concentration values. The median values for the scalder wastewater, feather flume and viscera flume were 2268 mg/L, 1919 mg/L, and 1005 mg/L, respectively [7]. EPA (1973) reported that the BOD of scalder water has been measured as high as 1182 mg/L. In 1977, Woodward et al., reported wastewater recovered from a defeathering operation had a BOD level of nearly 600 mg/L. The BOD concentrations of the two stages in a chiller process were measured by EPA in 1973 and reported to be 422 mg/L and 320 mg/L [50]. In 1978, Hamza et al., while doing research on an Egyptian poultry processing plant, found out the BOD and COD of scalder wastewater to be 978 and 1330 mg/L [51]. In 2007, Del Nery et al. compared the PPW generated during processing versus sanitation. The average BOD and COD from the slaughtering process were 1780 and 3102 mg/L, respectively, while the average BOD and COD from sanitation was 801 and 1311 mg/L, respectively [40].

Particulates

One of the most important characteristics of PPW is the amount of total solids it contains, which is composed of floating matter, settleable matter, and colloidal matter [37]. Total solids (TS) are defined as the left over material residue in the vessel after evaporating a wastewater sample at less than $100^{o}C$, and then drying the residue at 103 to $105^{o}C$ for a minimum of one hour. Incorrect temperature or the length of heating time can lead to weight loss due to volatilization of organic matter, mechanically occluded water, water of crystallization, and gases from heat-induced chemical decomposition, as well as weight gains from oxidation [39].

TS in a PPW sample can be separated based on particle size or organic content. TS can be categorized by particle size into total suspended solids (TSS) and total dissolved solids (TDS) or TS can be categorized by organic content into total volatile solids (TVS) and fixed solids (FS) [39].

TSS is defined as the portion the TS retained on a filter with a specific pore size (i.e., $\leq$ 2.0 μm). Suspended solids include both organic and inorganic materials. Organic materials include grease, oil, tar, animal and vegetable fats, fibers and hair. The inorganic components include silt, sand, and clay [42]. TDS is the portion of TS that passes through the filter during the TSS test [39]. Dissolved solids mainly consist of chlorides, sulfates, phosphates, carbonates, iron, manganese, and other elemental substances [42].

A TVS is one that can be burned off when ignited at $500 \pm 50^{o}C$ [37]. TVS is the amount of combustible material present in both TSS and TDS and is a measure of the amount of organic matter in wastewater [42]. FS is defined as the residue that is left behind after complete combustion of TS [37].

Both suspended and dissolved solids are considered pollutants in wastewater effluents for several reasons. Suspended solids can settle to form bottom deposits and alter the natural habitat for fish, shellfish and benthic organisms. Suspended solids can also act as an adsorption surface and serves as a medium for the transport of other pollutants, nutrients, pathogens, metals and toxic compounds. Suspended solids can reduce oxygen transport by clogging fish's gills and causing asphyxiation. In addition, suspended solids can increase turbidity and reduce light penetration in water bodies; thereby, limiting the growth of aquatic vegetation that serves as a habitat for aquatic organisms. Dissolved solids can also affect indigenous aquatic biota by altering the chemistry of natural waters [1]. Dissolved solids that are present in industrial waters can affect the purity, color or taste of many finished products. Dissolved solids affect the ionic nature of receiving waters and serve as nutrients for bacteria and protozoans; thereby, increasing eutrophication. Water with dissolved solids concentrations over 500 mg/L have decreasing utility as irrigated water [42].

The EPA reported in 1975 that the TSS in the PPW from a series of U.S. plants had a range from 75 to 1100 mg/L. EPA also revealed that TDS ranged from 170 to 2300 mg/L in the PPW, and that TVS ranged from 175 to 2400 mg/L [42]. Research done in Brazil in 2007 from the slaughtering process of poultry plants reported 2457 mg/L for TS, 872 mg/L for TSS, 1782 mg/L for TVS, 674 mg/L for FS [40].

In 1975, EPA reported TSS for scalder water samples to be at 473 mg/L and 687 mg/L, and the TSS in a feather flume was reported to be 512 mg/L [42]. A study done in 1989 by Merka on wastewater pollutant concentrations and loadings in a broiler slaughter plant reported PPW to have an average TSS of 1446 mg/L and TVS of 1745 mg/L [46].

Inorganics

In addition to significant concentrations of organics, food processing industries also discharge various inorganic constituents including phosphorus (P) and nitrogen (N) into their wastewater streams [52]. P and N, when added in the right amount, act as valuable nutrients to natural ecosystems, however, they can be detrimental if added in excess. The addition of excess nutrients can lead to an acceleration of the enrichment process and natural aging of water bodies known as eutrophication. Acceleration of the natural eutrophication process is irreversible. [53].

Eutrophication

Eutrophication is defined as the naturally occurring biological process of the enrichment of water bodies with nutrients such as nitrogen and phosphorus. Eutrophication is a normal process until accelerated by man-made sources. N and P are made available by natural means. However, man-made sources such as industrial wastes from food processing plants, discharge of untreated sewage, the run-off of fertilizers, and a variety of point and non-point sources can create significant acceleration of this natural process. Once eutrophication has been accelerated by man, it is termed cultural eutrophication [53].

Cultural eutrophication can lead to algae blooms which are explosive growths of one or more algal types or species to the detriment or exclusion of others. Some blooms are dominated by blue-green algae which is generally not a good source of food in aquatic biosystems. With the accumulation of algae, organic deposits build up on the bottom of lakes and turbidity increases. As decay accelerates, BOD concentration level increases and eventually DO levels decrease. It has been estimated that about 75% of the phosphorus and 80% of the nitrogen currently entering natural waters in the U.S. come from anthropogenic (i.e., man-made) sources [53]. If conditions become extremely eutrophic, invertebrate and vertebrate species can be eliminated from an aquatic biosystem [53].

Nitrogen

There are several forms of nitrogen that are viewed as pollutants of concern in PPW [1]. The different forms exist because nitrogen has a high number of oxidation states, varying from +5 to -3 that move through the environment cyclically. The different forms of nitrogen are organic nitrogen, ammonia, nitrate (+5), nitrite (-3), and nitrogen gas. Uncollected blood and manure from poultry processing plants are significant sources of nitrogen in PPW [1]. In raw wastewater, ammonia accounts for ~60% of the total nitrogen, organic nitrogen accounts for ~40%, and less than 1% exists as nitrite and nitrate [53].

TKN is the measure of the sum of organic nitrogen and ammonia nitrogen in wastewater [1]. EPA states the average TKN concentration from PPW to be 180 mg/L [1]. Ammonia exists as a byproduct of anaerobic decomposition of protein. Decaying plants and animals along with human and animal body wastes account for the majority of ammonia that enters aquatic ecosystems [42]. In raw sewage, the typical concentration for organic nitrogen is 20 mg/L [39]. Schmitz (1996) reported that animal waste can contain organic nitrogen as high as 600 mg/L [53]. Bacteria oxidize ammonia into nitrite and nitrate by a process called nitrification [42].

Nitrate and nitrite, normally reported as N-N, are usually accumulated in PPW from salts used in further processing. EPA stated in their 1975 survey that the concentration of nitrites in PPW was between 0.001 to 2.0 mg/L, and nitrates between 0.3 to 4.1 mg/L [42]. Toxicity of nitrogen compounds occurs mainly through the ammonia and nitrates forms [53]. If the intake of nitrate is high in infants, it is reduced to nitrites by bacteria in the body. The nitrites bind to hemoglobin in the bloodstream more readily than oxygen, forming methemoglobin. This results in reduced oxygen in the tissues with the resultant 'blue baby' syndrome. The resulting disease is called methemoglobinemia. Because of this, EPA recommends a maximum limit of 10 mg/L of N-N or 45 mg/L of nitrate in drinking water [53].

Phosphorus

Primary sources of phosphorus in PPW include particulate bone from cutting, detergents used in cleaning, food additives, boiler water additives, uncollected blood and manure. Phosphorus is considered as a limiting nutrient in the productivity of freshwater ecosystems due to its critical role as a key element required by freshwater plants. Because of its role in cultural eutrophication, phosphorus is a regulated pollutant of concern in PPW. EPA states the threshold concentration of phosphorus that leads to eutrophication in receiving bodies to be about 0.01 mg/L. Phosphorus in its elemental form is toxic and can lead to bioaccumulation in the same way as mercury. Phosphorus is capable of accumulating in the organs and soft tissues of fish. EPA reports that 0.001 mg/L of phosphorus is sufficient to be accumulated in marine fish [1, 42].

Poultry Byproducts

Poultry byproducts (i.e., offal) from processing include bone, blood, feathers, viscera, and heads [16]. Offal is a general term used to describe inedible poultry byproducts that are normally not acceptable for human consumption [14]. Rendering is the process that converts poultry byproducts into animal feed and inedible fats and proteins for agricultural and industrial use. Rendered products include animal feedgrade fats, meat and poultry byproduct meal, feather meal and blood meal [1]. The growth of the poultry industry has resulted in a corresponding growth in the availability of offal for rendering [35].

Blood

The most common method of killing poultry is by severing the carotid artery and/or jugular vein [1]. During the process of bleeding a animal, about 40 to 60 % of the blood drains from the body while about 3 to 5% stays in the muscles and the rest remains in the viscera [54]. The collection and handling of blood in processing plants has a significant impact on PPW since blood that is allowed to enter the wastewater stream will elevate pollutants of concern, especially BOD and TKN [55]. Thus, processing plants need to maximize the time carcasses spend in the blood tunnel where blood is collected and retained for rendering. The blood tunnel is an area that is walled and is designed to confine the blood that is subsequently pumped to tankers for transport to rendering [1].

Each broiler is held in the tunnel for 45 to 125 seconds for bleeding, with an average of 80 seconds [1]. Newell and Schaffner indicated that the 35 to 50% of a chicken's blood is lost in the killing area with considerable variation in individual blood loss [56]. To recover protein as blood meal, the blood is dried using heat. Blood meal contains 16 to 18% total protein solids. In animal feed, blood meal is a valuable ingredient due to its high lysine content [1].

Uncollected blood plays a significant role in the amount of organics and nitrogen present in PPW [1]. Blood that is not captured in the blood tunnel is allowed to remain on the slaughter area floor. This results in large quantities of blood entering the PPW drains during washdown of the plant [57]. The potential impact of uncollected blood on PPW is substantial since the BOD of blood has been shown to be in the range of 92,000 to 156,000 mg/L [1, 9, 50, 58]. When blood is effectively collected, PPW strength has been shown to be reduced by 35 to 50% (17 to 18 lbs of BOD/1000 broilers) [50].

Feathers

Broiler feathers are removed mechanically by pickers equipped with rubber fingers. These fingers rub against the carcass and pull the feathers out. Approximately, 7% of the chicken live body weight is feathers [59].

A large proportion of poultry offal consists of feathers which are mainly keratinous protein [35]. There has been interest in the nutritional studies of feathers due to their high protein content of 85 to 99% [60]. It has been concluded that a mixture of poultry byproduct and hydrolyzed feathers is an excellent protein source for broilers and layers [35]. However, since keratinous proteins cannot be digested by animals in its natural form, various methods have been developed in order to make feathers digestible to animals [35, 60]. Feathers are processed in a bath cooker at temperatures ranging from 138 to 149^{o}C (280 to 300^{o}F), and pressures ranging from 40 to 50 psi for 30 to 45 minutes. Blood is usually processed along with feathers increasing the protein content of the final feather meal [1]

Large quantities of water are used in the dewatering process both during defeathering and during cleanup operations. Along with feathers, PPW from defeathering contains substantial amounts of external debris and uncollected blood. EPA stated in a 1973 report that the BOD of defeathering water averaged 590 mg/L [50].

Viscera

Evisceration is the process that removes the edible and inedible viscera from the carcass. There are three basic objectives when eviscerating a broiler: 1) opening the body cavity by making a cut from the posterior tip of the breastbone to the cloaca (i.e., anus); 2) removal of the viscera from the body cavity, and 3) harvesting the edible offal or ‘giblets’ (i.e., heart, liver and gizzard) [25].

It has been estimated that evisceration is responsible for one third of the entire PPW pollutant load [61]. Wastewater generated from evisceration is high in BOD, TSS and O&G. It also contains substantial quantities of blood and bacteria from the intestinal tract. The offal that is generated from evisceration is continuously flushed to the wastewater system with relatively large quantities of chlorinated potable water. The amount of eviscerating flume water used per bird has been reported to be 11 L (3 gal) [50]. Gizzard cleaning is a sub-process that when added to evisceration increases water use to 23 L (6.1 gal) per bird and generates a BOD of 230 mg/L. BOD from the final bird wash PPW after evisceration has been reported to be 440 mg/L [50].

CHAPTER 2

EFFECTS OF INDIVIDUAL AND GROUPS OF BROILER CARCASSES BLEED TIME AND SCALD TEMPERATURE ON POULTRY PROCESSING WASTEWATER[1]

[1]Plumber, H.S., and B.H. Kiepper. To be submitted to the *Journal of Applied Poultry Research*

SUMMARY

Two experiments were conducted to measure the effects of bleed time and scald temperature on individual and groups of carcasses' impact on scalder poultry processing wastewater (PPW) during the initial slaughter process. In Experiment 1 (24 male experimental broilers) and Experiment 2 (120 commercial broilers) birds were randomly assigned to 4 treatment groups (n=6): SS (short-bleed/soft-scald), SH (short-bleed/hard-scald), LS (long-bleed/soft-scald), and LH (long-bleed/hard-scald) (short-bleed = 60 s, long-bleed = 120 s, soft-scald = 50^{o}C, hard-scald = 60^{o}C). Birds were electrically stunned, decapitated and bled for either 60 s or 120 s with draining blood captured. Blood loss as % live weight was significantly greater at 120 s than at 60 s. Carcasses were scalded for 2 min individually (Experiment 1), or in groups of 5 carcasses (Experiment 2), in scald tanks heated to either 50^{o}C or 60^{o}C. Samples of resulting scalder PPW were analyzed (mg/L) for COD, TS, TSS, TVS, TKN and 18 chemical elements (Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si, and Zn) in Experiment 1. Experiment 2 PPW samples were analyzed for COD, TS and TSS. A PPW load (g/kg^{lwt}) was calculated for each concentration (mg/L) data point. The highest mean loading (g/kg^{lwt}) in the scalder PPW samples from Experiment 1 was for COD (2.00), followed by TS (1.66), TVS (1.36), TSS (0.42) and TKN (0.24). The highest mean loading (g/kg^{lwt}) in the scalder PPW samples from Experiment 2 was for TS (3.02), followed by COD (1.62) and TSS (0.61). The 82% increase in TS mean loading (g/kg^{lwt}) from Experiment 1 (i.e, experimental broilers) versus Experiment 2 (i.e., commercial broilers) indicates the impact of broiler external cleanliness on solids loadings in scalder PPW.

Keywords: poultry processing, wastewater, blood loss, COD, TSS, TKN

Primary Audience: Processing Plant Managers, Processing Plant Wastewater Operators

DESCRIPTION OF PROBLEM

The U.S. Environmental Protection Agency (EPA) states that blood is the strongest single pollutant impacting PPW in a slaughter plant [42]. During the slaughter process about 40 to 60% of the blood drains from the broiler carcass, 3 to 5% stays in the muscles and the rest remains in the viscera [54]. The potential impact of uncollected blood on PPW is substantial since the biochemical oxygen demand (BOD) of blood has been shown to be in the range of 92,000 to 156,000 mg/L [1, 9, 58]. When blood is effectively collected, PPW strength has been shown to be reduced by 35 to 50% (17 to 18 lbs of BOD/1000 broilers) [50]. Along with uncollected blood, manure and other debris from the carcass enters the PPW stream from the cleaning action of the scalder [9]. The efficient collection of blood during the slaughter process can significantly impact the PPW stream by reducing the plant's effluent BOD [55] and costs associated with that discharge [1].

Extensive research has been conducted on establishing the concentration (mg/L) of various pollutants in PPW in operating commercial plants both in isolated streams within plants as well as final effluents [8, 9, 43]. Little or no research has been done to establish the actual mass or 'load' of each pollutant contributed to the PPW stream by each broiler carcass during isolated processing operations, which is essential in identifying critical processing operations that have the greatest impact on PPW.

This experiment was conducted to: 1) measure the variation of individual and groups of carcasses and poultry byproduct (e.g., blood, external debris) impacts on PPW based on bleed time and scald temperature, and 2) establish mean carcass PPW loads (grams per kilogram live weight) for the common wastewater analytical parameters of COD, total solids (TS), total suspended solids (TSS), total volatile solids (TVS) and total Kjeldahl nitrogen (TKN) and common chemical elements.

MATERIALS AND METHODS

Experiment 1

An experimental broiler flock was reared to 8 weeks of age in six 32-bird pens on pine shavings. Twenty-four (24) male broilers were randomly selected and divided among four treatments: 1. **SS** (Short Bleed Time/Soft-Scald), 2. **SH** (Short Bleed Time//Hard-Scald), 3. **LS** (Long Bleed Time/Soft-Scald), and 4. **LH** (Long Bleed Time/Hard-Scald). Bleed time levels were set at Short = 60 s or Long = 120 s [62], while scalder water temperature levels were set at Soft-Scald = 50^{o}C (122^{o}F) or Hard-Scald = 60^{o}C (140^{o}F).

To best simulate commercial transport conditions, feed was withdrawn from the flock at 12:00 am the day of processing. At 6:00 am, selected broilers were placed in one of 4 treatment coops (6 per treatment). Pieces of cardboard box were placed at the bottom on each open-bottom coop to simulate solid-bottom coops (i.e., industry standard). Birds were processed starting at 10:00 am (i.e., 10 h minimum feed withdrawal, 4 h minimum hold time in coops).

Birds were processed in eight (8) batches of 3 birds each. Birds were removed from coops by hand, weighed and then hung from shackles. Birds were electrically stunned using a 25-volt DC high frequency stunner (12 to 15 mA per bird) followed by a 25-volt AC post-stunner. Each batch of 3 birds was simultaneously decapitated within 30 seconds of exiting the stunning tunnel. The birds were bled for either 60 s (S) or 120 s (L) into plastic bags and weighed as described in Kang and Sams, 1999 [63]. Additional blood was allowed to drip into an individual metal container of scalder water set beneath each bird. Each container held 16 L of scalder water at either the soft-scald temperature of 50^{o}C (122^{o}F, designated ‘S’) or the hard-scald temperature of 60^{o}C (140^{o}F, designated 'H'). Make-up water for each scalding container was taken from the laboratory's commercial scalding tank pre-set at the soft-scald or hard-scald temperature. A 2 L background sample of source scalder make-up water was collected and placed on ice. The carcasses were then simultaneously submerged into each scalding container and agitated for 2 min. After agitation, carcasses were removed and a 2 L sample of well-mixed scalder PPW was collected from each scald container and placed on ice. The batch orders for the birds were as follows: 1. SS1, 2. LS1, 3. LS2, 4. SS2, 5. SH1, 6. LH1, 7. LH2, and 8. SH2.

Experiment 2

One hundred and twenty (120) commercial broilers were used for this experiment. The experiment was conducted on one day per week for 3 weeks, with 40 birds processed each week. On the day of processing, 40 birds were randomly selected from a commercial-style dump coop at a north Georgia processing plant and transferred to plastic top-loading coops for transport to the processing laboratory. The birds were divided into 4 treatment groups similar to Experiment 1. The birds were then processed as described in Experiment 1 with the following exceptions: each metal container of scalder water held 20 L of either the soft-scald temperature of 50^{o}C or the hard-scald temperature of 60^{o}C and each scalder container received 5 carcasses in succession. Following the scalding of the 5 carcasses, 2 L samples of well-mixed scalder water were collected from each scald container and placed on ice.

Analytical Methods

The scalder background and scalder PPW samples from Experiment 1 were analyzed for COD (chemical oxygen demand method 5220D), TS (total solids method 2540B), TSS (total suspended solids method 2540D), TVS (total volatile solids 2540E), and TKN (total Kjeldahl nitrogen method 4500-NorgD) [39]. Samples were also analyzed for 18 chemical element concentrations (i.e., Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si and Zn) using ICP (inductively coupled plasma method 3125B) [39]. Scalder PPW samples from Experiment 2 were analyzed for COD, TS, and TSS.

Data Treatment

Blood – Each blood collection bag was weighed prior to processing. After the blood was collected, the weight of the empty sample bag was subtracted from weight of collected blood and sample bag to determine total weight of blood. Total weight of blood was then divided by the live weight of the broiler and multiplied by 100 to determine the % of blood loss based on live weight.

Scalder PPW - If the background sample concentration was at a detectable level, that background concentration value was subtracted from the data point. If the background sample concentration was below detectable limit (BDL), the concentration data point remained as reported. In Experiment 1, a load value in grams per kilogram of live weight (g/kg^{lwt}) was determined for each data point by multiplying the volume of scalder water (16 L) by the concentration (mg/L) of that parameter. The result (mg) was first divided by 1000 to determine the load in grams (g) for each bird processed and then divided by the live weight (kg) of the broiler to determine g/kg^{lwt}. The same procedure was used in Experiment 2 with the exception that 20 L was used in the initial calculation and the scalder water gram loading was divided by the average kilogram live weight of the 5 broilers in the corresponding batch.

Statistical Analysis

Data were subjected to statistical analysis by using the GLM procedure of the SAS/STAT program. Data from the 4 treatments (SS, SH, LS, LH) with 6 replications were analyzed by factorial ANOVA (2 x 2). The scalder wastewater data was first run as a factorial ANOVA with an interaction term between the main factors (i.e., bleed time and scald temperature). If the interaction was not significant (*P*>0.05), ANOVA was re-run without the interaction term and each factor was analyzed independently. Means were separated using the Tukey-HSD multiple comparisons procedure [64]. Differences in means were regarded as significant at $P < 0.05$.

RESULTS AND DISCUSSION

Experiment 1

Blood Loss

The mean live weight of 24 male broilers was 4.09 kg (9.02 lbs) with no significant difference between treatment groups (*P*=0.5208). Analysis of blood loss data in Table 2.1 shows that the mean mass of blood recovered (*P*=0.0383) and mean % of live weight (*P*=0.0155) blood loss at 120 s (101.4g and 2.51%) was significantly greater than at 60 s (82.7g and 2.00%). Percentage (%) blood loss is graphically represented in Figure 2.1.

The mean blood loss as % of live weight observed at 120 s (2.51%) is substantially lower than observed in previous research, such as results reported by Kang and Sams at 3.0% [63] and McNeal et al. at 3.49% [65]. However, the blood volume in broilers has a curvilinear relationship with body weight such that the % of blood decreases as body weight increases [66]. Average live weight of broilers in the Kang and Sams experiment was 2.14 kg [63], and 1.92 kg in the McNeal et al. experiment [65], compared with 4.09 kg in this experiment. Thus, it is expected that the approximate doubling of the average live weight of the broilers in this experiment would result in a lower bleed out percentage. Previous research has shown that there is no significant difference in blood loss volume between broilers exsanguinated via neck cut versus decapitation [65]. Also, unlike the McNeal et al. experiment where % blood loss was calculated using carcass weight after bleed out versus live weight [65], this experiment, like

Kang and Sams [63], used the actual weight of collected blood versus live weight to calculate % blood loss. Thus it is expected that the McNeal et al. % blood loss data could contain other non-blood loss components released from the carcass during slaughter.

Blood loss as % live weight was more variable with birds bled for 60 s (i.e., 31% versus 12% coefficient of variation - cov). These results are consistent with findings in both Kang and Sams [63] and McNeal et al. [65] work. Both papers reported that electrically stunned birds showed vigorous excitation and strong muscle contractions during the first 60 s of bleed out, with variation among individual birds, and greatly diminishing after 60 s. In the present work, we saw a wide range of physical excitation from electrical stunning, resulting in a more varied bleed out rate at 60 s and then diminishing at 120 s.

Scalder PPW – Organics

Statistical analysis of COD results showed no interaction between bleed time and scald temperature (P=0.4690), therefore the main effects were analyzed independently. The COD results for bleed time are summarized in Table 2.2 and are graphically represented in Figure 2.2. The COD results for scald temperature are summarized in Table 2.3. The short bleed time had a mean COD load of 2.38 g/kg^{lwt} and concentration of 616 mg/L which was significantly greater than the long bleed time (1.61 g/kg^{lwt} and 406 mg/L). A higher COD load for the broilers that were bled for 60 s compared to 120 s was expected because more blood enters the scalder water following the shorter bleed time. Scalder temperature did not produce a significant difference in COD loading (P=0.3135), which averaged 2.00 g/kg^{lwt} and 511 mg/L.

The individual carcass variation between the short and long bleed time treatment pairs seen in the blood loss results is also seen in the COD data. As shown in Figure 2.2, the COD load at the short bleed (31%) had a cov that was double that of the COD load at long bleed 14%),

Scalder PPW – Solids (TS, TSS, TVS)

Total Solids (TS)

There was no interaction between bleed time and scald temperature (*P*=0.8627) for TS, so main effects were analyzed independently. There was a significant difference between the bleed time treatments (*P*=0.0017) for TS, but no significant difference between the scald temperatures (*P*=0.7302). The TS results for bleed time are summarized in Table 2.2 and are graphically represented in Figure 2.3. The TS results for scald temperature are summarized in Table 2.3. The short bleed time at 60 s had a mean TS load of 1.97 g/kg^{lwt} and concentration of 510 mg/L which was significantly greater than the long bleed time 120 s (1.34 g/kg^{lwt} and 339 mg/L). Scald temperature TS results averaged 1.66 g/kg^{lwt} and 425 mg/L. The variation in individual blood loss and COD data in the short and long bleed time treatments was diminished in the TS results. TS data showed the short bleed time treatment cov of 28% was greater than the long bleed time (19% cov) treatment.

Total Suspended Solids (TSS)

There was no interaction between bleed time and scald temperature (*P*=0.4434) for TSS, so main effects were analyzed independently. There was also no significant difference between TSS means for the bleed times (*P*=0.0792) or the scald temperatures (*P*=0.1311), which averaged 0.42 g/kg^{lwt} and 106 mg/L. The TSS results for bleed time and scald temperature are summarized in Tables 2.2 and 2.3.

TS can be defined in terms of particulate size as the sum of TSS and TDS as represented in the equation [39]: TS = TSS + TDS. The mean % of TSS and TDS in relationship to TS for bleed times at 60 s and 120 s is shown in Figure 2.4. The mean TSS% for all samples was 25%.

Previous research on PPW streams from 3 processing plants reported TSS at 43%, 46% and 59% of TS. Our results were substantially lower, but emphasizes the impact of blood on PPW which is high in TDS[67].

Total Volatile Solids (TVS)

There was no significant interaction between bleed time and scald temperature (P=0.5939) for TVS, so main effects were analyzed independently. Significant differences were found between the bleed times mean (P=0.0047), but not between the scald temperatures means (P=0.8144). TVS results for bleed time are summarized in Table 2.2 and are graphically represented in Figure 2.5. TVS results for scald temperature are summarized in Table 2.3. The short bleed time had a mean TVS load of 1.64 g/kg^{lwt} and concentration of 425 mg/L, which was significantly greater than the long bleed time (1.07 g/kg^{lwt} and 270 mg/L). Scald temperature TVS results averaged 1.36 g/kg^{lwt} and 348 mg/L.

TS can be defined in terms of organic content as the sum of TVS (i.e., organic) and TFS (i.e., inorganic) as represented in the equation [39]: TS = TVS + TFS. The mean % of TVS and TFS in relationship to TS for bleed times at 60 s and 120 s treatments is shown in Figure 2.6. The mean TVS% for all samples was 82%. These results are similar to PPW reported from 3 processing plants that showed TVS accounted for 78%, 79% and 80% of TS [67].

Total Kjeldahl Nitrogen (TKN)

Statistical analysis of TKN results showed no interaction between bleed time and scald temperature (P=0.6541), so main effects were analyzed independently. Statistical analysis showed a significant difference between the bleed times means (P=0.0062), but not between the scald temperatures means (P=0.4147). TKN results for bleed time are summarized in Table 2.2 and are graphically represented in Figure 2.7. TKN results for scald temperature are summarized in Table 2.3. The short bleed time had a mean TKN load of 0.27 g/kg^{lwt} and concentration of 70 mg/L, which was significantly greater than the long bleed time (0.20 g/kg^{lwt}, 49 mg/L). Scald temperature TKN results averaged 0.24 g/kg^{lwt} and 60 mg/L.

The highest mean loadings (g/kg^{lwt}) in the scalder PPW samples were for COD (2.00), followed by TS (1.66), TVS (1.36), TSS (0.42) and TKN (0.24). The trend towards the highest loading being produced by the short bleed time treatment, as seen in the COD, TS and TVS results, continued with TKN.

Scalder PPW – Elemental Minerals

Of the 18 elements analyzed, 8 had results of below detectable limit (BDL) for $\geq$75% of the scalder samples and not analyzed further. These elements with associated BDL percentages were Al (92%), B (96%), Cd (100%), Cr (100%), Mo (100%), Ni (100%), Pb (79%), and Si (75%).

There was no statistical interaction between the main effects for the remaining 10 elements, thus effects of bleed time and scald temperature were analyzed independently. Statistical analysis showed that only two elements, iron (Fe) and phosphorus (P) were significantly different based on bleed time (P=0.0022, P=0.0075). However, neither element was significantly different based on scald temperature. The short bleed time treatment had a mean Fe load of 0.001 g/kg^{lwt}, which was significantly greater than the long bleed time mean of 0.0004 g/kg^{lwt}. Results also showed the short bleed time treamtment had a mean P load of 0.01 g/kg^{lwt} which was significantly greater than the long bleed time mean load of 0.009 g/kg^{lwt} (Figure 2.8 and 2.9). These results were expected due to the high Fe and P content in blood that was introduced in the scalder when broilers were bled for 60 s.

The mean concentrations (mg/L), mean loadings (g/kg^{lwt}) and *P*-values for the remaining 8 chemical elements are shown in Table 2.4. Results showed that only one element averaged >10 mg/L and >0.06 g/kg^{lwt}, K (potassium, 16.16 mg/L, 0.0634 g/kg^{lwt}). Sodium (Na), calcium (Ca), sulfur (S) and magnesium (Mg) had mean concentrations in the range of 1 to 10 mg/L and mean loads 0.01 to 0.06 g/kg^{lwt}. Manganese (Mn), zinc (Zn) and copper (Cu) all had mean concentrations <1.0 mg/L and mean loadings <0.01 g/kg^{lwt}.

Extensive work done in 2009 by Kiepper [67] revealed Na as the element with the highest concentration (mg/L) in the total PPW stream from 3 plants, and the only element with concentrations >100 mg/L. K, Ca, P and Si had mean concentrations from 10 to 100 mg/L. Mg and Fe had mean concentrations ranging from 1.0 to 10 mg/L. Remaining elements (i.e., Al, B, Cu, Cr, Mn, Mo, Ni and Zn) had mean concentrations that were <1.0 mg/L [67].

Experiment 2

Blood Loss

The mean live weight of the 120 broilers was 2.09 kg (4.61 lb) with no significant difference between treatments (*P*=0.6469). Analysis of blood loss data is summarized in Table 2.5 and graphically shown in Figure 2.10. The mean mass of blood recovered (*P*=0.0067) and mean % of live weight (*P*=0.0016) blood loss at 120 s (59.0g and 2.81%) was significantly greater than at 60 s (53.6g and 2.59%). This blood loss % of live weight is greater than Experiment 1. This was expected since the mean live weight of birds in this experiment was 2.09 kg compared to 4.09 kg in Experiment 1. The coefficient of variation (cov) was the same between birds bled for 60 s and 120s (i.e., 14% cov) in contrast to Experiment 1.

Scalder PPW – Organics

Statistical analysis showed no significant interaction between bleed time and scald temperature (*P*=0.0912) for COD means. Therefore, the scalder COD data were analyzed separately for bleed time and scald temperature. COD results for bleed time are summarized in Table 2.6 and are graphically represented in Figure 2.11. COD results for scald temperature are summarized in Table 2.7. As predicted and seen in Experiment 1, the short bleed time (*P*=0.0126) at 60 s had a mean organic load of 1.72 g/kg^{lwt} and concentration of 886 mg/L, which was significantly greater than the long bleed time at 120 s (1.51 g/kg^{lwt}, 792 mg/L). The scalding container receives blood, manure, dissolved fats, greases, feathers and external debris that wash from the carcass during submersion and agitation [50]. Previous research done on PPW collected from operating scalders in commercial processing plants has shown the COD concentration to be at 1330, 1678, and 2268 mg/L [7, 51, 68]. Scalder temperature did not produce a significant differences in COD loading or concentration in scalder PPW (*P*=0.9207), which averaged 1.62 g/kg^{lwt} and 862 mg/L.

Mean carcass PPW loads (g/kg^{lwt}) can be used to calculate economic impact of pollutant reductions (e.g., increasing bleed time) based on processing surcharges. As an example, the mean scalder PPW COD load for carcasses bled for 60 s was 1.72 g/kg^{lwt} versus 1.51 g/kg^{lwt} at 120 s. Thus, on average, an additional 0.21 g/kg^{lwt} COD entered the scalder for carcasses bled for the shorter time. Using the typical value of $0.30/lb COD surcharge fee the following calculation can be made for a typical poultry processing plant slaughtering 250,000 birds per day (bpd), weighing 2.1 kg per bird for 260 processing days per year:

(250,000 bpd) (2.1kg) = 525,000 kg/d

525,000 kg (0.21 g/kg^{lwt}) = 110,250 g COD/d

110,250 g/d = 243 lbs/d

(243 lbs/d) ($0.30/lb) = $ 72.90/d

($ 72.90/d) (260 processing days/yr) = $ 18,954/yr

Scalder PPW – Solids (TS and TSS)

Total Solids (TS)

There was no interaction between bleed time and scald temperature (*P*=0.6477) for TS. When analyzed independently, there was also no significant difference found between the bleed times means (*P*=0.6178) or the scald temperatures means (*P*=0.8147) for TS, which averaged 3.02 g/kg^{lwt} and 1572 mg/L. The TS results for bleed time and scald temperature are summarized in Tables 2.6 and 2.7.

The scalder not only loosens the feathers to aid in picking, but also provides a first wash to the carcass [50]. Previous research states that the scald tank in a poultry processing plant contains blood, manure, dirt and external debris that washes from the feathers [7, 9]. The experimental TS results (1572 mg/L) compare relatively closely to Hamm (1972) where he characterized TS of scalder waste water to be 1635 mg/L in a commercial scald tank [7].

Total Suspended Solids (TSS)

There was no interaction between bleed time and scald temperature in terms of TSS (*P*=0.5470). When main effects were analyzed independently, there was no significant difference found between the bleed times (*P*=0.5517) or the scald temperatures (*P*=0.4604) treatments, which averaged 0.61 g/kg^{lwt} and 314 mg/L. The TSS results for load and concentration are summarized in Tables 2.6 and 2.7. The mean TSS concentration achieved in the scalder (314 mg/L) is lower than reported in commercial scalding units, such as a survey done in 1975 by the EPA in which it was reported that TSS in scalder PPW was 473 mg/L and

687 mg/L [42]. The mean % of TSS and TDS in relationship to TS for bleed times and scald temperatures are shown in Figure 2.12. The TSS averaged 20%. Previous research on PPW streams from 3 processing plants reported TSS at 43%, 46% and 59% of TS, which are substantially higher than the results of this experiment, but emphasize the impact of blood on PPW in this experiment since blood is highly soluble and relatively high in TDS [67].

CONCLUSIONS AND APPLICATIONS

1. Blood loss as a % of live weight was significantly greater at 120 s than at 60 s for both Experiments 1 and 2.
2. No interaction between bleed time and scald temperature was seen in scalder PPW.
3. Bleed time (i.e., 60 s versus 120 s) had a significant impact on the volume of blood entering the scalder and thus on PPW loadings for COD for both Experiments 1 and 2.
4. Bleed time (i.e., 60 s versus 120 sec) had a significant impact on TS, TVS, and TKN in Experiment 1.
5. Bleed time did not significantly impact TSS loadings in scalder PPW in either Experiment 1 or 2.
6. Scalder water temperature (i.e., soft-scald versus hard-scald) did not have a significant impact on wastewater loadings (g/kg^{lwt}) of COD, TS, TSS, TVS or TKN in either Experiment 1 or 2.
7. The highest mean loading (g/kg^{lwt}) in the scalder PPW samples from Experiment 1 was for COD (2.00), followed by TS (1.66), TVS (1.36), TSS (0.42) and TKN (0.24).
8. The highest mean loading (g/kg^{lwt}) in the scalder PPW samples from Experiment 2 was for TS (3.02), followed by COD (1.62) and TSS (0.61).
9. The 82% increase in TS mean loading (g/kg^{lwt}) from Experiment 1 (i.e, experimental

broilers) versus Experiment 2 (i.e., commercial broilers) indicates the impact of broiler external cleanliness on solids loadings in scalder PPW.

CHAPTER 3

IMPACT OF WATER-FLUME TRANSPORT OF INDIVIDUAL AND GROUPS OF CARCASSES FEATHER AND VISCERA OFFAL ON POULTRY PROCESSING WASTEWATER[1]

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[1]Plumber, H.S., and B.H. Kiepper. To be submitted to the *Journal of Applied Poultry Research*

SUMMARY

Two experiments were conducted to measure the effects of bleed time and scald temperature on individual and groups of carcasses' impact on feather and viscera rinse poultry processing wastewater (PPW). In Experiment 1 (24 male experimental broilers) and Experiment 2 (120 commercial broilers) birds were randomly assigned to 4 treatment groups: SS (short-bleed/soft-scald), SH (short-bleed/hard-scald), LS (long-bleed/soft-scald), and LH (long-bleed/hard-scald) (short-bleed = 60 s, long-bleed = 120 s, soft-scald = 50^{o}C, hard-scald = 60^{o}C). Feathers were removed from individual slaughtered carcass (Experiment 1: ~100g) or from each batch of 5 carcasses (Experiment 2: ~100g/carcass). Feathers were agitated in bags with 2 L of rinse water (Experiment 1) or plastic containers with 4 L of rinse water (Experiment 2) for 2 min and then screened with feather rinse PPW samples retained for analyses. Broilers were then manually eviscerated. Viscera were initially agitated in bags with 4 L of rinse water (Experiment 1) or plastic containers with 8 L of rinse water (Experiment 2) for 1 min with half the volume of PPW then screened with viscera rinse PPW samples retained for analyses. Viscera containers were then agitated for 2 additional min, the contents screened and the remaining viscera rinse PPW samples retained for analyses. Samples of feather and viscera rinse PPW were analyzed for concentration (mg/L) of COD, TS, TSS, TVS, and TKN in Experiment 1 and COD, TS, and TSS in Experiment 2. A PPW load (g/kg^{lwt}) was calculated for each concentration (mg/L) data point. The highest mean loading (g/kg^{lwt}) in the feather rinse PPW samples from Experiment 1 was for COD (0.303), followed by TS (0.214), TVS (0.171), TSS (0.097) and TKN (0.030). The highest mean loading (g/kg^{lwt}) in the feather rinse PPW samples from Experiment 2 was for COD (0.345), followed by TS (0.681), and TSS (0.115).

Keywords: poultry processing, wastewater, feathers, viscera, COD, TSS, TKN

Primary Audience: Processing Plant Managers, Wastewater Operators, Researchers

DESCRIPTION OF PROBLEM

U.S. poultry processing plants use a water-based 'flow-away system' where large quantities of water move processing byproducts such as uncollected blood, feathers, and viscera in a flume to a screening (i.e., offal recovery) station Mechanical screens capture the large solids from the poultry processing wastewater (PPW) stream while a portion of the liquid is typically recirculated through the 'flow-away' flumes [13, 42]. As an example, the amount of water used at a typical defeathering station has been estimated to be 10.6 L (2.8 gal) per broiler where 50% of the water used is fresh and the other 50% is reused or recirculated [42]. The U.S. Environmental Protection Agency (EPA) states that defeathering PPW contains feces, dirt, uncollected blood and feathers that will increase biochemical oxygen demand (BOD) concentration (mg/L). Feathers themselves are somewhat resistant to degeneration in PPW. However, the PPW feather flume has been reported by EPA in 1973 to have a BOD of 600 mg/L [50]. In 1978, Hamza et al., indicated that the mean BOD and chemical oxygen demand (COD) from feather flumes within a poultry processing plant were 937 mg/L and 1449 mg/L, respectively [51].

Evisceration increases PPW pollutant loading and it has been reported to be responsible for one third of the entire plant PPW pollutant load [61]. Large quantities of water are used in the evisceration process in carcass cleaning, rinsing of automated evisceration equipment, viscera flow-away flumes and sanitation. Wastewater generated from evisceration is high in BOD, total suspended solids (TSS), oil and grease (O&G), blood and bacteria from the intestinal tract. The amount of eviscerating flume water used per broiler has been reported to be 11.7 L

(3.1 gal). BOD from the final bird wash after evisceration has been reported by EPA to be 440 mg/L [50].

This experiment was conducted to: 1) measure the variation of individual and groups of carcasses and poultry byproduct (i.e., feathers and viscera) impacts on PPW based on bleed time and scald temperature, and 2) establish mean carcass PPW loads (grams per kilogram live weight) for the common wastewater analytical parameters of COD, total solids (TS), TSS, total volatile solids (TVS), and total Kjeldahl nitrogen (TKN).

MATERIALS AND METHODS

Experiment 1

An experimental broiler flock was reared to 8 weeks of age in six 32-bird pens on pine shavings. Twenty-four (24) male broilers were randomly selected and divided among four treatments: 1. **SS** (Short Bleed Time/Soft-Scald), 2. **SH** (Short Bleed Time//Hard-Scald), 3. **LS** (Long Bleed Time/Soft-Scald), and 4. **LH** (Long Bleed Time/Hard-Scald). Bleed time levels were set at Short = 60 s or Long = 120 s [62], while scalder water temperature levels were set Soft-Scald = 50^{o}C (122^{o}F) or Hard-Scald = 60^{o}C (140^{o}F).

Birds were processed in eight (8) batches of 3 birds each. After the birds were stunned, decapitated and scalded as described in Chapter 2, Experiment 1, they were taken to a defeathering station. A representative sample of approximately 100 g of feathers were plucked by hand from each carcass and placed in a pre-weighed plastic bag. Weight of feathers was determined and 2 L of potable rinse water were added to each bag and manually agitated for 2 min. A 2 L background sample of source rinse make-up water was collected and placed on ice. The feathers and rinse PPW were then sieved through a 500 µm sieve. The resulting 2 L feather rinse PPW sample was collected and placed on ice.

After the birds were defeathered they were eviscerated by hand. The viscera from each carcass was removed and placed in a pre-weighed plastic bag. Viscera weight was determined and 4 L of potable rinse water was added to the bag. A 2 L background sample of source rinse make-up water was collected and placed on ice. Each bag was first agitated for 1 min following which 2 L of rinse water was poured from the bag through a 500 µm sieve, collected and placed on ice. Each bag was then agitated for an additional 2 min (i.e., 3 min total) and the remaining 2L of rinse water poured through a 500 µm sieve, collected and placed on ice.

Analytical Methods

The rinse water background, and feather and viscera rinse PPW samples from Experiment 1 were analyzed for COD (chemical oxygen demand method 5220D), TS (total solids method 2540B), TSS (total suspended solids method 2540D), TVS (total volatile solids 2540E), and TKN (total Kjeldahl nitrogen method 4500-NorgD) [39].

Data Treatment

1. ***Weight of Feathers and Viscera*** - Each feather and viscera collection bag was weighed in grams. After the byproduct (i.e., feathers or viscera) was collected, the weight of the empty sample bag was subtracted from weight of collected byproduct and sample bag to determine total weight of the byproduct.
2. ***Feather Data Values*** - Feathers account for approximately 7% of a broiler's live weight [59]. Thus, each broiler's measured live weight was multiplied by 0.07 to determine the approximate weight of total feathers per bird. During the experiment approximately 100 g of feathers were collected. Both feather rinse PPW concentration (mg/L) and load values were normalized to 7% of each broiler's live weight to account for the approximate weight of total feathers. Normalization was

accomplished by dividing the 7% of live weight value by the actual weight of feathers collected from each carcass. Each concentration (mg/L) and load (g/kg^{lwt}) data point was then multiplied by the resulting normalization value.

3. ***Feather Rinse PPW*** - If the background sample concentration was at a detectable level, that background concentration value was subtracted from the data point. If the background sample concentration was below detectable limit (BDL), the concentration data point remained as reported. A load value in grams/bird (g/b) was determined for each data point by multiplying the volume of rinse water (2 L) by the concentration (mg/L) of that parameter. The result (mg) was divided by 1000 to determine the load in grams (g). The result of the normalized feather weight in grams was multiplied by final load value of grams/bird (g/b). A load in g/kg^{lwt} was then calculated by dividing the g/b value by the kilogram live weight of the broiler.
4. ***Viscera Rinse PPW*** - A g/b load was first obtained for the 1 min agitation time by multiplying the concentration (mg/L) by the 4 L of rinse water initially used. Next, the concentration of the additional 2 min of agitation time was obtained by subtracting the reported concentration value (mg/L) at the 1 min from the concentration value (mg/L) reported at the additional 2 min agitation time. A g/b load value was calculated for the 2 additional min of viscera agitation using 2 L of rise water. The loading for the 3 min of agitation time was calculated by adding the load obtained for 1 min agitation time and additional 2 min agitation time.

Experiment 2

One hundred and twenty (120) commercial broilers were used for this experiment. The experiment was conducted on one day per week for 3 weeks, with 40 birds processed each week.

On the day of processing, 40 birds were randomly selected from a commercial-style dump coop at a north Georgia processing plant and transferred to plastic top-loading coops for transport to the processing laboratory. The birds were divided into 4 treatments similar to Experiment 1. The birds were then processed as described in Chapter 2, Experiment 2 with the following exceptions: First, broilers were processed in 5 bird batches. Second, representative feathers from each batch of 5 birds were plucked by hand and placed in a 10 L plastic container and weighed. 4 L of rinse water was added and the container was manually agitated for 2 min and sieved. Third, the viscera from each batch of 5 birds was collected and placed in a plastic container. 8 L of rinse water was added and manually agitated for 1 min following which 4 L of viscera rinse PPW sample was poured from the container through a 500µm sieve. The container was then agitated for an additional 2 min (i.e., 3 min total) and the remaining 4 L of PPW was screened through a 500µm sieve.

Data Treatment

1. ***Weight of Feathers and Viscera*** – The byproduct (i.e., feathers or viscera from 5 carcasses) was collected in 10 L plastic containers and treated similarly to Experiment 1 to determine the total weight of the byproduct.
2. ***Feather Data Values*** – Feathers were treated similarly to Experiment 1 with the following exception: to determine the approximate weight of total feathers in each batch, results were multiplied by 5 and normalization was accomplished using the average live weight of the corresponding batch.
3. ***Feather Rinse PPW*** – Feather rinse PPW samples were treated similarly to Experiment 1 with the following exceptions: 4 L of feather rinse water was used to calculate a load value in grams per batch. Since the loading represented a 5 bird

batch, results were divided by 5 to get a gram/bird (g/b) value. To obtain a g/kg^{lwt} load, g/b results were divided by the average kilogram broiler kg live weight in each corresponding batch.

4. ***Viscera Rinse PPW*** – Viscera rinse PPW samples were treated similarly to Experiment 1 with the following exceptions: 8 L of rinse water was initially used to calculate a grams per batch load for the 1 min agitation time. 4 L of rinse water was used to calculate a grams per batch load for the 2 additional min of viscera agitation. Since the loading represented a 5 bird batch, results were divided by 5 to get a g/b value. To obtain a g/kg^{lwt} load, g/b results were divided by the average broiler kg live weight in each corresponding batch.

Statistical Analysis

Data were subjected to statistical analysis by using the GLM procedure of the SAS/STAT program. Data from the 4 treatments (SS, SH, LS, LH) with 6 replications were analyzed by factorial ANOVA (2 x 2). The feather and viscera rinse PPW data were first run as ANOVA with an interaction term between the main factors (i.e., bleed time and scald temperature). If the interaction was not significant (P>0.05), ANOVA was re-run without the interaction term and each factor was analyzed independently. Means were separated using the Tukey-HSD multiple comparisons procedure [64]. Differences in means were regarded as significant at P<0.05.

RESULTS AND DISCUSSION

Experiment 1

Feather Rinse PPW – Organics

Feather rinse PPW COD means showed no significant main effects interaction (P=0.5343). Therefore, feather rinse PPW COD data were analyzed separately for bleed time and scald temperature. Feather rinse PPW COD results for bleed time are summarized in Table 3.1. Feather rinse PPW results for scald temperature are summarized in Table 3.2 and are graphically represented in Figure 3.1.

There was no significant difference in mean COD load and concentrations for bleed time (P=0.6386), which averaged 0.303 g/kg^{lwt} and 619 mg/L. However, scalder temperature did produce a significant differences in COD loading and concentration (P=0.0233). Results showed that the hard scald treatment produced a mean COD load of 0.330 g/kg^{lwt} and concentration of 676 mg/L, which was significantly greater than the soft scald treatment (0.275 g/kg^{lwt} and 562 mg/L).

The COD concentration results are significantly lower than reported in previous research where the median COD of feather flume PPW samples collected from ten poultry processing plants was reported to be 1919 mg/L. However, in addition to the fact that this experiment reports concentrations generated by individual carcass feather washing, Hamm (1972) explained that in commercial processing plants feather flume PPW contains pollutants from sources in addition to the defeathering process. These additional sources include the bleed out area, overflow from the scalders, and the whole bird washers within the defeathering area [7].

Feather Rinse PPW – Solids (TS, TSS, TVS)

Total Solids (TS)

There was no significant interaction between bleed time and scald temperature for TS (P=0.8586), thus the main effects were analyzed independently. The feather rinse PPW TS results for bleed time and scald temperature are summarized in Tables 3.1 and 3.2.

There was no significant difference between the bleed time (P=0.4314) or scald temperature treatments (P=0.2484). The feather rinse PPW TS load averaged 0.214 g/kg^{lwt} and concentration averaged 436 mg/L. Previous research by Hamm (1972) found that feather flume PPW from ten commercial poultry processing plants had a median TS of 974 mg/L [7].

Total Suspended Solids (TSS)

There was no significant interaction between bleed time and scald temperature (*P*=0.8600) in terms of TSS, so main effects were analyzed independently. The TSS results for load (g/kg^{lwt}) and concentration (mg/L) are summarized in Tables 3.1 and 3.2. There was no significant difference between the bleed time (*P*=0.2325) or scald temperature treatments (*P*=0.7145). The feather rinse PPW TSS load averaged 0.097 g/kg^{lwt} and concentration averaged 198 mg/L. EPA has reported the TSS concentration in a commercial feather flume to be 512 mg/L [42].

TS can be defined in terms of particulate size as the sum of TSS and TDS as represented in the equation [39]: TS = TSS + TDS. The mean % of TSS and TDS in relationship to TS for bleed times (60 s and 120 s) and scald temperatures (50^{o}C and 60^{o}C) is shown in Figure 3.2. The mean % for TSS for all 24 samples was 45%.

Total Volatile Solids (TVS)

There was no significant interaction between bleed time and scald temperature (*P*=0.7922) in TVS results, so main effects were analyzed independently. There was no significant difference found between the bleed time (*P*=0.3588) or scald temperature treatments (*P*=0.9809) for TVS. The TVS results for load (g/kg^{lwt}) and concentration (mg/L) are summarized in Tables 3.1 and 3.2, which averaged 0.171 g/kg^{lwt} and 349 mg/L. Previous research by Hamm (1972) reported that the TVS of feather flume PPW from a poultry processing plant was 808 mg/L [7].

TS can be defined in terms of organic content as the sum of TVS (i.e., organic) and TFS (i.e., inorganic) as represented in the equation [39]: TS = TVS + TFS. The mean % of TVS and TFS in relationship to TS for bleed times (60 s and 120 s) and scald temperatures (50°C and 60°C) is shown in Figure 3.3. The mean TVS% for all 24 samples was 81%. These results compare closely to previous research done on feather flume wastewater from ten commercial poultry processing plants where TS was 83% TVS and 17% TFS [7].

Feather Rinse PPW - Total Kjeldahl Nitrogen (TKN)

There was no significant interaction between bleed time and scald temperature (P=0.3911) in terms of TKN, so main effects were analyzed independently. There was no significant difference between the bleed time (P=0.8172) or scald temperature treatments (P=0.1426) for TKN. The treatment mean TKN loads (g/kg^{lwt}) and concentrations (mg/L) are summarized in Tables 3.1 and 3.2, which averaged 0.03 g/kg^{lwt} and 60 mg/L.

The highest mean loading (g/kg^{lwt}) in feather rinse PPW samples were from COD (0.303), followed by TS (0.214), TVS (0.171), TSS (0.097) and TKN (0.03).

Viscera Rinse PPW – Organics

Viscera rinse PPW showed no significant interaction between the main effects for any of the wastewater parameters tested at either agitation time. Therefore, bleed time and scald temperature were analyzed independently.

The COD results for bleed time and scald temperature at 1 min viscera agitation time are summarized in Tables 3.3 and 3.4, and for the 2 min additional agitation time in Tables 3.5 and 3.6. There was no significant difference between the bleed time (P=0.8303) or scald temperature treatments (P=0.5698) in terms of COD mean loads at 1 min agitation time, which averaged 0.301 g/kg^{lwt} and 307 mg/L. There was also no significant difference between the bleed time

(P=0.3583) or scald temperature treatments (P=0.0513) in terms of COD means at the 2 min additional agitation time that averaged 0.205 g/kg^{lwt}.

Previous research completed in 1976 and 1990 reported that the COD of commercial evisceration troughs from a poultry processing plant were 2389 and 6720 mg/L, respectively [46, 68]. Evisceration PPW contains more byproducts such as blood, bits of fat, and meat scraps than any other plant PPW stream. Therefore, it is expected that the evisceration wastewater will contain a higher COD concentration [7, 9] compared to our experiment (724 mg/L). Research also says water from the viscera flume consists of water from the chiller process, the evisceration trough, the giblet chiller, and the final bird washers [7].

Table 3.7 summarizes viscera rinse PPW load for COD at 1 min and 3 total min agitation time. Figure 3.4 graphically represents the comparison between the 1 and 3 min agitation time on viscera rinse PPW COD load. As expected (P=0.0001), the 3 min agitation time had a mean organic load of 0.506 g/kg^{lwt} and concentration of 724 mg/L, which were both significantly greater than the 1 min agitation time (0.301 g/kg^{lwt} and 307 mg/L) and represented an increase of 68%.

Viscera Rinse PPW – Solids (TS, TSS, TVS)

Total Solids (TS)

The TS results for bleed time and scald temperature at 1 min agitation time are summarized in Tables 3.3 and 3.4, and for 2 min additional agitation time in Tables 3.5 and 3.6. There was no significant difference between the bleed time (P=0.7664) or scald temperature treatments (P=0.9991) for TS means at 1 min agitation time, which averaged 0.157 g/kg^{lwt} load and 161 mg/L. There was also no significant difference between the bleed time treatments (P=0.3199) or the scald temperature treatments (P=0.0656) for TS means at the 2 min additional agitation time, which averaged 0.121 g/kg^{lwt}.

Table 3.7 summarizes viscera rinse PPW for TS at 1 min and 3 total min agitation time. Figure 3.5 graphically represents the comparison between the 1 min and 3 total min agitation times on viscera rinse PPW TS load. As expected ($P<0.0001$), the 3 min total agitation time had a mean TS load of 0.277 g/kg^{lwt} and concentration of 406 mg/L, which was significantly greater than the 1 min agitation time (0.157 g/kg^{lwt} and 160 mg/L), and represented an increase load of 76%. Previous research has reported TS in evisceration flumes from ten poultry processing plants to average 382 mg/L [7, 9].

Total Suspended Solids (TSS)

The 1 min agitation time results for viscera rinse PPW TSS load for bleed time and scald temperature is summarized in Table 3.3 and 3.4. The 2 min additional agitation time TSS data for bleed time is shown in Table 3.5. The 2 min additional agitation time TSS data for scald temperature is shown in Table 3.6 and graphically represented in Figures 3.6. There was no significant difference between the bleed time ($P=0.7788$), or scald temperature treatment means ($P=0.8227$) for TSS at 1 min agitation time, which averaged 0.062 g/kg^{lwt} and 64 mg/L. There was also no significant difference between the bleed time treatment means ($P=0.9887$) for viscera rinse PPW TSS at the 2 min additional agitation time that averaged 0.058 g/kg^{lwt} and 118 mg/L. However, there was a significant difference between scald temperature treatment means ($P=0.0347$) for TSS at the 2 min additional agitation time. The viscera rinse PPW TSS load and concentration means at the 2 min additional agitation time for soft scald were 0.073 g/kg^{lwt} and 150 mg/L, respectively, which were significantly greater than the hard scald means (0.042 g/kg^{lwt} and 86 mg/L).

Table 3.7 compares viscera rinse PPW means for TSS at 1 min and 3 min total agitation time. Figure 3.7 graphically represents the comparison. As expected, 3 min total agitation time had a mean TSS load of 0.120 g/kg^{lwt} and concentration of 182 mg/L, which was significantly greater than the 1 min agitation time (0.062 g/kg^{lwt} and 64 mg/L), and represented an increase load of 94%. Research done in 1990 by Merka reported the TSS from evisceration PPW at a broiler processing plant to be 2599 mg/L [46].

Total Volatile Solids (TVS)

The TVS results for bleed time and scald temperature means of viscera rinse PPW TVS at 1 min agitation time are summarized in Tables 3.3 and 3.4, and for 2 min additional agitation time in Tables 3.5 and 3.6. There was no significant difference between the bleed time treatment means (P=0.8200), and the scald temperature treatment means (P=0.3446) for viscera rinse PPW TVS at 1 min agitation time, which averaged 0.155 g/kg^{lwt} and 158 mg/L. There was also no significant difference between the bleed time (P=0.5654) or scald temperature treatment (P=0945) means for TVS at the 2 min additional agitation time that averaged 0.119 g/kg^{lwt}.

The impact of the additional 2 min of agitation on viscera rinse PPW TVS load and concentration is summarized in Table 3.7 and graphically represented in Figure 3.8. As expected, the 3 min total agitation time had a mean TVS load of 0.274 g/kg^{lwt} and concentration of 399 mg/L, which was significantly greater than the 1 min agitation time (0.155 g/kg^{lwt} and 158 mg/L/b) and represented an increase load of 77%.

Evisceration PPW from a broiler processing plant was reported by Merka in 1991 to have a TVS concentration of 4146 mg/L [46]. This is substantially higher than research done in 1972 where TVS of eviscerating flumes from poultry processing plants were reported to have a median of 289 mg/L with the highest concentration being 651 mg/L [7].

Viscera Rinse PPW - Total Kjeldahl Nitrogen (TKN)

The 1 min agitation time data for viscera rinse PPW TKN load and concentration for bleed time and scald temperature are summarized in Tables 3.3 and 3.4, and for the 2 min additional agitation time in Table 3.5. TKN results for scald temperature at the 2 min additional agitation time are summarized in Table 3.6 and shown in Figure 3.9. There was no significant difference between the bleed time (P=0.4844), and scald temperature treatment means (P=0.8147) for viscera rinse PPW TKN at 1 min agitation time, which averaged 0.018 g/kg^{lwt} and 20 mg/L. There was also no significant difference between the bleed time treatment means (P=0.5644) for TKN at the 2 min additional agitation time that averaged 0.001 g/kg^{lwt} and 20 mg/L. However, there was a significant difference between scald temperature treatment means (P=0.0242) for TKN at the 2 min additional agitation time. The viscera rinse PPW TKN load and concentration means at the 2 min additional agitation time for soft scald were 0.012 g/kg^{lwt} and 24 mg/L, respectively, which were significantly greater than the hard scald means (0.008 g/kg^{lwt} and 16 mg/L).

The comparison of viscera rinse PPW TKN load at 1 min and 3 total min agitation times is summarized in Table 3.7 and graphically shown in Figure 3.10. The 3 min agitation time had a TKN mean load of 0.029 g/kg^{lwt} and concentration of 40 mg/L, which was significantly greater than the 1 min agitation time (0.018 g/kg^{lwt} and 20 mg/L) and represented an increase load of 61%. Previous research done by Merka stated that the TKN of evisceration PPW was 70 mg/L [46].

Experiment 2

Feather Rinse PPW – Organics

Statistical analysis showed no interaction between bleed time and scald temperature (*P*=0.9814) for COD load, therefore, main effects were analyzed independently. The COD results for bleed time and scald temperature are summarized in Tables 3.8 and 3.9. There was no significant difference in the means for bleed time (*P*=0.3970) or scald temperature (*P*=0.7042) in feather rinse PPW which averaged 0.345 g/kg^{lwt} and 880 mg/L.

Water sprays are used to flush feathers from the defeathering process into a flume which serves as a flow-away removal system for feathers and associated external debris [69]. Previous research conducted at commercial plants reported that the COD of 2 feather flumes was 1919 mg/L [7] and 1449 mg/L [51]. These reported concentration values are substantially greater than the mean results for this experiment's feather rinse PPW wastewater of 880 mg/L.

Feather Rinse PPW – Solids (TS, and TSS)

Total Solids (TS)

There was no interaction between bleed time and scald temperature (*P*=0.7095) in TS results. Independent analysis showed that there was no significant difference between the bleed time treatments (*P*=0.8972), which averaged 0.681 g/kg^{lwt} and 1769 mg/L. The soft scald produced a mean TS load of 0.712 g/kg^{lwt} and concentration of 1893 mg/L, which was significantly greater than the hard scald at 60^{o}C (0.648 g/kg^{lwt} and 1645 mg/L). The TS results for bleed time are summarized in Tables 3.8. The TS results for scald temperature are shown in Table 3.9 and graphically represented in Figure 3.11.

The function of the scalder is not only to loosen the feathers but it also provides a first wash to the carcass [50]. Feathers have a high water absorptive capacity and are able to retain water during scalding. Research says that the moisture content of feathers is about 75 to 80% after scalding [70]. This allows the feathers to retain water that is high in blood and external debris. Results show that the average TS for both bleed time and scald temperature in this experiment was 1769 mg/L. This mean concentration is substantially higher in TS than previous research from commercially operating feather flumes. Hamm (1972) reports the median TS of a feather flume from ten poultry processing plants to be 974 mg/L [7]. A project done on waste management at a Gold Kist plant in Durhan, NC further states TS from the feather flume to be 894 mg/L [69].

Total Suspended Solids (TSS)

There was no interaction between bleed time and scald temperature (P=0.9914) in terms of TSS. Independently, there was also no significant difference found between the bleed times (P=0.4619) or the scald temperatures (P=0.2807) which averaged 0.115 g/kg^{lwt} and 293 mg/L for TSS. The TSS results for load and concentration are summarized in Tables 3.8 and 3.9.

TSS are solids that can be removed from the wastewater by laboratory filtration, but it does not include coarse or floating materials that can be easily screened [42]. The average TSS concentrations for both bleed time and scald temperature is 293 mg/L. A project done on waste management at a Gold Kist plant in Durhan, NC reports the TSS from the feather flume to be 512 mg/L [69]. On the other hand Merka reports a greater average TSS from the feather flow of five broiler processing plants to be 1667 mg/L [46].

The mean % of TSS and TDS in relationship to TS for bleed times (60 s and 120 s) and scald temperatures (50^{o}C and 60^{o}C) are shown in Figure 3.12. The mean % for TSS for all samples was 17%. These results are substantially different from previous research reported on a Gold Kist Plant in Durham, NC. Results from a feather flume showed that in relation to TS, TSS was 57% and TDS was 43% [69].

Viscera Rinse PPW – Organics

There was no significant interaction between bleed time and scald temperature treatments for COD, TS, and TSS load at either the 1 min or 2 min additional agitation times. Therefore, the viscera data for all 3 parameters were analyzed separately for bleed time and scald temperature.

The COD results for viscera rinse PPW for bleed time and scald temperature at the 1 min agitation time are summarized in Tables 3.10 and 3.11. The COD results for bleed time at the additional 2 min agitation are summarized in Tables 3.12, and graphically represented in Figure 3.13. The COD result for scald temperature at additional 2 min agitation time is summarized in Table 3.13. There was no significant difference between the bleed time (P=0.0827), and the scald temperature treatments (P=0.0678) for COD mean load or concentration at 1 min agitation time, which averaged 0.674 g/kg^{lwt} and 876 mg/L. At the additional 2 min agitation time, the short bleed time (P=0.0468) treatments averaged was 0.377 g/kg^{lwt} which was significantly greater than the long bleed time mean of 0.289 g/kg^{lwt}. There was also no significant difference between the scald temperature treatments (P=0.3544) for COD load at 2 additional min agitation, which averaged 0.334 g/kg^{lwt} and 876 mg/L.

Table 3.14 compares the viscera load for COD at the 1 min agitation time and the 3 min agitation time and Figure 3.14 graphically represents the comparison. As expected (P<0.0001), the 3 min agitation time had a mean organic load of 1.01 g/kg^{lwt} and concentration of 1752 mg/L, which was significantly greater than the 1 min agitation time (0.674 g/kg^{lwt}, 876 mg/L) and represented an increase load of 50%.

Individual PPW loads (g/kg^{lwt}) can be used to calculate economic impact of pollutant reductions based on processing changes (i.e., reducing viscera agitation time). As an example, the mean PPW COD load for 1 minute of viscera agitation was 0.674 g/kg^{lwt} versus 1.01 g/kglwt after 3 minutes of agitation. Thus, on average, an additional 0.336 g/kg^{lwt} of COD was produced by the 2 additional min of agitation. Using the typical value of $0.30/lb COD surcharge fee the following calculation can be made for a typical poultry processing plant slaughtering 250,000 birds per day (bpd), weighing 2.1 kg per bird for 260 processing days per year:

(250,000 bpd) (2.1kg) = 525,000 kg/d

525,000 kg (0.336 g/kg^{lwt}) = 176,400 g COD/d

176,400 g/d = 389 lbs/d

(389 lbs/d) ($0.30/lb) = $ 116.70/d

($ 116.70/d) (260 processing days/yr) = $ 30,342/yr

Viscera Rinse PPW – Solids (TS, TSS, TVS)

Total Solids (TS)

The TS results for bleed time and scald temperature at the 1 min agitation time are summarized in Tables 3.10 and 3.11, and for the 2 min additional agitation time in Table 3.12, and graphically seen in Figure 3.15. The TS results for scald temperature at the 2 min additional agitation time are summarized in Table 3.13. There was no significant difference between the bleed time (P=0.1837) or the scald temperature means (P=0.0530) for TS mean load at 1 minute agitation time, which averaged 1.16 g/kg^{lwt} and 1516 mg/L. At the 2 min additional agitation time, the short bleed time (P=0.0312) had a mean load of 0.291 g/kg^{lwt} and concentration of 764 mg/L, which was significantly greater than the long bleed time (0.184 g/kg^{lwt} and 480 mg/L).

However, there was no significant difference between scald temperature treatments (*P*=0.2376) for TS means at the 2 min additional agitation time which averaged 0.237 /kg^{lwt} and 622 mg/L.

Previous research has found the median TS of a viscera flume from 10 poultry processing plants (532 mg/L) [7] to be substantially lower than our results (1516 mg/L). Due to the increased use of potable water in commercial evisceration system, especially inside-outside bird washers (IOBW), the dilution effect on concentration of TS is predictable.

The comparison between viscera load for TS at 1 min and 3 min agitation time is summarized in Table 3.14 and graphically shown in Figure 3.16. The 3 min agitation time had a mean load of 1.40 g/kg^{lwt} and concentration of 2138 mg/L, which was significantly greater (*P*<0.001) than the 1 min agitation time (1.16 g/kg^{lwt} and 1516 mg/L) and represented an increase load of 21%.

Total Suspended Solids (TSS)

The 1 min agitation time for viscera rinse PPW TSS loads and concentrations for bleed time and scald temperature are summarized in Tables 3.10 and 3.11, and the 2 min additional agitation time in Tables 3.12 and 3.13. There was no significant difference between the bleed time (*P*=0.2787) or scald temperature (*P*=0.0708) treatments on TSS mean load (0.111 g/kg^{lwt}) or mean concentration (144 mg/L) at 1 minute agitation time. There was also no significant difference between bleed time (*P*=0.4630) or scald temperature (*P*=0.2495) treatment for TSS mean load (0.0775 g/kg^{lwt}) or mean concentration (204 mg/L) at the 2 min additional agitation time. Research done in 1991 by Merka shows the TSS from evisceration PPW of a broiler processing plant to be 2599 mg/L [46].

The comparison between viscera load for TSS at 1 min and 3 min agitation time is summarized in Table 3.14 and graphically shown in Figure 3.17. The 3 min agitation time had a mean load of 0.188 g/kg^{lwt} and concentration of 348 mg/L for TSS, which was significantly greater (*P*<0.0001) than the 1 min agitation time (0.111 g/kg^{lwt} and 144 mg/L) and represented an increased load of 71%.

As described previously, total solids (TS) can be defined in terms of particulate size as the sum of total suspended solids (TSS) and total dissolved solids (TDS) [71]. The mean % of TSS and TDS in relationship to TS for the 1 min and 3 min agitation time is shown Figure 3.18. The mean % for TSS for all samples was 12%. Thus in respect to particulate size, the TS in the viscera water samples averaged 12% TSS and 88% TDS. These results emphasizes the impact of blood and fine tissue particulates on evisceration PPW in this experiment since blood is highly soluble (i.e., high in TDS) and low in TSS.

CONCLUSIONS AND APPLICATIONS

1. No interaction was seen between bleed time and scald temperature treatments in feather or viscera rinse PPW.
2. Bleed time (i.e., 60 s versus 120 s) did not have a significant impact on feather rinse PPW loadings (g/kg^{lwt}) either Experiment 1 (COD, TS, TSS, TVS, or TKN) or Experiment 2 (COD, TS, or TSS).
3. Scald water temperature (i.e., soft-scald versus hard-scald) had a significant impact on feather rinse PPW COD loading (g/kg^{lwt}) with COD in Experiment 1 and TS in Experiment 2.
4. The highest mean loading (g/kg^{lwt}) in the feather rinse PPW samples from Experiment 1 was for COD (0.303), followed by TS (0.214), TVS (0.171), TSS (0.097) and TKN (0.030).
5. The highest mean loading (g/kg^{lwt}) in the feather rinse PPW samples from Experiment 2

was for TS (0.681), followed by COD (0.345), and TSS (0.115).

6. Two (2) additional minutes of viscera agitation in Experiment 1 significantly increased COD (68%), TS (76%), TSS (94%), TVS (77%), and TKN (61%) loadings in PPW.
7. Two (2) additional minutes of viscera agitation in Experiment 2 significantly increased COD (50%), TS (21%), TSS (71%) loadings in PPW.
8. The highest mean loading (g/kg^{lwt}) in viscera rinse PPW after 3 total min agitation time in Experiment 1 was COD (0.506) followed by TS (0.277), TVS (0.274), TSS (0.120) and TKN (0.029).
9. The highest mean loading (g/kg^{lwt}) in viscera rinse PPW after 3 total min agitation time in Experiment 2 was COD (1.40) followed by TS (1.01), and TSS (0.188).

CHAPTER 4

SUMMARY AND CONCLUSIONS

Two experiments, described in Chapters 2 and 3, were conducted to measure the effects of bleed time and scald temperature and variation in individual and groups of carcasses' impact on poultry processing wastewater (PPW) in terms of uncollected blood, external debris, and feather and viscera rinse PPW. The first experiment, described in Chapter 2, utilized 24 experimental flock male broilers that were reared at the University of Georgia Poultry Research Center (UGAPRC) as part of an independent litter treatment study flock. The second experiment, described in Chapter 3, used 120 birds from a commercial broiler slaughter plant in north Georgia. Similarities of the two experiments included capture of carcass blood during slaughter for blood loss as % live weight calculations, main effect treatment levels of bleed time (60 s and 120 s) and scald temperature (50^{o}C and 60^{o}C), and measurement and analyses of the conventional wastewater parameters of COD, TS, and TSS. These similarities allowed for comparisons to be made between the two experiments. Conversely, the differences between the two experiments included number of experimental units (N=24 in Experiment 1, N=120 in Experiment 2), experimental flock (Experiment 1) versus commercial flock (Experiment 2) broilers, the mean live weights of broilers (4.09 kg in Experiment 1, 2.09 kg Experiment 2), and the method of scalding the birds (Experiment 1 - individual broiler scalding versus Experiment 2 - batch of 5 broiler scalding). Any differences between the two experiments were taken into consideration when comparisons were made. Statistical comparisons between the two experiments were conducted using one-way ANOVA to evaluate the experiments' main effects (i.e., bleed time and scald temperature, each at 2 levels) independently since previous statistical analyses revealed no main effects interaction. Main effects data for the two experiments were subjected to statistical analysis by using the GLM procedure of the SAS/STAT program [64]. Differences in means will be regarded as significant at $P < 0.05$.

Blood Loss

A greater blood loss % was seen in Experiment 2 versus Experiment 1 (2.6% versus 2.0% for short bleed time, 2.8% versus 2.5% for long bleed time). These results were expected because of the established curvilinear relationship with body weight and % of blood loss as described in Chapter 2.

Scalder PPW

Bleed time (i.e., 60 s versus 120 s) had a significant impact on the volume of blood entering the scalder and thus on PPW loadings for COD for both Experiments 1 and 2. Results showed that for both experiments, the short bleed time at 60 s had a mean COD load (2.38 g/kg^{lwt} and 1.72 g/kg^{lwt}) which was significantly greater than the long bleed time at 120 s (1.61 g/kg^{lwt}, and 1.51 g/kg^{lwt}). It is interesting to note that despite the differences in the two experiments (i.e., size and number of birds, and experimental versus commercial birds), bleed time had a significant impact on COD loading for Experiments 1 (P=0.0016) and 2 (P=0.0149). In addition, the overall scalder PPW mean COD load in Experiment 1 (1.99 g/kg^{lwt}) was significantly greater (P=0.0091) than experiment 2 (1.61 g/kg^{lwt}). In both experiments, scalder water temperature (i.e., soft-scald versus hard-scald) did not have a significant impact on wastewater loadings (g/kg^{lwt}) either for Experiment 1 (COD, TS, TSS, TVS and TKN) or Experiment 2 (COD, TS, and TSS)

Results show that Experiment 2 had mean loads for TS and TSS of 3.02 g/kg^{lwt} and 0.602 g/kg^{lwt}, respectively, which were significantly greater than Experiment 1 (1.66 g/kg^{lwt} and 0.416 g/kg^{lwt}). Results indicated that even though Experiment 1 had a greater COD load, Experiment 2 had a greater TS and TSS load indicating that the commercial flock broilers in Experiment 2 had significantly more external debris than the UGA experimental flock broilers in Experiment 1.

Feather Rinse PPW

Experiment 2 had a mean TS load of 0.680 g/kg^{lwt}, which was significantly greater than Experiment 1 (0.214 g/kg^{lwt}). This was expected since scald PPW had a higher TS load for Experiment 2, indicating a significant external debris content in the commercial flock broilers versus the experimental flock broilers. Thus, when the carcasses were pulled in succession from the experimental scalders in Experiment 2, suspended particulates attached to the feathers in conjunction with the water absorptive capacity of feathers.

Viscera Rinse PPW

Significant % increases in COD, TS and TSS loads from 2 min additional agitation time was seen in both Experiments 1 and 2. However, the % increases were higher in Experiment 1. The additional 2 min of agitation time increased COD (68%), TS (76%) and TSS (93%) in Experiment 1, whereas in Experiment 2 the % increases were 50%, 21% and 71% for COD, TS and TSS, respectively.

THESIS CONCLUSIONS AND APPLICATIONS

1. Bleed time (i.e., 60 s versus 120 s) will have a significant impact on PPW loading.
2. Bleed time will significantly impact COD loading in scalder PPW. Increasing the bleed time to 120 s will significantly reduce COD loading in scalder PPW.
3. Scalder water temperature (i.e., soft-scald versus hard-scald) will not have a significant

impact on wastewater loadings, but trends indicate a larger wastewater load occurs at soft-scald (50°C, 122°F) versus hard-scald temperature (60°C, 140°F).

4. External debris will significantly impact PPW loading by increasing TS in feather rinse PPW.
5. The pollutant loading in viscera PPW will significantly increase based on the amount and time of agitation involved.
6. Mean carcass PPW loads (g/kg^{lwt}) can be used to calculate economic impact of pollutant reductions (i.e., increasing bleed time) based on processing charges. As an example, the mean scalder PPW COD load for carcasses bled for 60 s with the commercial flock broilers was 1.72 g/kg^{lwt} versus 1.51 g/kg^{lwt} at 120 s. Thus, on average, an additional 0.21 g/kg^{lwt} COD entered the scalder for carcasses bled for the shorter time. Using the typical value of $0.30/lb COD surcharge fee the following calculation can be made for a typical poultry processing plant slaughtering 250,000 birds per day (bpd), weighing 2.1 kg per bird for 260 processing days per year:

   (250,000 bpd) (2.1kg) = 525,000 kg/d

   525,000 kg (0.21 g/kg^{lwt}) = 110,250 g COD/d

   110,250 g/d = 243 lbs/d

   (243 lbs/d) ($0.30/lb) = $ 72.90/d

   ($ 72.90/d) (260 processing days/yr) = $ **18,954/yr**

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Table 2.1. Blood loss values for exsanguinated 8-wk old broilers electrically-stunned and bled for 60 (n=12) or 120 (n=12) seconds*

Bleed Time (Units)	Minimum Value	Maximum Value	Mean ± SEM	Standard Deviation	Coefficient of Variation (%)†
60 sec (% Live Wt)	0.97	2.93	$2.00^{b} \pm 0.18$	0.61	31
120 sec (% Live Wt)	2.01	2.84	$2.51^{a} \pm 0.09$	0.30	12
60 sec (grams)	39.6	122.5	$82.7^{b} \pm 7.6$	26.3	32
120 sec (grams)	76.9	117.4	$101.4^{a} \pm 3.8$	13.1	13

*^{a,b} - *differing superscripts with a column indicates statistically significant differences (P<0.05)*

† Coefficient of Variation (cov) = (standard deviation / mean) x 100

Table 2.2. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 bleed times (short = 60 s, long = 120 s) for SCALDER (16 L/bird) wastewater samples from 24 male broilers*

Bleed Time (n=12)	**COD** g ± SEM (mg/L ± SEM)	**TS** g ± SEM (mg/L ± SEM)	**TSS** g ± SEM (mg/L ± SEM)	**TVS** g ± SEM (mg/L ± SEM)	**TKN** g ± SEM (mg/L ± SEM)
Short Bleed	$2.38^{a} \pm 0.06$ ($616^{a} \pm 56$)	$1.97^{a} \pm 0.16$ ($510^{a} \pm 41$)	0.50 ± 0.09 (128 ± 21)	$1.64^{a} \pm 0.15$ ($425^{a} \pm 38$)	$0.27^{a} \pm 0.02$ ($70^{a} \pm 6$)
Long Bleed	$1.61^{b} \pm 0.25$ ($406^{b} \pm 16$)	$1.34^{b} \pm 0.07$ ($339^{b} \pm 18$)	0.33 ± 0.03 (84 ± 8)	$1.07^{b} \pm 0.10$ ($270^{b} \pm 25$)	$0.20^{b} \pm 0.008$ ($49^{b} \pm 2$)

*^{a,b} - *differing superscripts with a column indicates statistically significant differences (P<0.05)*

Table 2.3. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 temperatures levels (soft = 50°C, hard = 60°C) for SCALDER (16 L/bird) wastewater samples from 24 male broilers

Scald Temp (n=12)	**COD** g ± SEM (mg/L ±SEM)	**TS** g ± SEM (mg/L ± SEM)	**TSS** g ± SEM (mg/L ± SEM)	**TVS** g ± SEM (mg/L ± SEM)	**TKN** g ± SEM (mg/L ± SEM)
Soft Scald	2.12 ± 0.18 (547 ± 52)	1.69 ± 0.13 (437 ± 39)	0.34 ± 0.03 (89 ± 8)	1.38 ± 0.14 (358 ± 40)	0.24 ± 0.02 (63 ± 5)
Hard Scald	1.86 ± 0.19 (474 ± 49)	1.63 ± 0.17 (412 ± 42)	0.49 ± 0.09 (124 ± 22)	1.33 ± 0.16 (338 ± 39)	0.22 ± 0.02 (56 ± 6)

Table 2.4. Mean concentrations (mg/L), mean loads (g/kg^{lwt}) and *P*-values for 8 chemical elements in scalder water samples for 24 male broilers (n=6)

	K	Na	Ca	S	Mg	Mn	Zn	Cu
Concentration (mg/L)	16.16	9.54	6.18	3.60	1.93	0.10	0.05	0.01
Load (g/kg^{lwt})	0.0634	0.0377	0.0241	0.0143	0.0075	0.0004	0.0002	.00006
P-value	*0.3536*	*0.7745*	*0.8821*	*0.4210*	*0.6305*	*0.7379*	*0.1000*	*0.3693*

Table 2.5. Blood loss values for exsanguinated broilers electrically-stunned and bled for 60 (n=60) or 120 (n=60) seconds*

Bleed Time (Units)	Minimum Value	Maximum Value	Mean ± SEM	Standard Deviation	Coefficient of Variation (%)†
60 sec (% Live Wt)	1.74	3.32	$2.59^{b} \pm 0.046$	0.36	14
120 sec (% Live Wt)	2.00	3.53	$2.81^{a} \pm 0.049$	0.38	14
60 sec (grams)	32.6	76.07	$53.6^{b} \pm 1.3$	10.12	19
120 sec (grams)	37.7	81.6	$59.0^{a} \pm 1.4$	11.1	19

*^{a,b} *- differing superscripts with a column indicates statistically significant differences (p<0.05)*

† Coefficient of Variation (cov) = (standard deviation / mean) x 100

Table 2.6. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for SCALDER (20 L) wastewater samples from 120 broilers*

Bleed Time (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	$1.72^{a} \pm 0.057$ ($886^{a} \pm 30$)	3.06 ± 0.10 (1588 ± 74)	0.62 ± 0.02 (319 ± 15)
Long Bleed	$1.51^{b} \pm 0.050$ ($792^{b} \pm 29$)	2.97 ± 0.15 (1555 ± 86)	0.59 ± 0.04 (309 ± 19)

*^{a,b} *- differing superscripts with a column indicates statistically significant differences (p<0.05)*

Table 2.7. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 temperatures levels (soft = 50°C, hard = 60°C) for SCALDER (20 L) wastewater samples from 120 broilers

Scald Temp (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	1.62 ± 0.071 (862 ± 40)	2.99 ± 0.16 (1595 ± 93)	0.62 ± 0.037 (329 ± 21)
Hard Scald	1.61 ± 0.051 (816 ± 23)	3.04 ± 0.089 (1549 ± 66)	0.59 ± 0.019 (299 ± 12)

Table 3.1. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for FEATHER RINSE wastewater samples from 24 male broilers

Bleed Time (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.308 ± 0.02 (634 ± 34)	0.201 ± 0.02 (415 ± 46)	0.103 ± 0.008 (213 ± 17)	0.158 ± 0.02 (327 ± 43)	0.030 ± 0.002 (61 ± 4)
Long Bleed	0.297 ± 0.01 (603 ± 45)	0.226 ± 0.02 (456 ± 47)	0.091 ± 0.006 (183 ± 15)	0.184 ± 0.02 (370 ± 31)	0.029 ± 0.001 (59 ± 3)

Table 3.2. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 scalder temperatures levels (soft = 50°C, hard = 60°C) for FEATHER RINSE wastewater samples from 24 male broilers

Scald Temp (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ±SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.275^b ± 0.01 (562^b ± 19)	0.195 ± 0.02 (399 ± 33)	0.095 ± 0.005 (195 ± 10)	0.171 ± 0.02 (349 ± 36)	0.028 ± 0.001 (57 ± 2)
Hard Scald	0.330^a ± 0.02 (676^a ± 47)	0.232 ± 0.03 (472 ± 56)	0.099 ± 0.009 (202 ± 21)	0.171 ± 0.02 (348 ± 41)	0.031 ± 0.002 (63 ± 5)

**differing superscripts with a column indicates statistically significant differences (p<0.05)*

Table 3.3. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for VISCERA RINSE wastewater samples at 1 MIN agitation time from 24 male broilers

Bleed Time (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.307 ± 0.04 (318 ± 48)	0.162 ± 0.02 (169 ± 27)	0.059 ± 0.01 (62 ± 15)	0.151 ± 0.03 (157 ± 29)	0.019 ± 0.003 (20 ± 3)
Long Bleed	0.295 ± 0.03 (295 ± 29)	0.152 ± 0.02 (152 ± 20)	0.065 ± 0.01 (66 ± 12)	0.159 ± 0.02 (159 ± 19)	0.017 ± 0.001 (19 ± 1)

Table 3.4. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 temperatures levels (soft = 50^{o}C, hard = 60^{o}C) for VISCERA RINSE wastewater samples at 1 MIN agitation time from 24 male broilers

Scald Temp (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.317 ± 0.04 (326 ± 42)	0.157 ±0.03 (163 ± 28)	0.064 ± 0.01 (66 ± 13)	0.139 ± 0.03 (143 ± 26)	0.018 ± 0.003 (22 ± 3)
Hard Scald	0.285 ± 0.04 (287 ± 36)	0.157 ± 0.02 (158 ± 20)	0.060 ± 0.01 (62 ± 14)	0.171 ± 0.02 (173 ± 21)	0.018 ± 0.002 (18 ± 2)

Table 3.5. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for VISCERA RINSE wastewater samples at 2 MIN ADDITIONAL agitation time from 24 male broilers

Bleed Time (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.187 ± 0.02 (447 ± 53)	0.110 ± 0.01 (227 ± 29)	0.058 ± 0.007 (120 ± 15)	0.112 ± 0.02 (232 ± 32)	0.009 ± 0.001 (19 ± 2)
Long Bleed	0.223 ± 0.03 (387 ± 66)	0.131 ± 0.02 (262 ± 32)	0.058 ± 0.01 (116 ± 27)	0.125 ± 0.02 (249 ± 32)	0.010 ± 0.001 (20 ± 2)

Table 3.6. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters representing 2 temperatures levels (soft = 50°C, hard = 60°C) for VISCERA RINSE wastewater samples at 2 MIN ADDITIONAL agitation time from 24 male broilers

Scald Temp (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.245 ± 0.03 (504^a ± 65)	0.141 ±0.02 (287^a ± 31)	0.073^a ± 0.01 (150^a ± 20)	0.138 ± 0.02 (283^a ± 32)	0.012^a ± 0.001 (24^a ± 2)
Hard Scald	0.165 ± 0.02 (331^b ± 42)	0.100 ± 0.01 (201^b ± 25)	0.042^b ± 0.01 (86^b ± 18)	0.100 ± 0.02 (197^b ± 26)	0.008^b ± 0.001 (16^b ± 2)

**differing superscripts with a column indicates statistically significant differences (p<0.05)*

Table 3.7. Mean load (g/kg^{lwt} ±SEM) and concentration (mg/L±SEM) values for 5 wastewater parameters at 2 agitation times (1 minute versus 3 minutes) for viscera (4 L/bird) rinse PPW samples from 24 male broilers

Agitation Time (n=24)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ±SEM)	**TVS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TKN** g/kg^{lwt} ± SEM (mg/L ± SEM)
1 min	0.301^b ± 0.03 (307^b ± 61)	0.157^b ±0.02 (160^b ± 17)	0.062^b ± 0.009 (64^b ± 9)	0.155^b ± 0.02 (158^b ± 17)	0.018^b ± 0.002 (20^b ± 2)
3 min	0.506^a ± 0.04 (724^a ± 27)	0.277^a ± 0.02 (406^a ± 33)	0.120^a ± 0.012 (182^a ± 19)	0.274^a ± 0.02 (399^a ± 31)	0.029^a ± 0.002 (40^a ± 3)

**differing superscripts with a column indicates statistically significant differences (p<0.05)*

Table 3.8. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for FEATHER RINSE (4 L/5bird) wastewater samples from 120 broilers

Bleed Time (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.367 ± 0.03 (928 ± 83)	0.679 ± 0.02 (1747 ± 43)	0.120 ± 0.01 (305 ± 21)
Long Bleed	0.322 ± 0.04 (831 ± 83)	0.682 ± 0.02 (1791 ± 75)	0.109 ± 0.04 (281 ± 25)

Table 3.9. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 scalder temperatures levels (soft = 50^{o}C, hard = 60^{o}C) for FEATHER RINSE (4 L/5bird) wastewater samples from 120 broilers

Scald Temp (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.334 ± 0.03 (881 ± 74)	0.712^{a} ± 0.02 (1893^{a} ± 51)	0.106 ± 0.009 (280 ± 21)
Hard Scald	0.354 ± 0.04 (878 ± 93)	0.648^{b} ± 0.02 (1645^{b} ± 48)	0.123 ± 0.01 (306 ± 25)

***differing superscripts with a column indicates statistically significant differences ($p<0.05$)**

Table 3.10. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for VISCERA RINSE (8 L/bird) wastewater samples at 1 MIN from 120 broilers

Bleed Time (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.642 ± 0.02 (829 ± 25)	1.11 ± 0.05 (1440 ± 78)	0.106 ± 0.005 (137 ± 7)
Long Bleed	0.706 ± 0.03 (922 ± 39)	1.21 ± 0.05 (1591 ± 87)	0.116 ± 0.10 (151 ± 10)

Table 3.11. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 temperatures levels (soft = 50^{o}C, hard = 60^{o}C) for VISCERA RINSE (8 L/bird) wastewater samples at 1 MIN agitation time from 120 broilers

Scald Temp (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.640 ± 0.03 (852 ± 37)	1.09 ±0.05 (1451 ± 75)	0.102 ± 0.006 (137 ± 9)
Hard Scald	0.708 ± 0.02 (899 ± 32)	1.23 ± 0.05 (1580 ± 91)	0.119 ± 0.007 (151 ± 9)

Table 3.12. Mean load (grams/kilogram live wt ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 bleed times (short = 60 seconds, long = 120 seconds) for VISCERA RINSE (8 L/bird) wastewater samples at 2 MIN ADDITIONAL agitation time from 120 broilers

Bleed Time (n=12)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Short Bleed	0.377^{a} ± 0.03 (985^{a} ± 95)	0.291^{a} ± 0.04 (764^{a} ± 108)	0.082 ± 0.01 (216 ± 29)
Long Bleed	0.289^{b} ± 0.02 (767^{a} ± 71)	0.184^{b} ± 0.02 (480^{b} ± 60)	0.073 ± 0.007 (192 ± 18)

**differing superscripts with a column indicates statistically significant differences (p<0.05)*

Table 3.13. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 2 temperatures levels (soft = 50°C, hard = 60°C) for VISCERA RINSE (8 L/bird) wastewater samples at 2 MIN ADDITIONAL agitation time from 120 broilers

Scald Temp (n=60)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
Soft Scald	0.353 ± 0.03 (939 ± 68)	0.265 ±0.04 (702 ± 95)	0.085 ± 0.008 (225 ± 20)
Hard Scald	0.314 ± 0.04 (814 ± 104)	0.209 ± 0.04 (542 ± 93)	0.070 ± 0.009 (184 ± 27)

Table 3.14. Mean load (g/kg^{lwt} ± SEM) and concentration (mg/L±SEM) values for 3 wastewater parameters representing 1 and 3 min agitation time for viscera from 120 broilers

Agitation Time (n=120)	**COD** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TS** g/kg^{lwt} ± SEM (mg/L ± SEM)	**TSS** g/kg^{lwt} ± SEM (mg/L ± SEM)
1 min	0.674^{b} ± 0.02 (876^{b} ± 25)	1.16^{b} ±0.04 (1516^{b} ± 59)	0.111^{b} ± 0.004 (144^{b} ± 6)
3 min	1.01^{a} ± 0.03 (1752^{a} ± 69)	1.40^{a} ± 0.03 (2138^{a} ± 71)	0.188^{a} ± 0.007 (348^{a} ± 18)

**differing superscripts with a column indicates statistically significant differences (p<0.05)*

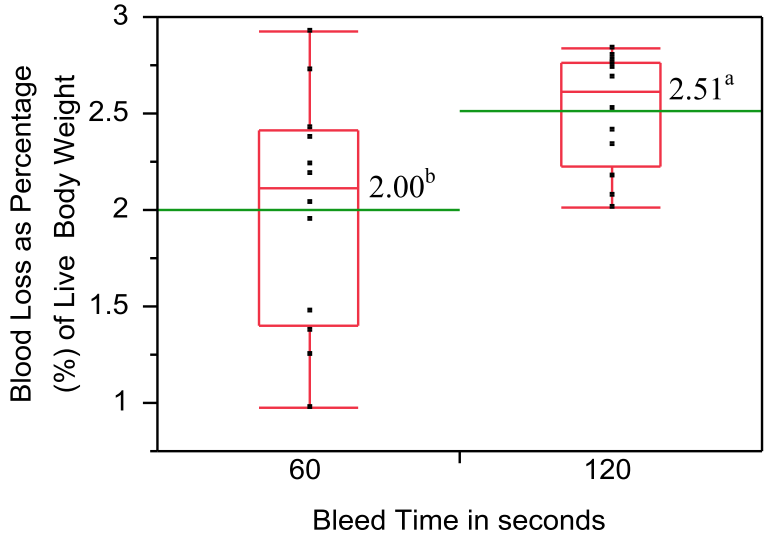

Figure 2.1. Blood loss as % live weight values for exsanguinated 8-wk old broilers electrically-stunned and bled for 60 (n=12) or 120 (n=12) seconds with mean live weight of 4.09 kg

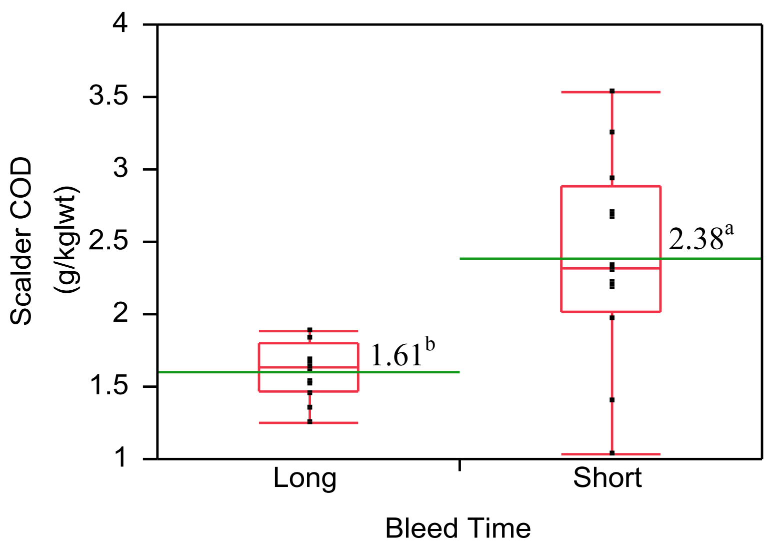

Figure 2.2. Scalder COD load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) for 24 male broilers (n=12)

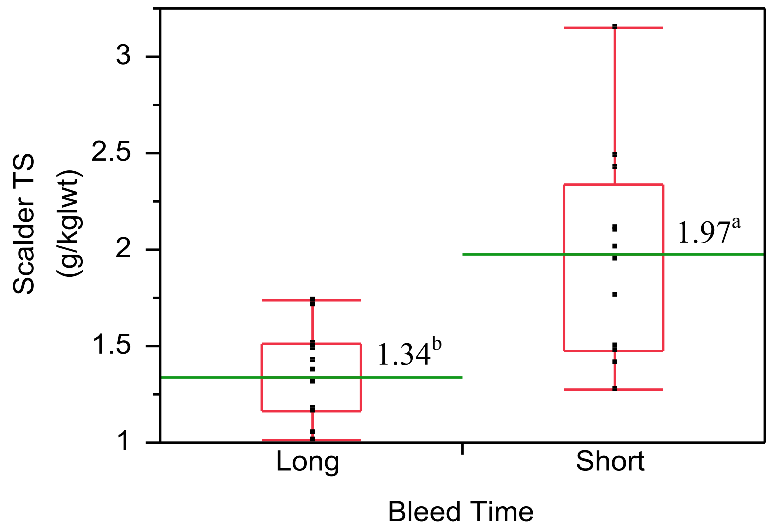

Figure 2.3. Scalder TS load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) for 24 male broilers (n=12)

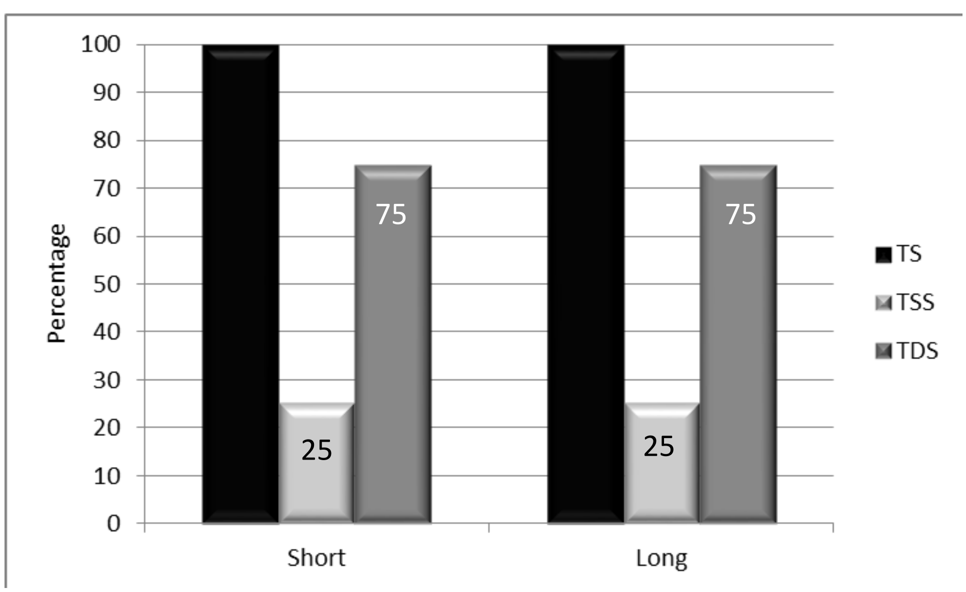

Figure 2.4. Relative mean percentages (%) of TSS and TDS to TS loads (g/kg^{lwt}) in scalder PPW samples for 2 bleed times (short = 60 sec, long = 120 sec) for 24 male broilers (n = 12)

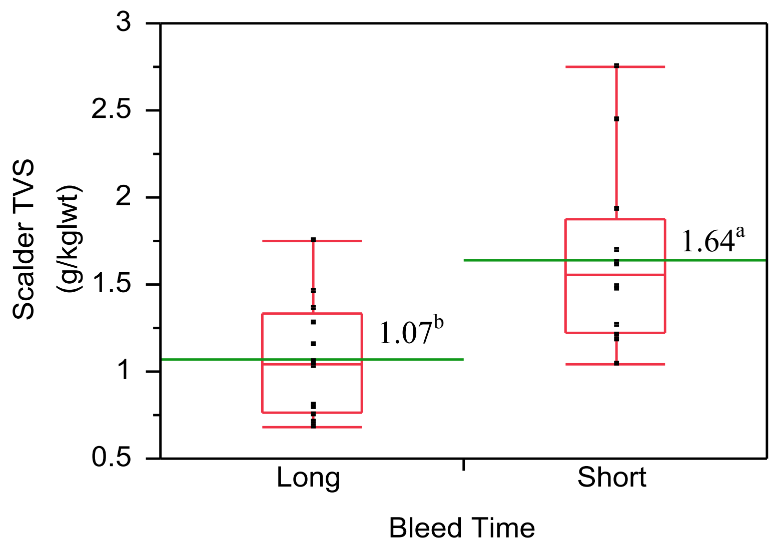

Figure 2.5. Scalder TVS load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) for 24 male broilers (n=12)

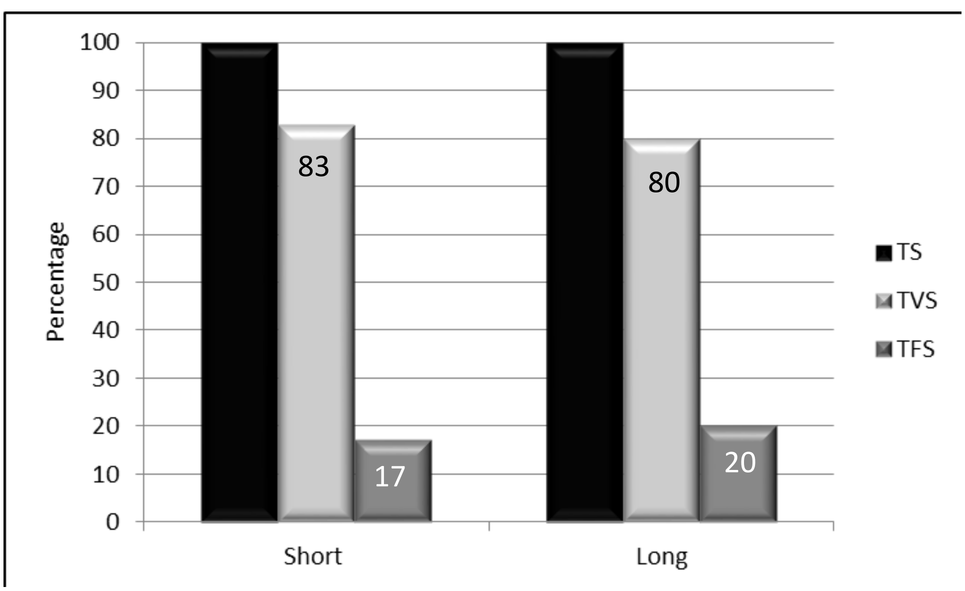

Figure 2.6. Relative mean percentages (%) of TVS and TFS to TS loads (g/kg^{lwt}) in scalder water samples for 2 bleed times (short = 60 sec, long = 120 sec) 24 male broilers (n = 12)

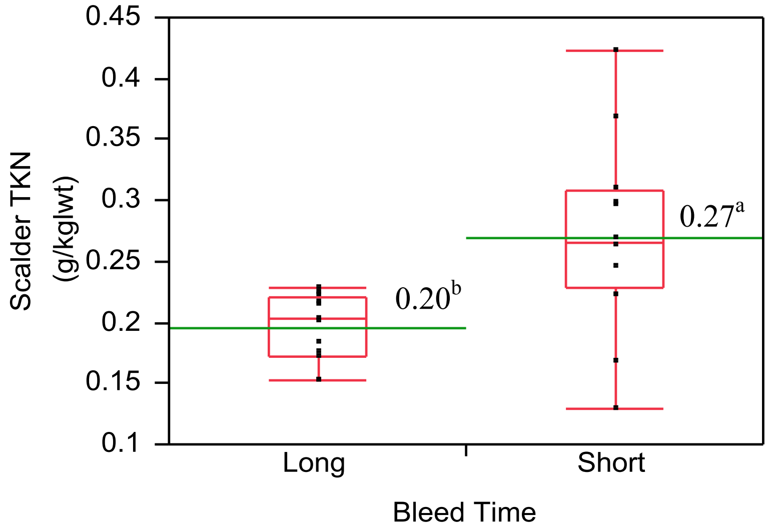

Figure 2.7. Scalder TKN load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) for 24 male broilers (n=12)

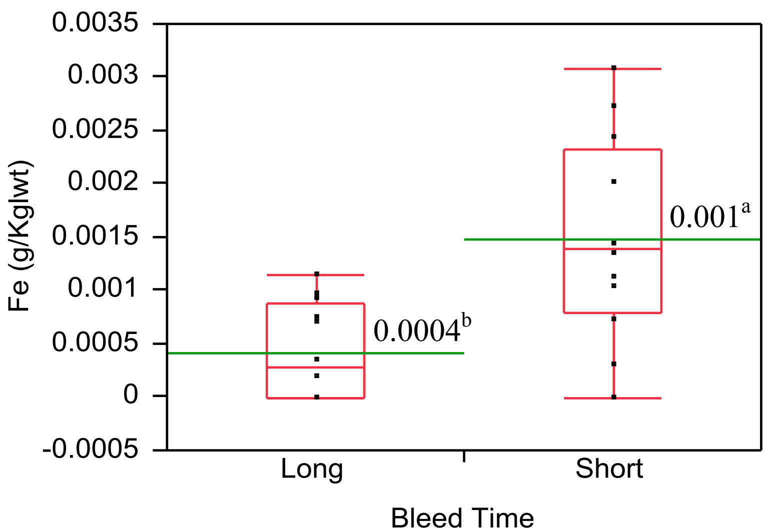

Figure 2.8. Scalder Iron (Fe) load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) 24 male broilers (n=12)

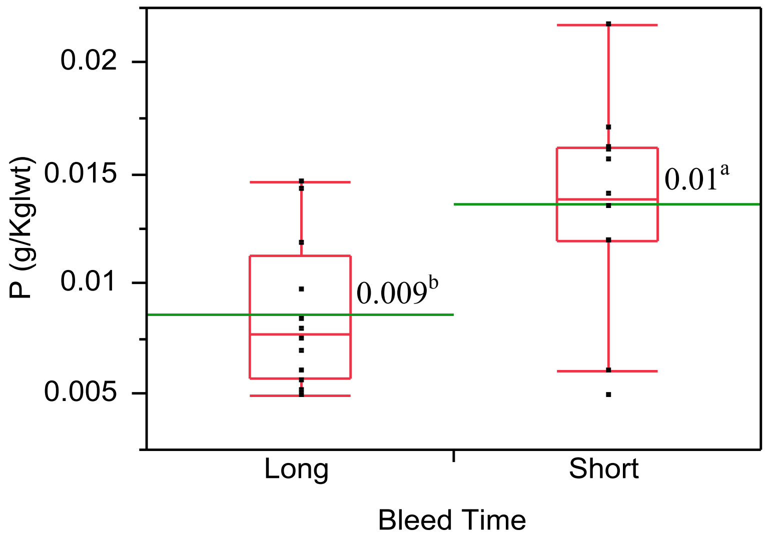

Figure 2.9. Scalder Phosphorus (P) load (g/kg^{lwt}) values for 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 24 male broilers (n=12)

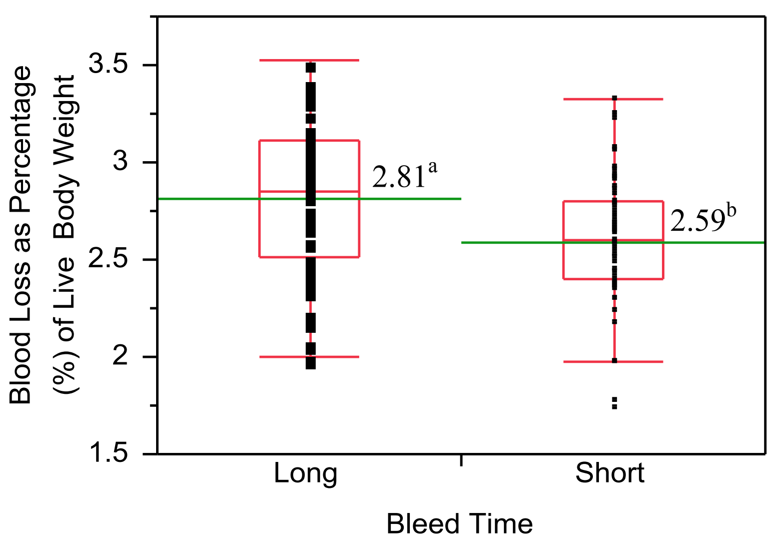

Figure 2.10. Blood Loss as % of live body weight for 2 bleed times (short=60sec, long=120sec) for 120 broilers (n=60) with mean live weight of 2.09 kg

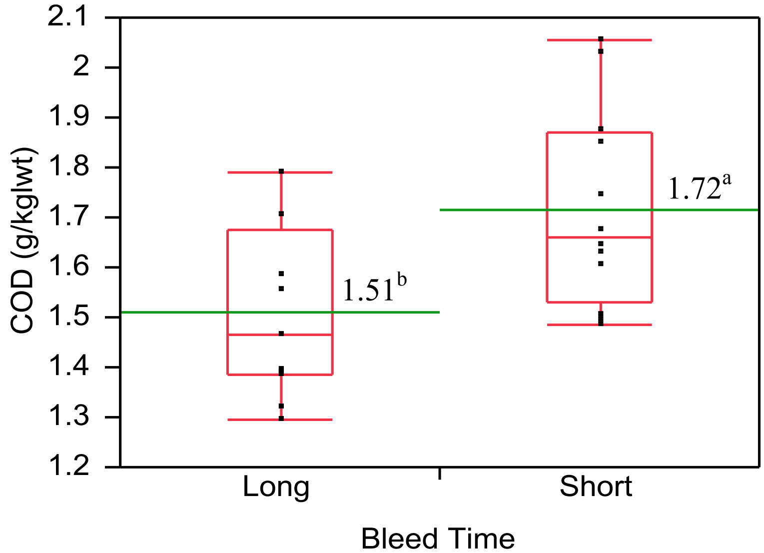

Figure 2.11. Scalder COD load (g/kg^{lwt}) values for 2 bleed times (short=60sec, long=120sec) for 120 broilers (n=60)

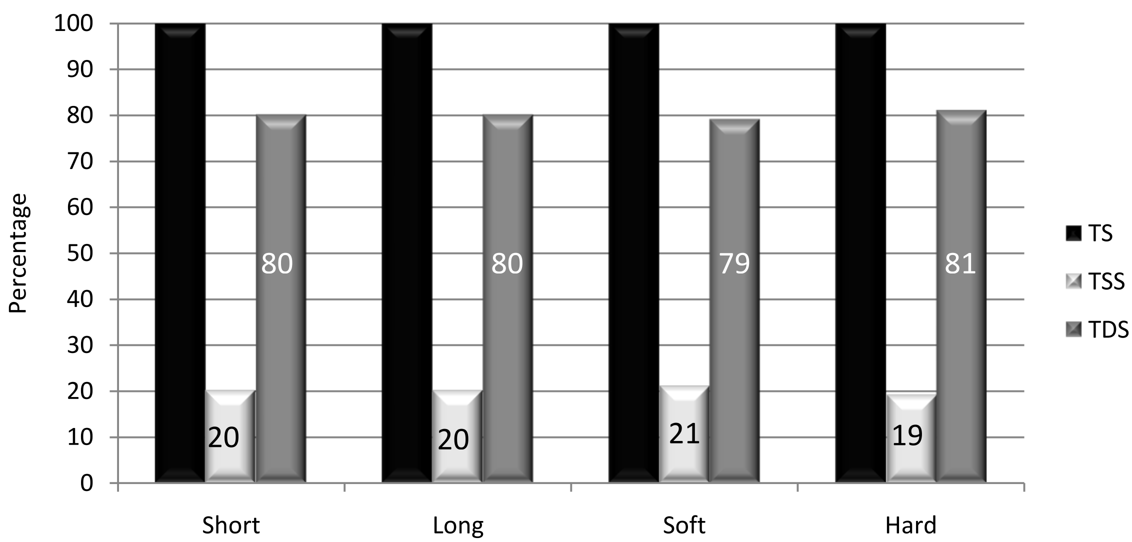

Figure 2.12. Relative mean percentages (%) of TSS and TDS to TS loads (g/kg^{lwt}) in scalder water samples for 2 bleed times (short=60sec, long=120sec) and 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 120 broilers (n=30)

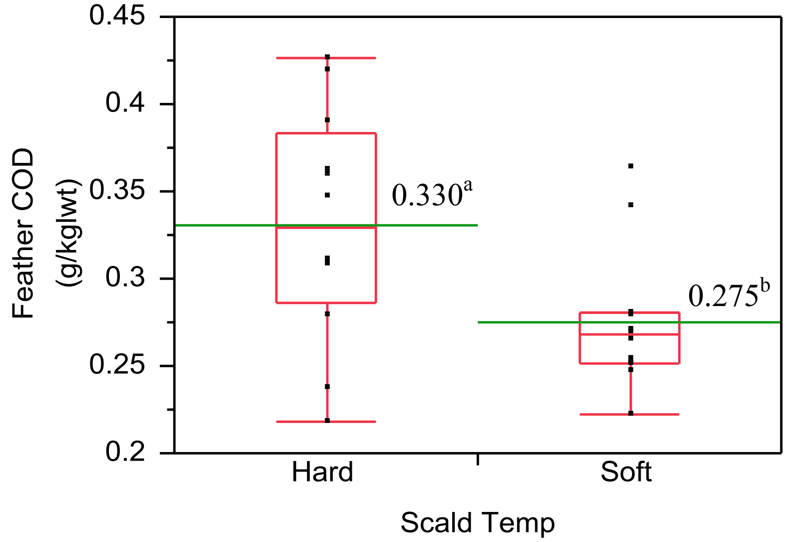

Figure 3.1. Feather rinse PPW COD load (g/kg^{lwt}) values for 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 24 male broilers (n=12)

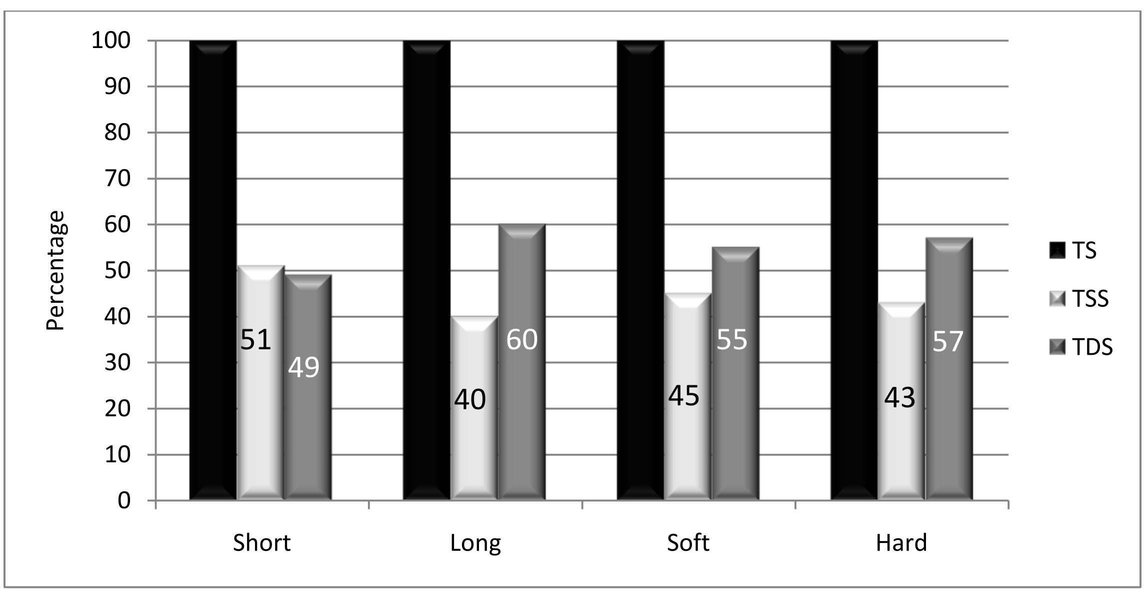

Figure 3.2. Relative mean percentages (%) of TDS and TSS to TS loads (g/kg^{lwt}) in feather rinse PPW samples for 2 bleed times (short = 60 sec, long = 120 sec), and 2 scald temperatures (soft = 50^{o}C, hard = 60^{o}C) 24 male broilers (n = 12)

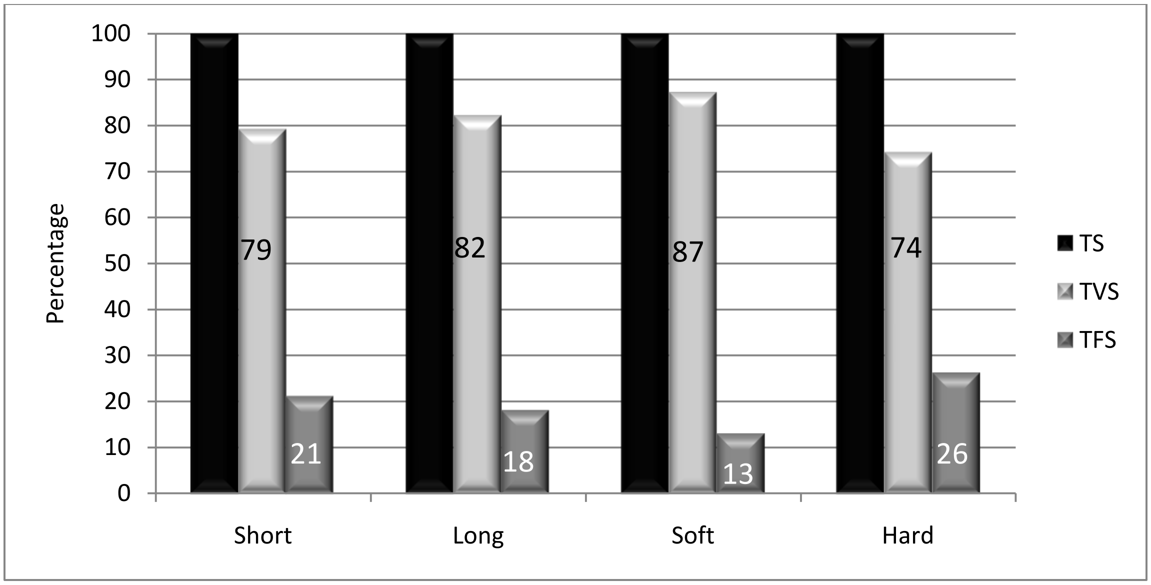

Figure 3.3. Relative mean percentages (%) of TDS and TSS to TS loads (g/kg^{lwt}) in feather rinse PPW samples for 2 bleed times (short = 60 sec, long = 120 sec), and 2 scald temperatures (soft = 50°C, hard = 60°C) 24 male broilers (n = 12)

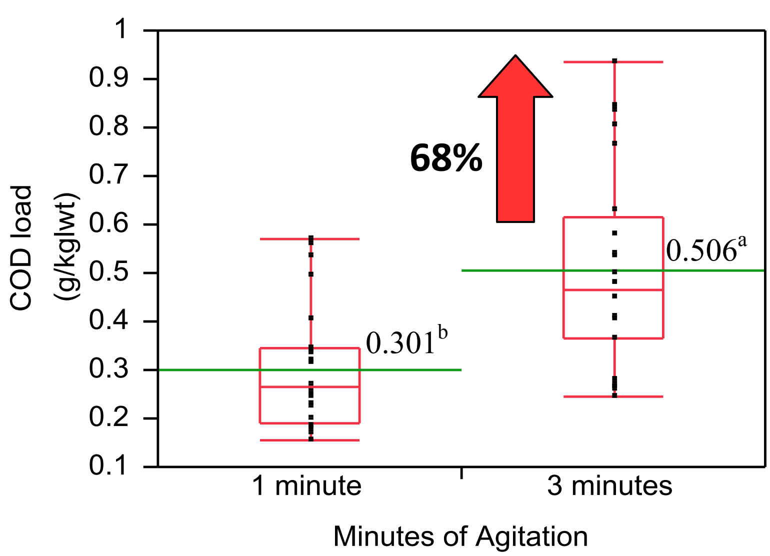

Figure 3.4. Viscera rinse PPW COD load (g/kg^{lwt}) values at 1min and 3 min agitation time for 24 male broilers (n=24)

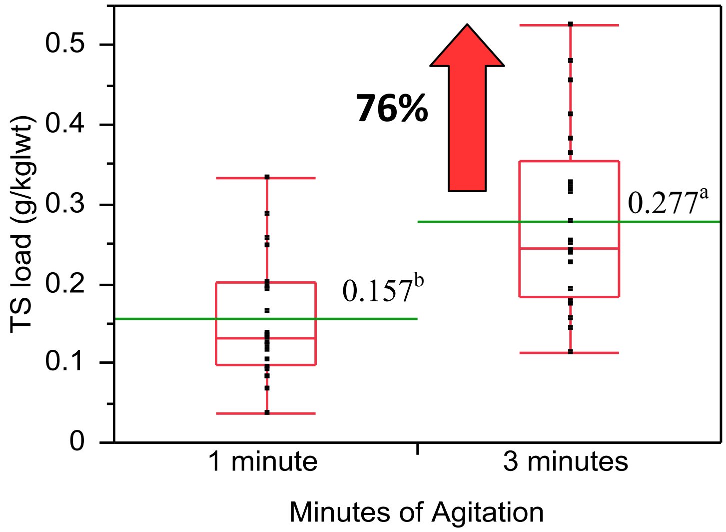

Figure 3.5. Viscera rinse PPW TS load (g/kg^{lwt}) values at 1min and 3 min agitation time for 24 male broilers (n=24)

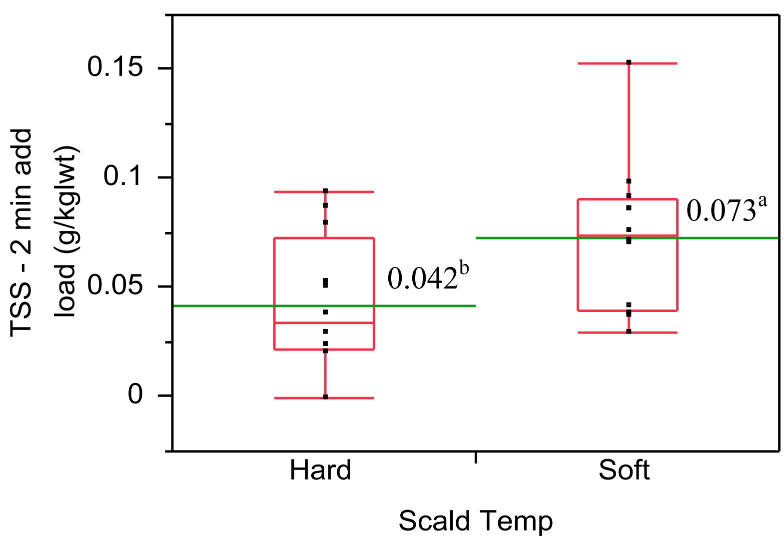

Figure 3.6. Viscera rinse PPW TSS load (g/kg^{lwt}) values at 2 min additional agitation time for 2 water temperatures (soft=50°C, hard=60°C) for 24 male broilers (n=12)

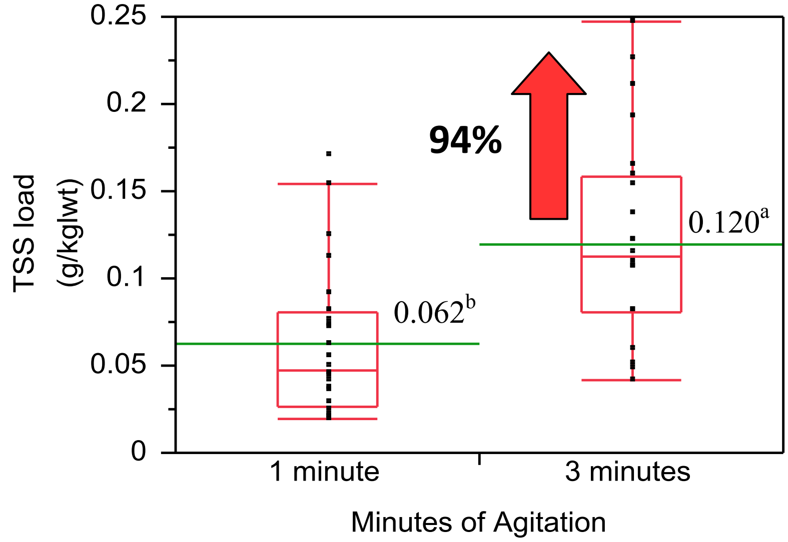

Figure 3.7. Viscera rinse PPW TSS load (g/kg[lwt]) values at 1min and 3 min agitation time for 24 male broilers (n=24)

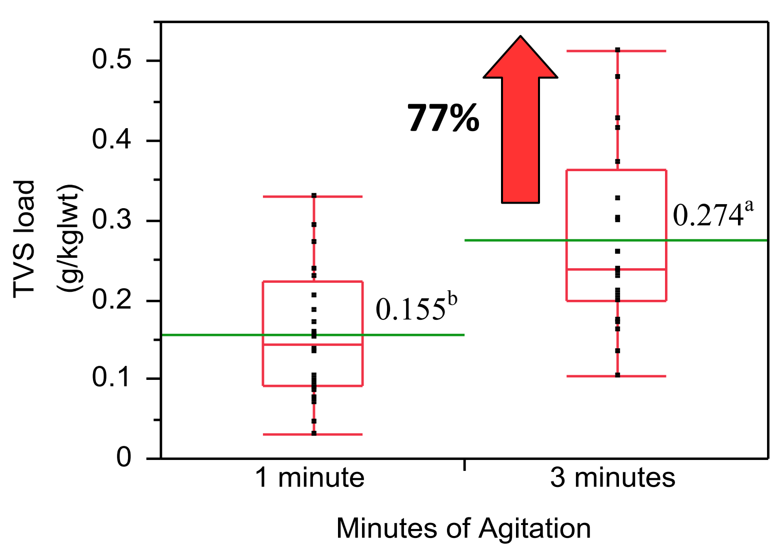

Figure 3.8. Viscera rinse PPW TVS load (g/kg[lwt]) values at 1min and 3 min agitation time for 24 male broilers (n=24)

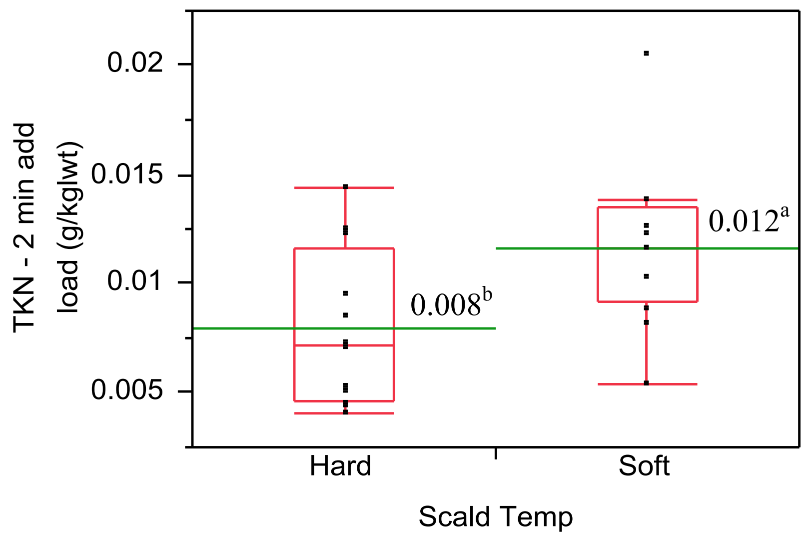

Figure 3.9. Viscera rinse PPW TKN load (g/kg^{lwt}) values at 2 min additional agitation time for 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 24 male broilers (n=12)

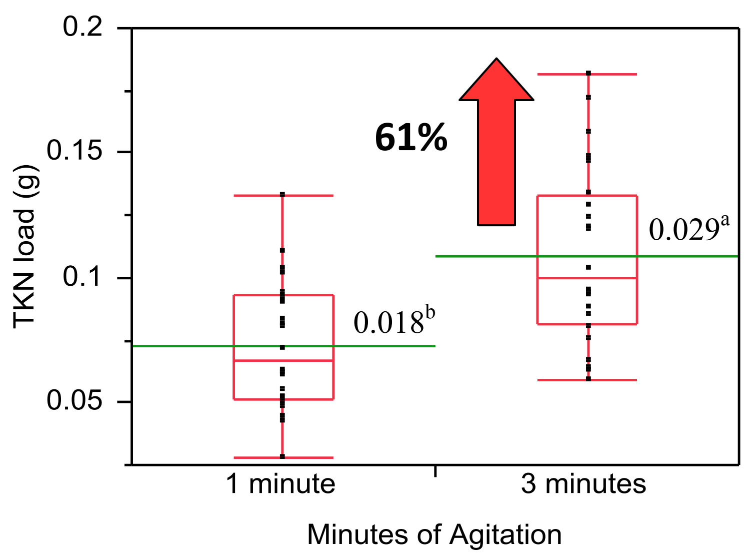

Figure 3.10. Viscera rinse PPW TKN load (g/kg^{lwt}) values at 1and 3 min agitation time for 24 male broilers (n=24)

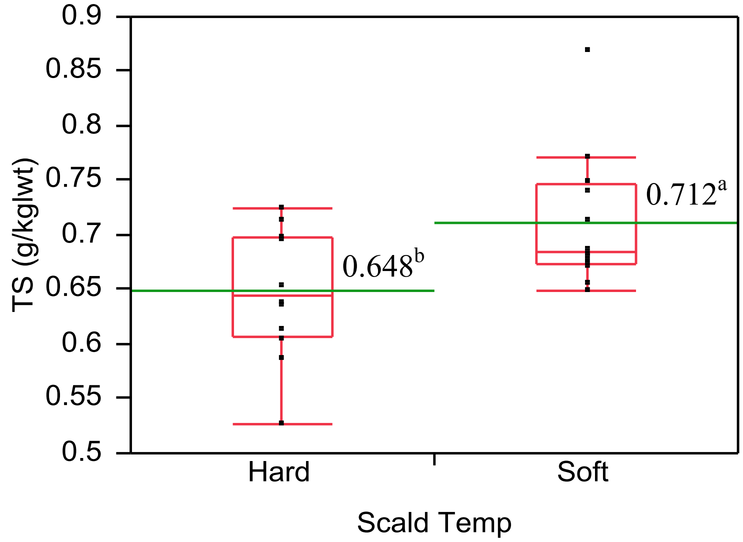

Figure 3.11. Feather TS load (g/kg^{lwt}) values for 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 120 broilers (n=60)

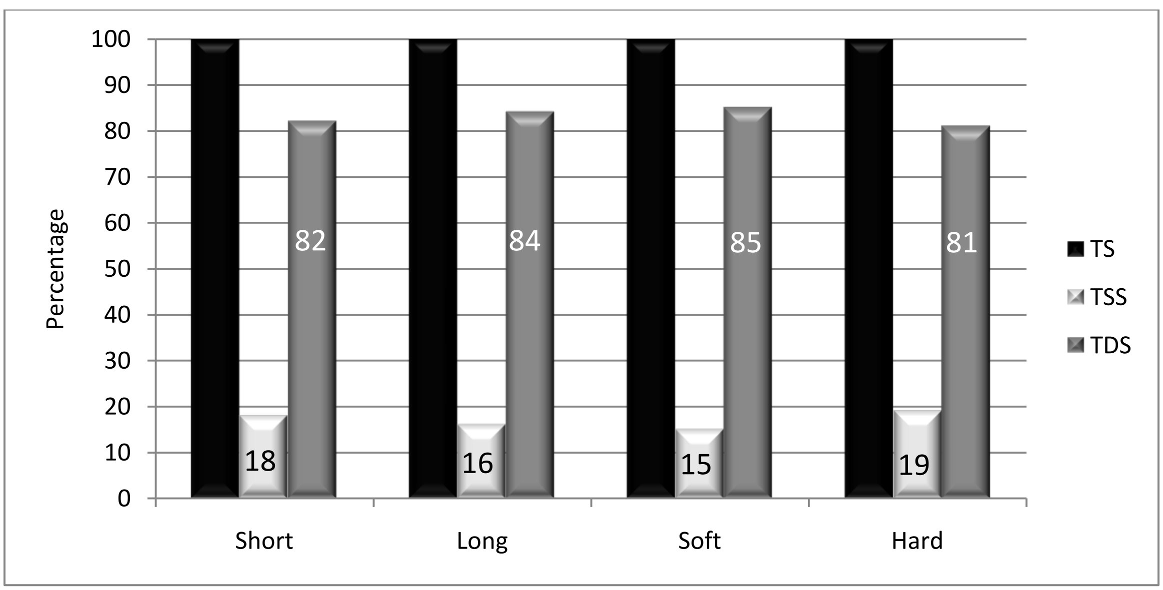

Figure 3.12. Relative mean percentages (%) of TSS and TDS to TS loads (g/kg^{lwt}) in feather water samples for 2 bleed times (short=60sec, long=120sec) and 2 water temperatures (soft=50^{o}C, hard=60^{o}C) for 120 broilers (n=30)

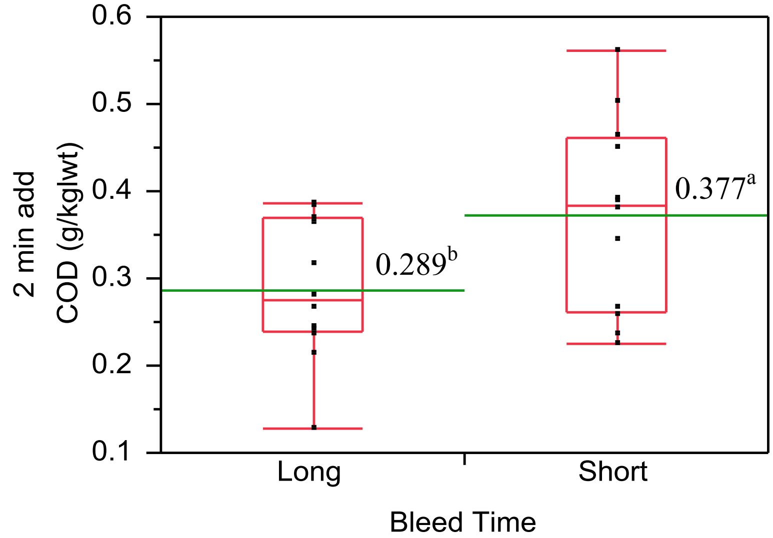

Figure 3.13. Viscera COD load (g/kg^{lwt}) values at 2 min additional agitation time for 2 bleed times (short=60sec, long=120sec) for 120 broilers (n=60)

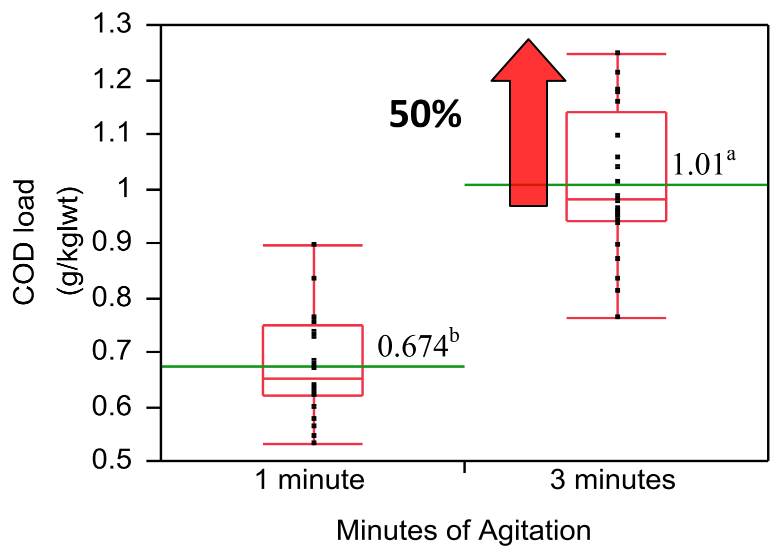

Figure 3.14. Viscera COD load (g/kg^{lwt}) values at 1and 3 min agitation time for 120 broilers (n=120)

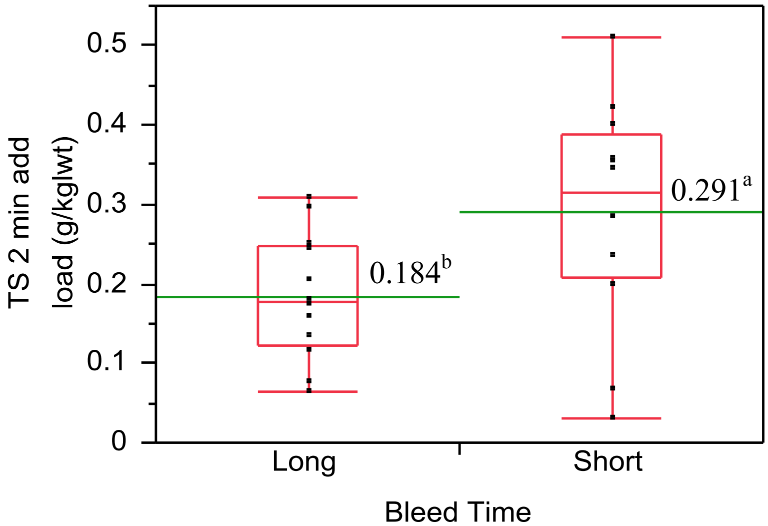

Figure 3.15. Viscera TS load (g/kg^{lwt}) values at 2 min additional agitation time for 2 bleed times (short=60sec, long=120sec) for 120 broilers (n=60)

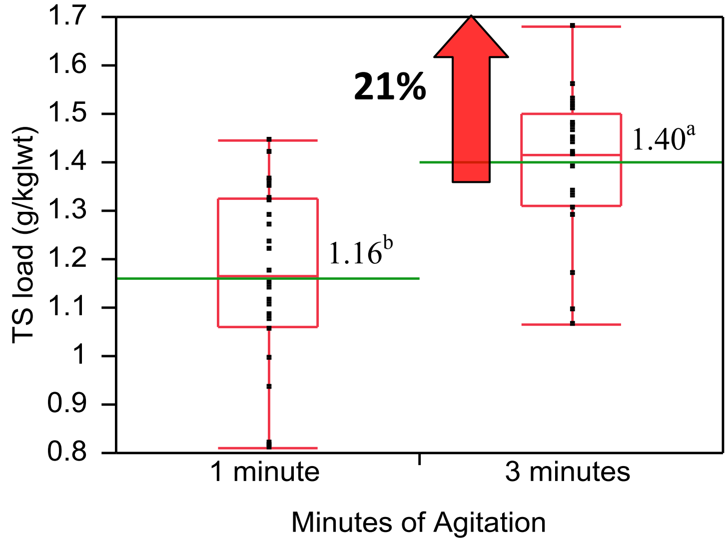

Figure 3.16. Viscera TS load (g/kg^{lwt}) values at 1and 3 min agitation time for 120 broilers (n=120)

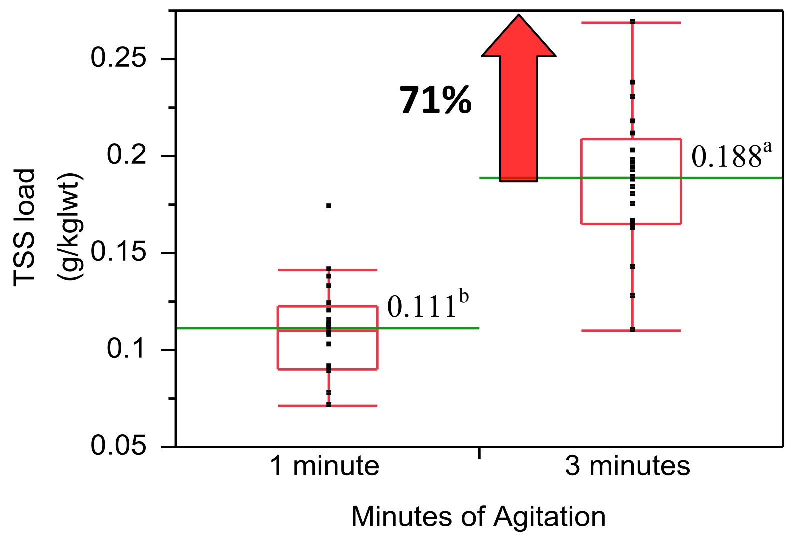

Figure 3.17. Viscera TSS load (g/kg^{lwt}) values at 1and 3 min agitation time for 120 broilers (n=120)

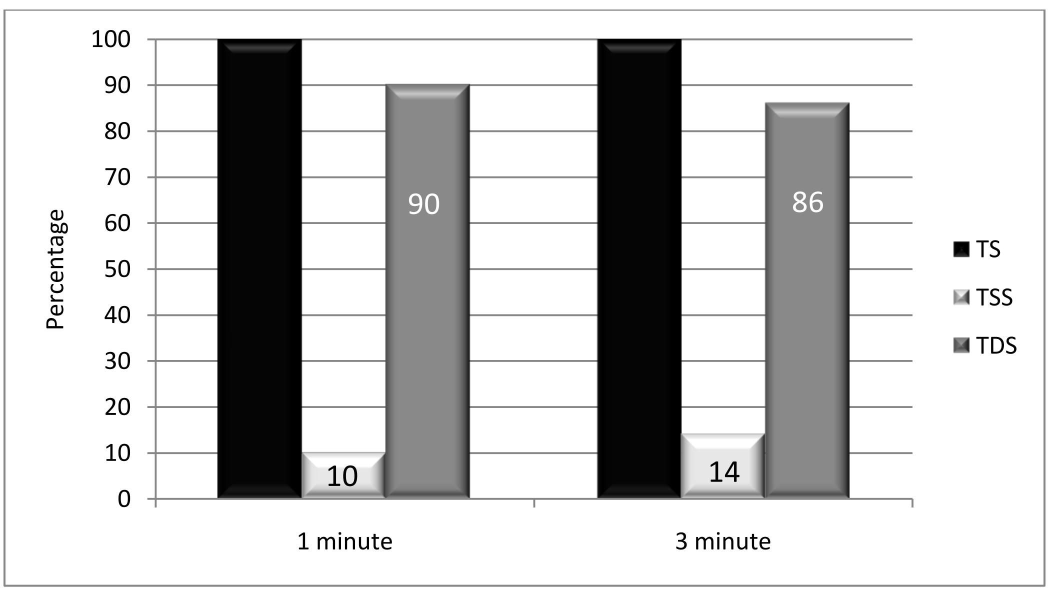

Figure 3.18. Relative mean percentages (%) of TSS and TDS to TS loads (g/kglwt) in viscera water samples for 1 min and 3 min agitation time for 120 broilers (n=120)