COMPLEXED TRACE MINERAL SUPPLEMENTATION

OF BROILER DIETS

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COMPLEXED TRACE MINERAL SUPPLEMENTATION OF BROILER DIETS

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A thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
August 4, 2007

COMPLEXED TRACE MINERAL SUPPLEMENTATION

OF BROILER DIETS

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Benya Saenmahayak, daughter of Police Lieutenant Colonel Prapat and Ubonwan Saenmahayak, was born May 12, 1982, in Pitsanulok, Thailand. She graduated from Samakkhi Wittayakom High School, Chiangrai, in March, 2000. She entered Mae Fah Luang University, Chiangrai in May 2000, and received a Bachelor of Science (Food Technology) in April 2004. During her study, she participated in the “One Tombon One Product” Entrepreneur Education Pilot Program, Ministry of Economy, Trade and Industry of Japan and Mae Fah Luang University and Asia SEED. She entered Graduate School in Department of Poultry Science at Auburn University, Alabama under the supervision of Dr. Sacit F. Bilgili in January, 2005 and conferred a Master of Science Degree in August, 2007.

THESIS ABSTRACT

COMPLEXED TRACE MINERAL SUPPLEMENTATION

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Master of Science, August 4, 2007
(B.Sc., Mae Fah Luang University 2004)

114 Typed Pages

Directed by S.F. Bilgili

Series of experiments were conducted to determine the effects of Zn and Mn complexes (C-Zn and C-Mn) on live performance, carcass, skin quality, and meat quality of male broilers. The first experiment evaluated the effects of C-Zn and C-Mn and post-mortem deboning time at 41 and 55 d of age. Body weight gain favored the standard inorganic control diet. No treatment effects ($P>0.05$) on feed conversion, mortality, carcass and parts yields and meat quality attributes were observed at 41 and 55 d of age.

Post-mortem deboning time had a significant influence ($P<0.05$) on processing yield. Breast deboned at 2 h PM exhibited higher yield, drip, cook loss,

and WHC as compared to those deboned at 24 h PM. At 41 d, cook loss was reduced with adding extra 40 ppm C-Zn. At 55 d, breast fillets were lighter in color when deboned at 24 h PM than at 2 h PM. No advantages were seen with organic Zn and Mn in live and processing performance at 41 and 55 d of age.

A second experiment was conducted to evaluate the effects of C-Zn and C-Mn on carcass and skin quality. No differences ($P>0.05$) in live performance were observed among treatments at 41 d of age. Adding extra 40 ppm C-Zn significantly reduced skin sores, scabs and scratches in the back area. However, adding extra 40 ppm C-Zn and 40 ppm C-Mn increased drumstick bruising ($P<0.05$). Overall carcass grade, whole carcass and parts yields were not significantly different among the treatments at 41 and 55 d of age. There were few effects of treatments on carcass and meat quality at 41 d of age.

The third experiment was conducted to evaluate the effects of C-Zn on carcass, skin, and foot pad quality. Birds on C-Zn showed significant improvements in weight gain and feed conversion, breast yield, thigh sores, scabs, and scratches, and pododermatitis incidence and severity. However, no advantages were seen with complexed Zn in meat quality attributes at 49 d of age.

Typical Corn-SBM based broiler diets provide adequate amounts of Zn and Mn. However, organic mineral products may increase mineral absorption over inorganic sources. Live and processing performance may be improved with complexed trace minerals. Complexed Zn appears to play an important role in wound healing as demonstrated in this study with improvements in skin quality and pododermatitis. Cost-benefit analysis of using complexed trace minerals may be warranted.

ACKNOWLEDGMENTS

The author would like to thank Drs. Sacit Bilgili and Joseph Hess for their help and guidance during all my studies in Auburn. Thanks to all the personnel of the Poultry Science Department and the Poultry Farm. Many thanks to all my friends that gave me support and help while I have been far away from my family and my country. Finally, the author wishes to extend a special thanks to her parents and all members of the family for their continuous love, support and constant encouragement.

Style manual or journal used Poultry Science

Computer software used Microsoft Word 2003, SAS statistical package (Version 9.01)

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I. INTRODUCTION

Consumption of broiler meat in the U.S. has been increasing over the last 50 years and developments of technology have allowed the poultry industry to meet the increasing market demand. The U.S. poultry industry is the biggest producer and exporter of poultry meat globally [1]. As much as 14% of the total production is exported to other countries [2]. Factors such as live production, efficiency, flock health and condemnations, and carcass/meat quality have been the primary economic drivers for the U.S. broiler industry.

Trace mineral supplementation of farm animal diets is usually accomplished with inorganic sources. Recent information suggests that complexed trace mineral sources may improve the bioavailability of these minerals for animals. Trace minerals complexed to organic compounds, such as proteins, short chain peptides or amino acids, are more soluble and mobile to the cell membranes and are more readily absorbed than from inorganic sources. Several trace elements including zinc (Zn), copper, manganese (Mn) and cobalt have become commercially available for use in animal feeds as organic complexes.

Zinc and Mn have been shown to be necessary for the development and growth of all species that have been studied [3]. Because Zn is a component of DNA and RNA polymerases [4], it has been shown to be involved in protein synthesis [3]. In poultry,

many studies examined the effects of Zn in areas such as the growth [5], bone integrity [6], skin problems [7] and meat sensory attributes [8]. Requirement of poultry for Mn is higher than mammals because of relatively inefficient intestinal absorption [9, 10]. Complexed Zn showed better absorption in animals than inorganic Zn sources [11]. Complexed Zn and Mn products may show performance advantages in poultry.

In this study, a series of experiments were conducted to investigate the effects of complexed Zn and Mn supplementation of broiler diets at different levels on live and processing performance of broiler chickens. In addition, skin, intestinal and bone strength, and meat quality attributes of breast fillets (cook loss, drip loss, water holding capacity, color and rancidity development) were assessed at various market ages.

II. LITERATURE REVIEW

Many dietary nutrients are required in order to promote good health and normal growth of animals. Studies have shown that mineral deficiencies cause many problems in animals. The roles and deficiency symptoms of most minerals have been well documented. This review will focus on Zn and Mn, highlighting on their functions in poultry nutrition, bone, intestinal, skin characteristic and meat quality. Current interests in organic minerals for broiler production have concentrated on organic Zn and Mn. Underwood [12] stated that Zn is a trace element essential for the development and growth of all species. O' Dell and Savage [13] demonstrated that Zn is important for normal growth, skeletal integrity, and optimal feathering in poultry. Zinc is a component of many proteins and is indispensable to their catalytic function and structural stability [14]. Similarly, Mn is an essential trace element for poultry in terms of growth and skeletal development [12, 15]. Manganese is involved in the synthesis of cartilage mucopolysaccharides, serving as a cofactor of polymerase, galactotransferase, and glycosyltransferase enzymes [16, 17, 18].

BIOAVAILABILITY OF TRACE MINERALS

Zinc is important trace mineral in poultry nutrition for growth, bone development, feathering, enzyme structure and function [19]. Trace mineral supplements such as Zn

and Mn are often added to broiler diets as sulfates, oxides, chelates, proteinates, or polysaccharides [20]. The two feed grade sources of Zn widely used in poultry industry are zinc oxide (72% Zn) and zinc sulfate (36% Zn). Zinc sulfates are highly water soluble, reactive metal ions that promote free radical formation. Free radicals decrease the nutritional value of the diet due to breakdown of vitamins, and fats [19]. Zinc oxide is less bioavailable than zinc sulfate. Zinc oxide has a bioavailability ranging from 61 to 77% relative to zinc sulfate, with tibia zinc being more responsive to dietary zinc source than weight gain [20, 21, 22].

Manganese sulfate has been reported to have more bioavailability in broilers when compared with manganese oxide and manganese carbonate [23, 24]. Manganese oxide had a relative bioavailability of 79, 58, and 64% for bone, kidney, and liver compared with manganese sulfate with a relative bioavailability of 100% for all response variables [25]. Because of the high bioavailability of the sulfate forms of trace minerals, they are used as to assess the bioavailability standards of organic trace minerals [26].

Organic mineral sources exist in the form of metal amino acid chelate, metal proteinate, and metal specific amino acid complexes. Metal amino acid chelate and metal proteinate are the chelation of a soluble salt with amino acids or hydrolysed protein. The molar ratio is 1 mole of a soluble salt with 2 or 3 moles of an amino acid. However, metal specific amino acid complexes and metal amino acid complexes consist of a specific amino acid or free amino acids compled with a soluble metal salt in a molar ratio of 1:1. Organic sources of trace minerals have greater bioavailability because of the ability of organic compounds, such as amino acids, to bind strongly to zinc under physiological pH conditions [27]. Ashmead [28] reported that the higher bioavailability of amino acid-

bound trace elements to animals was because they were more soluble than inorganic forms, such as oxides and sulfates, and the amino acid chelates remained intact to the site cell where zinc was needed. A study with metals in several chemical forms showed that rate of amino acid-zinc chelate absorption in intestine was 2.2 times greater than that zinc carbonate, 2.3 times faster than zinc sulfate and 2.9 times greater than that zinc oxide [28]. The organic forms of trace elements are less soluble because they are precipitated by anions in the digestive tract. Several studies showed no difference in bioefficiency, as determined by improvement in average daily gain and plasma zinc, between organic and inorganic form of Zn in steers, swine, and chickens [29, 30, 31]. Zinc amino acid has been compared to zinc sulfate as an alternative for pigs and chickens [32, 33]. Dozier et al. [34] evaluated the addition of zinc amino acid to decrease zinc excretion in broilers.

Wedekind et al. [20] demonstrated that zinc methionine has 177% of bioavailability of zinc sulfate for chickens by measuring bone zinc deposition. Cao et al. [35] reported that feed intake, daily gain, and bone zinc concentration were highest in birds supplemented with organic zinc compared with those supplemented with inorganic zinc. However, Mohanna and Nys [36] reported that weight gain, feed intake, and feed conversion in broilers were not influenced by zinc sulfate or zinc methionine. Furthermore, zinc source (zinc sulfate or zinc methionine) had no affect on growth and liver zinc levels, but broilers fed zinc methionine had higher levels of pancreatic zinc [31].

Manganese complexed with methionine has been reported to be 174% as available as manganese oxide [37] and 120% as available as manganese sulfate [38]. Baker and Halpin [26] reported that there was no difference between the bioavailability

of manganese sulfate and manganese proteinate based on bone manganese levels, weight gain, or feed efficiency. Henry et al. [38] reported that the relative bioavailability of manganese oxide ranged from 86 to 96%, while manganese methionine had a relative bioavailability of 108 to 132% compared with manganese sulfate based on liver and kidney manganese concentrations.

BIOCHEMISTRY OF TRACE MINERALS

Zinc (Zn) is an essential element in the nutrition of human beings, animals, and plants. Its atomic number is 30, atomic weight 65.38, found as a soil constituent (ZnS). The average Zn content of the animal body is approximately 30 mg/kg of body weight; a major portion of this is present in bone and is unavailable to metabolism [39]. About 65% of the body Zn is found in the skeletal muscle. High concentrations are also present in liver, kidney, skin, hair and wool, and intestines [39, 40, 41].

Dietary Zn is absorbed along the entire length of the small intestine. Zinc absorption in several animal species decreases with age [42]. When a soluble zinc salt is ingested, it is normally ionized in the stomach. The acid pH of the stomach encourages solubility. As the pH elevates in the intestines, the solubility is lost and Zn absorption is reduced. Zinc absorption is also influenced by various accompanying substances such as copper, and calcium ions, all of which compete for the same absorption sites [28].

Zinc is absorbed primarily in the ileum via a carrier-mediated system which involves chelation of zinc ions with proteins before absorption. Zinc is transported in the blood by albumin and α-2-macroglobulin which improves tissue uptake. In the liver, zinc is bound to a metal binding protein called metallothionein and superoxide dismutase (as a

cofactor). However, zinc is not stored to a large extent in animal tissues. Zinc is excreted through the pancreas into the intestine and excreted via feces [43].

The primary function of zinc is being a cofactor for enzyme activation. Zinc is known to be necessary for more than 100 enzymes associated with carbohydrate and energy metabolism, protein degradation and synthesis, nucleic acid synthesis, heme biosynthesis, carbon dioxide transport, and other reactions [39, 40, 44]. In enzymes systems, zinc acts as cross-link between enzyme proteins, thereby stabilizing enzyme structure. Because of its association with enzyme systems, Zn affected many physiological and metabolic activities [40, 43, 44]. In poultry, Zn maintains optimum growth rate and skin quality, bone strength, feather development, bone development and wound healing.

Manganese (Mn) is an essential element in the nutrition for humans and animals. Its atomic number is 25, atomic weight 54.94 and is, found as a soil constituent. Manganese can be found in bone, liver, kidney and pancreatic tissue, but manganese has low concentrations in animal tissues. Manganese is poorly absorbed from the intestinal tract; however, absorption occurs into mucosa cells throughout the small intestine. It is bound to α-2-macroglobulin when transported to the liver. Manganese is excreted through bile and pancreatic juices and ultimately via feces. Manganese is involved in numerous enzyme systems as both a cofactor and a structural component. The metabolic and physiological activities of Mn are attributable to its association with enzymes including oxidoreductases, transferases, hydrolases, lyases, and synthetases involved in carbohydrate, lipid, protein and nucleic acid metabolism. Manganese affects animals in three systems; bone, reproductive and brain [45].

Both humans and animals must have an appropriate intake of Zn in order to function properly. Adequate amounts of zinc are required to maintain animal health and productivity. Zinc efficiency reduces feed intake and animal growth [3]. Schurz et al. [46] reported that zinc is used with antibiotics to promote growth in chickens.

In evaluate the influence of zinc oxide or zinc methionine on reproductive performance of broiler breeder hens, Kidd et al. [51] could not demonstrate any effect of Zn source on fertility, hatchability, mortality, egg and chick weight, feed conversion and body weight. In turkeys, zinc methionine improved body weight and feed conversion, and decreased mortality and leg abnormality [52, 53]. Broiler chicks and turkeys fed low zinc diets reported high mortality rates [54].

Smith et al. [55] examined three supplemental manganese sources (manganese sulfate, manganese oxide, and manganese proteinate) fed at three different levels (1,000, 2,000 and 3,000 ppm), and could not demonstrate significantly feed intake and feed conversion differences in broiler chickens. They concluded that organic manganese may be more effective during heat stress periods when feed intake is reduced but availability is increased. In another study by Baker and Halpin [26], weight gain, feed intake and feed conversion were not different when chickens were fed manganese sulfate or manganese proteinate. Other studies similarly reported no differences in live performance of broiler chickens when fed with manganese sulfate, manganese oxide, and manganese carbonate or manganese methionine [56]. Lyons [11] reported that adding 40 ppm manganese to diet had no effect on performance of tom turkeys. However, adding the same amount of manganese and Zn in organic chelate form improved efficiency and decreased mortality in turkeys. Meat quality is a term to describe the overall meat characteristics including its

physical, chemical, biochemical, microbial, sensory, nutritional and culinary properties [57]. Meat quality can affect palatability, nutrient compositions, and consumer acceptability. Primary quality contributes include color, flavor, odor, texture, juiciness, safety, and compositions [58]. Many factors during production, including genetics, age, sex, diet, live animal management and handling can affect meat quality. However, little information is available on the effects of Zn and Mn on meat quality in poultry.

About 88 to 95% of the water in the muscle is held within the space between actin and myosin filaments. However, only 5 to 12% of water in the muscle is located between the myofibrils [59, 60]. Factors such as pH, sarcomere length, ionic strength, osmotic pressure, and development of rigor mortis can affect the meat quality by altering the cellular and extracellular components [61]. The quantitative measurements such as water holding capacity (WHC), expressible moisture, drip loss and cooking loss have been used to assess differences in muscle tissue water properties.

Some interest has been shown regarding the impact of zinc and manganese on meat quality. Carcass quality of beef steers were improved when dietary zinc was fed with organic zinc methionine compared to zinc oxide [29].

Carcass aesthetic qualities are very important and demanded by domestic and export markets. Many factors contribute to carcass grade, including the conformation and appearance of the carcass, blood splash, bone and skin defects. Animal nutrition is important in maintaining good carcass grade, and the level of zinc in the diet plays an important role in carcass quality.

Skin defects in broilers result in great economic losses in poultry industry every year. Types of skin defects include cuts, tears, lesions, scratches, bare backs, scabs,

bruises, breast blisters, and tumors. Skin scratches and scabs are the result of the production and processing phases of vertically integrated broiler operations. There are many factors in the broiler that affect broiler skin quality. Bird placement density can increase skin injuries. High temperature and humidity can cause problems due to birds trying to find cooler spots and crowding together. Birds with greater skin strength have fewer tears and scratches, therefore better skin quality. Plane of nutrition indirectly affects skin quality by affecting feathering rate and improving skin strength. Certain nutrients and supplements such as zinc, iron, copper, and vitamin C have been shown to improve the strength of skin by increasing the synthesis of collagen, the main structural component of skin [41, 62].

A secondary problem related to skin quality is rate of wound healing. Zinc plays an important role in protein synthesis because it is essential for the normal activity of DNA polymerase and is present in RNA polymerase [62]. Zinc also plays a role in cross-linking of collagen, as well as the strength of healing skin. There are three processes in wound healing; migration of cells, increased production of cells, and production of new connective tissue. Poor wound healing has been described in cases of Zn deficiency in many species [63]. In a wound healing period, more Zn is necessary to promote protein synthesis, collagen formation, or the incorporation of Zn into enzyme systems [64]. El-Swak et al. [48] reported that healing was slower in Zn deficient rats and faster in animals supplemented with Zn. Adequate Zn supplementation prevents skin dermatosis and maintains maximum wool, hair, and feather growth.

Trace minerals including Zn and Mn are also associated with bone formation in broilers [65]. Zinc may aid in calcification as an organic constituent or as an activator of

the calcification process itself. Zinc may be bound in some manner to the collagen matrix and may not be present in the interstitial fluids. Many bone malfunctions were reported in poultry when Zn deficiency occurred. A higher incidence of leg weakness was observed in broilers fed a purified basal diet with added rice bran than those fed the basal diet only, and this defect was related to lower Zn content of tibia [66]. Other studies showed that bones from Zn deficient broilers were shorter. The average ratio of tibia and humerus diameter to body weight was greater in deficient chicks, and the ratio of length to diameter was less [13]. Tibia of chickens were deformed when fed a low Zn diets. Bone collagen synthesis and turn over were reduced, and collagenase activity was decreased 40 to 80% when compared to normal chickens [67].

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III. EFFECT OF COMPLEXED ZINC AND MANGANESE SUPPLEMENTATION ON BROILER LIVE AND PROCESSING PERFORMANCE AT TWO MARKET WEIGHTS

SUMMARY

This study was conducted to evaluate the influence of supplemental dietary zinc (Zn) and manganese (Mn) sources on broiler live performance, carcass and deboning yields, and meat quality at 41 and 55 d of age. A total of 1,600 male broilers were provided four dietary treatments: inorganic control (80 ppm $ZnSO_4$ and 60 ppm $MnSO_4$), complexed Zn (C-Zn; Availa-Zinc, Zinpro Corp., Eden Prairie, MN) replaced 40 ppm $ZnSO_4$ in control diet, additional 40 ppm C-Zn on top of inorganic control, and additional 40 ppm C-Zn and 40 ppm complexed Mn (C-Mn; Availa-Mn, Zinpro Corp., Eden Prairie, MN) on top of inorganic control diet. A four stage feeding program with 50 birds per pen and 8 replicates per treatment were used. Body weight, feed conversion and mortality were determined on days 13, 27, 40 and 54. At 41 and 55 d of age, 10 birds per pen were processed to assess carcass and meat yield (deboned both at 2 and 24 h post-mortem) and meat quality attributes (drip loss, cooking loss, water holding capacity and color). Femur bone breaking strength was measured at 21, 41 and 55 d of age and small intestine strength was determined at 40 d of age.

Few differences in live performance were detected throughout the experiment. At 13, 27 and 40 d of age, body weight was significantly ($P<0.05$) influenced by dietary

treatments, with birds fed C-Zn and C-Mn treatments showing lower weights than the inorganic control treatment. Feed conversion differences ($P<0.05$) were limited to 13 d of age and favored the inorganic control diet. Mortality was highest for the inorganic control treatment at 40 d of age. Intestinal strength and bone breaking strength were not significantly affected ($P>0.05$) by the dietary treatments. Carcass weights (chilled and lean) and parts (leg quarters and fillets, tenders and total breast) weights were higher with the inorganic control diet at 41 d of age but not at 55 d of age. Meat quality attributes were not affected by the Zn sources. However, post-mortem deboning time had an effect on deboning yields. Whole carcass and parts yields were higher ($P<0.05$) when carcasses were deboned at 2 h as compared to those deboned at 24 h post-mortem. At both ages, breast deboned at 2 h post-mortem exhibited higher drip, cook loss, and WHC as compared to those deboned at 24 h post-mortem. At 55 d, breast fillets were lighter in color when deboned at 24 h as compared to those deboned at 2 h post-mortem. The yield advantage (0.5-1.2%) in breast meat from early deboning observed at 41 and 55 d of age was lost upon refrigerated storage and cooking. Level and source of dietary Zn and Mn had little influence on broiler live and processing performance.

Key words: Broilers, complexed Zinc, complexed Mn, meat quality

DESCRIPTION OF PROBLEM

Appearance is the major criterion of evaluation of meat quality and purchase for consumers. However, other quality attributes, such as tenderness, drip loss, cook loss, water holding capacity and pH are equally important during the preparation of meat. Assessment of water holding capacity (WHC), drip loss and cooking loss of meat is very

important for both fresh meat and further processed products, where high yield and low cooking losses are desired [1]. Raw meat used in further processed products should have excellent functional properties to ensure a final product of exceptional quality and profitability.

In recent years, the use of organic trace minerals in animal nutrition has received increasing attention. Zinc (Zn) and manganese (Mn) are important trace minerals that are commonly added to poultry diets to maintain optimum growth rate, skin quality and wound healing. Bioavailability and absorption of inorganic mineral supplements can be improved through complexing them with more readily available compounds (amino acids, proteins, carbohydrates, organic acids). Therefore, an amino acid complexed Zn product may contribute to improved animal performance and meat quality attributes beyond that of an inorganic Zn source. In chickens, Zn has been associated with growth, feathering and skin condition [2]. When Zn levels in the diet were below the requirement, mortality rates and leg abnormalities in broiler chicks and turkey poults were increased [3]. A study by Bonomi et al. [4] showed that ducks receiving feed with chelated trace elements showed improvement feed conversions. Little information is available regarding the effects of complexed Zn and Mn sources on live performance and meat quality in broiler chickens.

The objective of this study was to evaluate live performance, carcass and parts yields and meat quality of broilers fed inorganic or organic sources of Zn and Mn at two market weights. Breast muscles were deboned at 2 h and 24 h post-mortem to assess meat quality attributes.

MATERIALS AND METHODS

A total of 1,600 male broilers were raised in 32 floor pens to 55 d of age in new pine shaving litter-covered floor pens (8 pens/diet; 50 birds/pen), using a four phase feeding program. The starter feed was fed on days 1-13, the grower feed on days 14-27, the finisher on days 28-40, and the withdrawal on days 41-54. The dietary treatments consisted of (1) Inorganic Control [IC; 80 ppm $ZnSO_4$ and 60 ppm $MnSO_4$], (2) 40 ppm C-Zn [IC-C-Zn; complexed Zn replaced 40 ppm Zn from $ZnSO_4$], (3) 40 ppm C-Zn [IC+C-Zn; complexed Zn provided additional 40 ppm Zn on top of inorganic control], and (4) 40 ppm C-Zn + 40 ppm C-Mn [IC+C-Zn+C-Mn; 40 ppm complexed Zn and 40 ppm complexed Mn added on top of inorganic control]. Complexed Zn and Mn were supplied from Availa-Zinc and Availa-Manganese (Zinpro Corp., Eden Prairie, MN). All birds were weighed on a per pen basis at 13, 27, 40 and 54 d of age and body weights (BW), adjusted feed conversion (FC) and mortality were determined. The nutrient and ingredient composition of the experimental diets are shown in Tables 1 and 2.

At 21, 41 and 55 d of age, two birds were randomly chosen from each pen to assess femur breaking strength [5, 6, 7, 8]. At 40 d of age, two birds per pen were euthanized and 20 cm. segments of the intestines were removed to measure intestinal strength [9, 10].

Both at 41 and 55 d of age, 320 randomly selected birds (10 birds per pen) were processed at the Auburn University Poultry Science Department Processing Plant simulating commercial processing practices to assess the effect of treatments on carcass yield parameters. Carcasses were chilled for 1.5 h in static slush-ice. At each age, one-half of the birds (5 birds per pen) were deboned immediately after static chilling (2 h

postmortem; PM) and the remaining after overnight aging in a cooler at 4 C (24 h PM). Whole carcass, abdominal fat, parts (wings, leg quarters) and deboned breast (fillet and tender) weights and yields were determined. Deboned breast fillets (skinless *Pectoralis major* muscle) were individually bagged and stored at 4 C for drip loss (12 h and 48 h), cook loss, and water holding capacity (WHC) measurements [11]. Breast fillet color (L*, a* and b*) was also determined at 56 d age [12].

The data were statically analyzed by the General Linear Models procedure for the ANOVA using SAS 9.1 software (SAS Institute, 2002-2003) [13]. All percentage data was transformed to arcsine values prior to analysis. The Tukey's test was used to compare and separate means when main effects were significant ($P<0.05$).

RESULTS AND DISCUSSION

The dietary treatments had a significant effect ($P<0.05$) on body weights at 13, 27 and 40 d of age. Birds raised on inorganic control diet had higher body weights than other treatments (Table 3). Body weights were reduced by adding C-Zn extra (on the top) in the feed. The differences in body weight response may be an imbalance of Zn in relation to Mn, Cu and Fe. Hudson et al. [14] reported no differences in body weight of broiler breeder hens when fed $ZnSO_4$, Zn amino acid and a mixture of Zn amino acid and $ZnSO_4$. They also showed that Zn sources in hen diets did not alter final body weight at 41 d of age [15]. However, Larson [16] have reported that when a complexed zinc is added above 100 ppm $ZnSO_4$, broiler live performance is improved.

Mortality was significantly ($P<0.05$) higher in the inorganic control treatment at 40 d of age (Table 3). Adjusted feed conversion were significantly ($P<0.05$) lower with

the inorganic control diet 13 d of age compared to other treatments (Table 3). Dietary treatments did not affect feed conversion ($P>0.05$) at later ages. Hudson et al. [17] reported that broilers with diets having added Zn from Zn amino acid and $ZnSO_4$ improved feed conversion and body weight at 17 d of age, but no affect on feed intake, leg abnomalities or mortality was detected. Hess et al. [18] supplemented practical broiler diets (55 ppm from $ZnSO_4$) with 40 ppm Zn from three different amino acid complexes. Feed conversions of female broilers were improved from 0 to 35 d and from 0 to 42 d of age when supplemented with Zn amino acid complexes. Body weight and feed efficiency are generally not influenced by feeding excessive supplementary Mn and/or Zn [19].

Intestinal strength was not influenced by the dietary treatments 40 d of age (Table 4). This is contrary to studies by Richards and Dibner [20], who reported that intestinal strength was improved in birds fed organic zinc. Similarly, femur bone breaking strength was not significantly ($P>0.05$) affected by dietary treatments at 21, 42 and 56 d of age (Table 4).

At 41 d of age, chilled carcass, leg quarters, total breast (fillet + tender) weights were significantly higher ($P<0.05$) when birds were deboned at 2 h PM vs. those deboned at 24 h PM (Table 5, 6 and 7). Inorganic control treatment had highest breast muscle weights ($P<0.05$), but yields expressed as a proportion of pre-slaughter weight did not vary among the treatments. No differences in carcass and parts yields existed at 55 d (Table 8, 9 and 10). Collins and Moran [20] reported that supplemental Mn and Zn (0:0, 60:50, 120:100 and 180:190 ppm) did not alter carcass weights, percentage abdominal fat of the chilled carcass, or carcass yield after processing at 49 d. Birds fed supplemental Mn from organic sources had lower percentages of abdominal fat than those fed with

supplemental Mn from $MnSO_4$. Abdominal fat weight and yields were not affected by dietary treatments in the study. Mn source ($MnSO_4$ and Mn amino acid) did not affect abdominal fat deposition at 42 d of age [21].

Since carcass and parts yields did not differ among treatments, a separate analysis of the post-mortem deboning time on carcass and breast yields was performed (Table 11). At 41 d of age, breast fillet and total breast (fillet + tender) yields were significantly higher in the 2 h PM (25.7 and 30.8%) than in 24 h PM (25.2 and 30.3%) treatments, respectively. At 55 d of age, birds deboned 2 h PM had significantly higher parts yields than those deboned at 24 h. Deboned breast yields (fillet, tender and fillet + tender) were significantly different between the PM treatments, favoring the 2 h PM group. It is possible that the breast muscles lost moisture between 2 and 24 PM due to natural changes that occur in conversion of muscle to meat or that proteoysis increased in the muscle during this period. A loss of moisture in the muscle mass could result in a lower meat yield. Mehaffey et al. [22] reported that there were higher breast yield values at 2 h deboning time compared with 4 h deboning time at 42 and 49 d of age.

Meat quality attributes (drip loss, cooking loss, WHC and color) measured during this experiment were not influenced by Zn sources ($P>0.05$) at 41 and 55 d of age (Table 12, 13 and 14). Zinc supplementation, in inorganic or organic forms had no effect on meat color and drip loss in fattening bulls [23]. As expected, drip loss (12 h), and WHC were higher for 2 h than 24 h PM treatments, both at 41 and 55 d of age (Table 12 and 13). These results are similar to Lesiak et al. [24], who reported that as post-mortem time increased, drip loss also increased. Cook loss differed between the PM treatments at 41 d, but not at 55 d of age (Table 14). A significant ($P<0.05$) treatments and deboning time

interaction for cook loss at 41 d of age showed that birds with extra C-Zn showed a reduced cook loss at 2 h and 24 h PM compared to other treatments (Figure 1). Breast fillets deboned 2 h PM were significantly darker (L* = 54.8) as compared to those deboned at 24 h (L* = 56.5). An increase in breast yield did not affect WHC, drip and cook loss. There were no significant differences in cook loss at 42 d of age deboned at either 2 or 4 h PM. [22]

Postmortem enzymatic and oxidative tissue breakdown proceeds rapidly. This probably increases in WHC due to a proteolysis during aging. During post-mortem storage, proteolysis of proteins results in a progressive weakening of linkages between filaments. The loosely-held water would be expelled from the filament spaces into the interfibrillar spaces rather than into the extracellular spaces [25]. Another contributing factor to drip loss of raw meat products may be excessive cellular damage resulting from oxidation, creating leaks in cellular components and membranes [26]. Level and source of Zn and Mn had no influence on broiler live and processing performance.

CONCLUSIONS AND APPLICATIONS

1. Live performance was not significantly affected by the dietary treatments in this study.
2. Processing yields and meat quality attributes were not influenced by Zn treatments at both 42 and 56 d of age. As expected, parts and deboning yields increased with age.
3. There was a significant yield advantage in raw breast meat by early (2 h PM) deboning. However, this advantage was lost during cool stage and cooking.

4. Early deboning resulted in darker fillets (low lightness value) as compared to 24 h aging.
5. Significantly C-Zn appeared to reduce cook loss in early deboned (2 h post-mortem) breast meat.

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Cooking Loss: After weighing for drip loss determination, left fillets (2 h PM and 24 h PM) were weighed and recorded. Fillets were numbered, arranged on wire oven racks and placed in a preheated (1 h) convection oven (177 C). Fillets were cooked to an internal temperature of 77 C, removed from oven and allowed to cool to an internal temperature of 24 C, and reweighed. Cooking loss (%) was calculated between raw and cooked fillet weight divided by raw fillet weight.

Water Holding Capacity: Ten grams sample of ground right fillet meat (composite from 5 fillets/pen) was weighed into 50 ml polycarbonate centrifuge tube. Sixteen milliliters of a 0.6 M NaCl solution was pipetted into each tube. Sample tubes were vortexed approximately 30 sec, allowed to incubate for 30 min at 4 C, and

centrifuged at 7,000 g. for 25 min. Supernatant were decanted into a graduated cylinder and volume recorded. Water holding capacity (ml/g of tissue) was calculated as 16 ml minus decanted volume divided by sample weight.

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Table 1. Nutrient composition of experimental starter and grower diets

Ingredients and analysis	Starter (1-13 d)				Grower (14-27 d)			
	IC[1]	IC -C-Zn	IC +C-Zn	IC+C-Zn +C-Mn	IC	IC -C-Zn	IC +C-Zn	IC+C-Zn +C-Mn
Ground corn	56.60	56.60	56.60	56.60	62.52	62.52	62.52	62.52
Soybean meal (48% CP)	33.34	33.34	33.34	33.34	27.87	27.87	27.87	27.87
Poultry oil	3.12	3.12	3.12	3.12	3.00	3.00	3.00	3.00
Poultry by-product meal	3.00	3.00	3.00	3.00	2.95	2.95	2.95	2.95
Dicalcium phosphate	1.47	1.47	1.47	1.47	1.35	1.35	1.35	1.35
Limestone	1.15	1.15	1.15	1.15	1.00	1.00	1.00	1.00
Salt	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.43
DL-methionine	0.26	0.26	0.26	0.26	0.23	0.23	0.23	0.23
Trace mineral premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine	0.10	0.10	0.10	0.10	0.03	0.03	0.03	0.03
Coban-60	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Nutrient analysis (DM basis)								
CP %	23.38	24.69	25.13	23.31	21.44	22.50	21.50	22.50
ME, kcal/kg	2710	2690	2650	2690	2710	2690	2670	2690
Ca %	1.16	1.18	1.16	1.00	1.15	0.99	1.00	0.99
P %	0.54	0.51	0.54	0.50	0.52	0.48	0.49	0.48
Zn, ppm	209	205	299	237	199	174	244	227
Mn, ppm	121	120	134	133	119	100	101	119

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

Table 2. Nutrient composition of experimental finisher and withdrawal diets

Ingredients and analysis	Finisher[1] (28-40 d)				Withdrawal (41-54 d)			
	IC[1]	IC-C-Zn	IC+C-Zn	IC+C-Zn +C-Mn	IC	IC-C-Zn	IC+C-Zn	IC+C-Zn +C-Mn
Ground corn	70.15	70.15	70.15	70.15	71.71	71.71	71.71	71.71
Soybean meal (48% CP)	21.42	21.42	21.42	21.42	20.67	20.67	20.67	20.67
Poultry oil	3.00	3.00	3.00	3.00	2.63	2.63	2.63	2.63
Poultry by-product meal	2.11	2.11	2.11	2.11	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.17	1.17	1.17	1.17	1.11	1.11	1.11	1.11
Limestone	0.90	0.90	0.90	0.90	0.89	0.89	0.89	0.89
Salt	0.43	0.43	0.43	0.43	0.51	0.51	0.51	0.51
DL-methionine	0.21	0.21	0.21	0.21	0.19	0.19	0.19	0.19
Trace mineral premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine	1.00	1.00	1.00	1.00	0.08	0.08	0.08	0.08
Coban-60	-	-	-	-	-	-	-	-
Nutrient analysis (DM basis)								
CP %	19.06	18.95	19.69	19.06	19.00	18.75	17.31	19.19
ME, kcal/kg	2670	2650	2670	2670	2670	2670	2670	2690
Ca %	1.07	0.99	0.95	0.99	0.89	0.78	0.93	1.02
P %	0.46	0.48	0.46	0.45	0.42	0.38	0.43	0.45
Zn, ppm	199	191	222	221	146	156	232	224
Mn, ppm	119	100	102	115	87	84	101	129

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

Table 3. Influence of Zn sources on broiler live performance

Treatment[1]	1-13 d of age			1-27 d of age			1-40 d of age			1-54 d of age		
	BW (g)	FC[2]	% Mort	BW (g)	FC	% Mort	BW (g)	FC	% Mort	BW (g)	FC	% Mort
	**	*	NS[3]	**	NS	NS	*	NS	*	NS	NS	NS
IC	403[a]	1.068[b]	2.1	1383[a]	1.338	3.3	2516[a]	1.492	4.0[a]	3693	1.692	4.3
IC-C-Zn	397[ab]	1.077[ab]	1.0	1336[b]	1.356	1.5	2434[ab]	1.520	1.8[b]	3662	1.689	2.4
IC+C-Zn	387[b]	1.105[a]	1.3	1322[b]	1.376	1.6	2416[b]	1.524	2.5[ab]	3579	1.694	3.8
IC+C-Zn+C-Mn	391[ab]	1.096[ab]	1.5	1346[ab]	1.362	2.6	2472[ab]	1.534	3.5[ab]	3682	1.687	4.0
SEM[4]	3.1	0.009	0.4	10.9	0.012	0.5	25.2	0.016	0.5	48.2	0.02	0.6

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]FC=Feed conversion adjusted for mortality.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 4. Influence of Zn sources on broiler intestinal and bone breaking strength

Treatment[1]	Intestinal strength (g)	Femur bone breaking strength (kg)		
		21 d of age	41 d of age	55 d of age
	NS[2]	NS	NS	NS
IC	321	22.02	32.17	36.42
IC-C-Zn	297	24.22	31.40	37.32
IC+C-Zn	313	22.84	32.82	35.31
IC+C-Zn+C-Mn	304	23.91	31.81	37.56
SEM[3]	12.5	0.90	0.70	1.04

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

Table 5. Influence of Zn sources on chilled, lean carcass and abdominal fat weights and yields at 41 d of age

Treatment[1]	PSW[2]	Chilled Carcass				Lean Carcass[5]				Abdominal Fat			
		Weight		Yield[4]		Weight		Yield		Weight		Yield	
		2h[3]	24h	2h	24h	2h	24h	2h	24h	2h	24h	2h	24h
	NS[6]	**	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
IC	2738	1967[a]	1912	71.9	69.8	1923[a]	1870	70.2	68.3	44	43	1.6	1.6
IC-C-Zn	2632	1835[b]	1835	69.8	69.7	1795[b]	1792	68.3	68.1	40	43	1.1	1.6
IC+C-Zn	2742	1836[b]	1830	68.3	68.1	1798[b]	1787	66.8	66.6	39	42	1.4	1.6
IC+C-Zn+C-Mn	2681	1893[ab]	1890	70.7	70.4	1851[ab]	1844	69.1	68.8	42	46	1.6	1.7
SEM[7]	93	28	52	1.8	2.3	28	51	1.8	2.2	2.0	2.3	0.1	0.08

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Pre-slaughter weight.

[3]Deboning time after chilling.

[4]As percent of pre-slaughter weight.

[5]Excluding abdominal fat.

[6]Not significant (P>0.05).

[7]SEM = Pooled Standard Error of the Mean. [ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 6. Influence of Zn sources and post-mortem deboning time on wings and leg quarters weights and yields at 41 d of age

Treatment[1]	Wings				Legs			
	Weight		Yield[3]		Weight		Yield	
	2h[2]	24h	2h	24h	2h	24h	2h	24h
	NS[4]	NS	NS	NS	*	NS	NS	NS
IC	211	206	7.7	7.5	807[a]	786	29.5	28.7
IC-C-Zn	199	200	7.6	7.6	756[ab]	763	28.8	29.0
IC+C-Zn	199	205	7.4	7.7	753[b]	759	28.0	28.2
IC+C-Zn+C-Mn	208	202	7.8	7.6	771[ab]	776	28.8	28.9
SEM[5]	4.23	4.54	0.3	0.2	13.6	20.4	0.8	0.8

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Deboning time after chilling.

[3]As percent of pre-slaughter weight.

[4]Not significant (P>0.05).

[5]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 7. Influence of Zn sources and post-mortem deboning time on fillet and tender weights and yields at 41 d of age

Treatment[1]	Fillets				Tenders				Total Breast			
	Weight		Yield[3]		Weight		Yield		Weight		Yield	
	2h[2]	24h	2h	24h	2h	24h	2h	24h	2h	24h	2h	24h
	**	NS[4]	NS	NS	***	NS	NS	NS	***	NS	NS	NS
IC	501[a]	470	18.3	17.2	100[a]	97	3.7	3.5	601[a]	570	22.0	20.8
IC-C-Zn	457[b]	443	17.4	16.8	91[b]	90	3.5	3.4	548[b]	534	20.8	20.3
IC+C-Zn	457[b]	454	17.0	16.9	92[b]	91	3.4	3.4	549[b]	545	20.4	20.3
IC+C-Zn+C-Mn	477[ab]	467	17.8	17.4	95[ab]	93	3.6	3.5	573[ab]	563	21.4	21.0
SEM[5]	8.1	13.3	0.5	0.6	1.4	2.4	0.1	0.1	8.96	13.41	0.6	0.6

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Deboning time after chilling.

[3]As percent of pre-slaughter weight.

[4]Not significant (P>0.05).

[5]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 8. Influence of Zn sources on chilled, lean carcass and abdominal fat weights and yields at 55 d of age

Treatment[1]	PSW[2]	Chilled Carcass				Lean Carcass[5]				Abdominal Fat			
		Weight		Yield[4]		Weight		Yield		Weight		Yield	
		2h[3]	24h	2h	24h	2h	24h	2h	24h	2h	24h	2h	24h
	NS[6]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IC	3932	3054	2963	77.7	75.3	2979	2895	75.8	73.6	75.8	67.1	1.9	1.7
IC-C-Zn	3933	3031	2997	77.1	76.2	2957	2926	75.2	74.4	74.3	71.3	1.9	1.8
IC+C-Zn	3940	3071	2928	77.9	74.3	2990	2863	75.9	72.6	81.3	65.8	2.1	1.7
IC+C-Zn+C-Mn	3978	3059	2955	74.9	74.3	2981	2885	74.9	72.5	77.8	70.4	2.0	1.8
SEM[7]	63	53	74	0.4	1.2	50	72	0.4	1.2	4.0	4.6	0.09	0.1

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Pre-slaughter weight.

[3]Deboning time after chilling.

[4]As percent of pre-slaughter weight.

[5]Excluding abdominal fat.

[6]Not significant ($P>0.05$).

[7]SEM = Pooled Standard Error of the Mean.

Table 9. Influence of Zn sources and post-mortem deboning time on wings and leg quarters weights and yields at 55 d of age

Treatment[1]	Wings				Legs			
	Weight		Yield[3]		Weight		Yield	
	2h[2]	24h	2h	24h	2h	24h	2h	24h
	NS[4]	NS	NS	NS	NS	NS	NS	NS
IC	319	306	8.1	7.8	1259	1207	32.0	30.7
IC-C-Zn	315	308	8.0	7.8	1245	1241	31.7	31.5
IC+C-Zn	314	304	8.0	7.7	1273	1220	32.3	31.0
IC+C-Zn+C-Mn	317	303	8.0	7.6	1246	1214	31.3	30.5
SEM[5]	5.1	6.8	0.09	0.13	22	27	0.3	0.5

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Deboning time after chilling.

[3]As percent of pre-slaughter weight.

[4]Not significant ($P>0.05$).

[5]SEM = Pooled Standard Error of the Mean.

Table 10. Influence of Zn sources and post-mortem deboning time on fillet and tender weights and yields at 55 d of age

Treatment[1]	Fillets				Tenders				Total Breast			
	Weight		Yield[3]		Weight		Yield		Weight		Yield	
	2h[2]	24h	2h	24h	2h	24h	2h	24h	2h	24h	2h	24h
	NS[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IC	774	753	19.6	19.2	147	143	3.7	3.6	920	900	23.4	22.9
IC-C-Zn	761	743	19.3	18.9	150	145	3.8	3.7	911	894	23.2	22.7
IC+C-Zn	747	744	19.0	18.9	144	145	3.7	3.7	891	888	22.6	22.5
IC+C-Zn+C-Mn	756	760	19.0	19.1	148	149	3.7	3.8	903	907	22.7	22.8
SEM[5]	25	15	0.46	0.18	4	4	0.07	0.07	28	18	0.50	0.20

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Deboning time after chilling.

[3]As percent of pre-slaughter weight.

[4]Not significant ($P>0.05$).

[5]SEM = Pooled Standard Error of the Mean.

Table 11. Post-mortem deboning time influence on broiler carcass yields at 41 and 55 d of age

Age	Deboning time[1]	Chilled Carcass		Lean Carcass[3]		Abdominal Fat		Wings[4]		Leg quarters		Fillets		Tenders		Total Breast	
		Wt	Y[2]	Wt	Y	Wt	Y	Wt	Y	Wt	Y	Wt	Y	Wt	Y	Wt	Y
42 d	2 h	1883	70.2	1842	68.6	41	1.5	204	11.1	772	41.9	473	25.7[a]	95	5.1	568	30.8[a]
	24 h	1867	69.5	1823	67.9	43	1.6	203	11.2	771	42.3	458	25.2[b]	93	5.1	551	30.3[b]
	SEM[5]	21.6	1.0	20.9	1.0	1.1	0.04	2.2	0.1	8.8	0.2	5.9	0.2	1.1	0.04	6.8	0.2
56 d	2 h	3054[a]	77[a]	2976[a]	75.4[a]	77.3[a]	2.0[a]	316[a]	8.0[a]	1256[a]	31.8[a]	759	26.2[a]	147	5.1[a]	906	31.3[a]
	24 h	2961[b]	75[b]	2892[b]	73.3[b]	68.6[b]	1.7[b]	305[b]	7.7[b]	1220[b]	30.9[b]	750	25.2[b]	146	4.9[b]	896	30.1[b]
	SEM	30.9	0.4	29.9	0.4	2.1	0.05	2.9	0.05	12.1	0.2	10.1	0.2	1.9	0.04	11.5	0.2

[ab]Means with different superscript within a row significantly differences (P<0.05).

[1]Deboning time after chilling.

[2]As percent of pre-slaughter weight (PSW = 2698 g.).

[3]Excluding abdominal fat.

[4]As a percentage of lean carcass weight.

[5]SEM = Pooled Standard Error of the Mean.

Table 12. Influence of Zn sources on meat quality attributes at 41 d of age

Treatment[1]	Drip Loss (%)	Cook Loss (%)	WHC (%)
	NS[2]	NS	NS
IC	2.0	23.4	42.8
IC-C-Zn	1.7	23.2	40.4
IC+C-Zn	1.5	24.1	42.3
IC+C-Zn+C-Mn	1.6	23.9	41.5
SEM[3]	0.2	0.7	2.2
Post-mortem deboning time	**	***	***
No (2 hours)	1.9	25.8	46.7
Yes (24 hours)	1.5	21.5	36.8
SEM	0.1	0.5	1.5
Interaction	NS	*	NS

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Figure 1. Diets by post-mortem deboning time interaction for cooking loss at 41 d (SEM = 0.5)

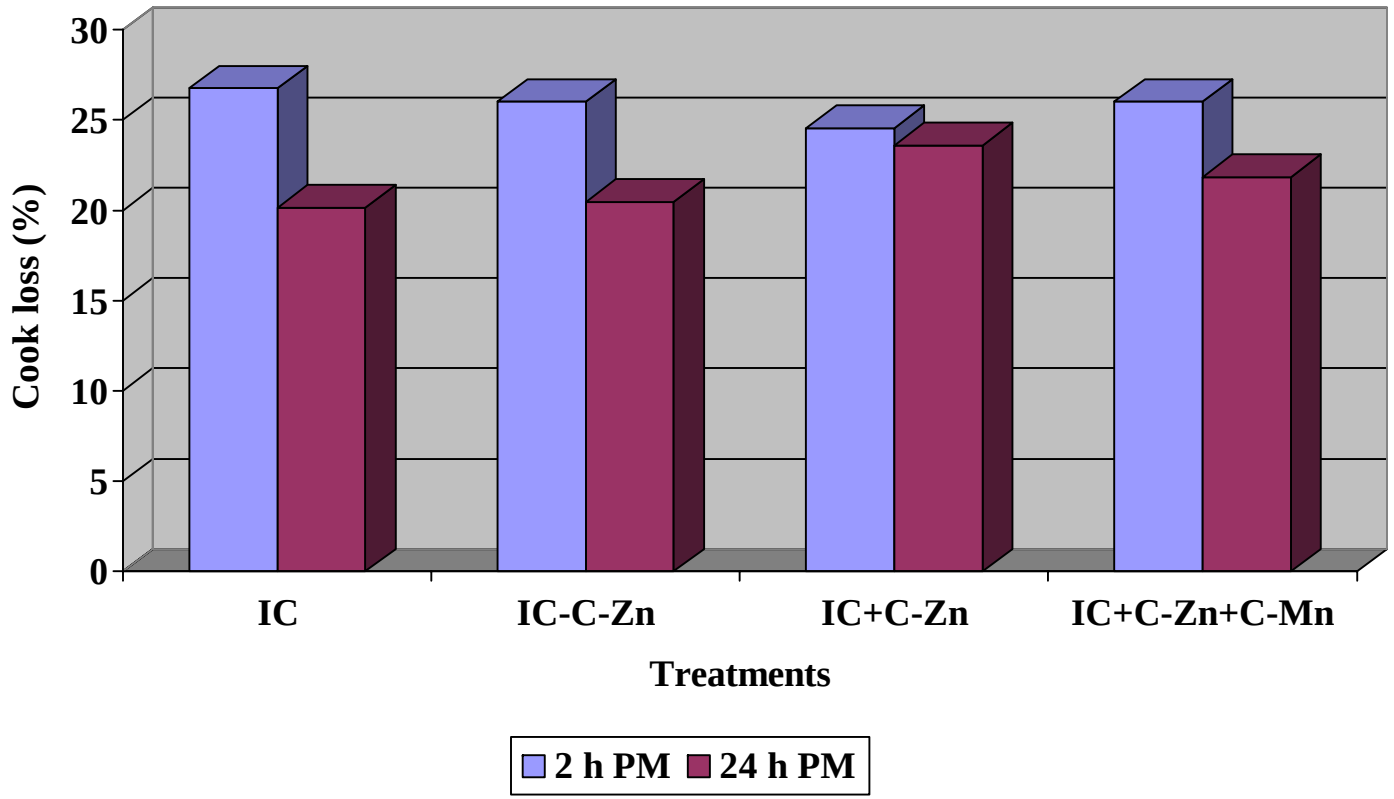

Table 13. Influence of Zn sources on meat quality attributes at 55 d of age

Treatment[1]	Drip Loss (%)		Cook Loss (%)	WHC (%)
	12 h	48 h		
	NS[2]	NS	NS	NS
IC	1.0	2.4	23.8	38.1
IC-C-Zn	0.9	2.5	23.9	43.5
IC+C-Zn	0.8	2.5	23.4	44.1
IC+C-Zn+C-Mn	1.0	2.6	24.0	45.0
SEM[3]	0.09	0.24	0.90	3.2
Post-mortem deboning time	***	NS	NS	*
No (2 hours)	1.2	2.7	24.6	46.8
Yes (24 hours)	0.6	2.3	22.9	38.5
SEM	0.1	0.2	0.6	2.3
Interaction	NS	NS	NS	NS

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 14. Influence of Zn sources on color measurement at 55 d of age

Treatment[1]	Color measurement		
	L*	a*	b*
	NS	NS	NS
IC	56.02	4.92	10.97
IC-C-Zn	55.42	4.99	10.62
IC+C-Zn	55.97	4.57	10.38
IC+C-Zn+C-Mn	55.27	5.10	10.64
SEM[3]	0.36	0.19	0.21
Post-mortem deboning time	***	NS	NS
No (2 hours)	54.84	4.97	10.63
Yes (24 hours)	56.50	4.83	10.67
SEM	0.25	0.13	0.15
Interaction	NS	NS	NS

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

IV. INFLUENCE OF COMPLEXED ZINC AND MANGANESE SUPPLEMENTATION ON SKIN QUALITY OF BROILERS PROCESSED AT DIFFERENT MARKET WEIGHTS

SUMMARY

This study evaluated the influence of supplemental dietary zinc (Zn) and Manganese (Mn) sources on broiler live and processing performance, carcass quality and yields, meat quality, and carcass and skin quality at 42 and 56 d of age. A total of 1,920 male Ross x Ross 708 broilers were placed for dietary treatments using a four stage feeding program (60 birds/pen; 8 replicates/treatment). Dietary treatments included: inorganic control (IC; 80 ppm $ZnSO_4$ and 80 ppm $MnSO_4$), complexed Zn (Availa-Zinc, Zinpro Corp., Eden Prairie, MN) replaced 40 ppm Zn in control diet (IC-C-Zn), additional 40 ppm Zn from Availa-Zn on top of control (IC+C-Zn), and additional 40 ppm complexed Zn and 40 ppm complexed Mn (Availa-Mn, Zinpro Corp., Eden Prairie, MN) on top of control (IC+C-Zn+C-Mn). Body weight, feed conversion and mortality were determined on days 14, 28, 41 and 55. At 42 and 56 d of age, 10 birds per pen were processed to assess carcass yield and meat quality attributes (drip loss, cooking loss, water holding capacity and color measurement). Carcass and skin defects were graded at 42 d of age. Femur bone breaking strength was measured at 21d of age and small intestine and skin puncture strength was determined at 41 d of age.

Few differences in live performance were detected throughout the study. No differences (P>0.05) were detected in mortality between the treatments. Bone breaking strength, intestinal and skin puncture strength did not vary (P>0.05) between the dietary treatments. Birds fed IC+C-Zn had lower (P<0.05) incidence of sores, scabs and scratches as compared to other treatments. Overall carcass grade, whole carcass and parts yields were not significantly different among the treatments. At 42 and 56 d of age, carcass and parts weights and yields were not affected by the dietary treatments (P>0.05). Breast fillet drip losses and WHC did not show any differences due to treatments at either age. However, at 42 d of age, cook loss was significantly reduced with IC+C-Zn+C-Mn as compared to inorganic control (22.3% vs. 29.7%). Color measurements at 42 d of age showed highest L* value and lowest a* values with the control treatment. In this study, broiler chickens responded positively to complexed trace mineral supplementation in terms on skin quality improvement and reduced cook loss.

Key words: Broilers, complexed zinc, complexed manganese, skin quality

DESCRIPTION OF PROBLEM

Skin associated downgrading problems (cuts and tears), continue to cause substantial economic losses to the U.S. broiler industry. Skin defects also result in lower productivity, loss of markets and decreases in product wholesomeness. Skin lesions, such as sores, scabs and scratches or underlying infections, mostly occur during the grow-out phase, and contribute to skin tearing during processing [1]. Skin lesions in broilers can be increased due to poor management conditions (overcrowding, poor feathering, inadequate water and feeder space and excessive bird activity) or improper handling during catching.

Skin with a higher percentage of total protein results in greater skin strength and lower skin tears during processing. Male broilers of slow feathering strains are more prone to scratches because their skin is exposed for longer periods of time. Also, high temperature and humidity can cause skin problems due to broilers trying to find cooler spots and crowding. [2].

Zinc (Zn) and Manganese (Mn) are important trace minerals in animal nutrition involved in many metabolic processes, including growth, skin quality and wound healing. Bioavailability of these trace mineral supplements can be improved through complexing them with more readily available compounds that can enhance mineral absorption. Zn complexed with organic compounds showed better absorption in animals than inorganic Zn sources. Zinc has been shown to be a cofactor for several enzymes that are involved in the synthesis of proteins as well as the synthetic and catabolic rates of RNA and DNA [3]. Zinc plays a role in the cross-linking process of collagen which contributes to tensile strength and wound healing. Deficiencies of Zn and vitamin C have been shown to reduce collagen synthesis, leading to weaker skin [4]. Organic Zn and Mn compounds may enhance growth and skin quality in poultry.

The objectives of this study were to evaluate live performance, carcass and parts yields, skin characteristics (skin strength and quality) and meat quality of broilers fed with inorganic or organic sources of Zn and Mn at two market weights.

MATERIALS AND METHODS

A total of 1,920 male Ross x Ross 708 broilers were raised in 32 floor pens to 56 d of age in floor pens bedded with new pine shaving (8 pens/diet; 60 birds/pen or 15

birds/m^2) using a four stage feeding program. The starter feed was fed on days 1-14, the grower feed on days 15-28, the finisher on days 29-41, and the withdrawal on days 43-55. Birds were provided four dietary treatments (1) Inorganic Control [IC; 80 ppm $ZnSO_4$ and 80 ppm Mn SO_4], (2) 40 ppm C-Zn [IC-C-Zn; complexed Zn replaced 40 ppm Zn from $ZnSO_4$], (3) 40 ppm C-Zn [IC+C-Zn; complexed Zn provided additional 40 ppm Zn on top of control], and (4) 40 ppm C-Zn + 40 ppm C-Mn [IC+C-Zn+Z-Mn; 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control]. Complexed Zn and Mn were supplied from Availa-Zinc and Availa-Mn (Zinpro Corp., Eden Prairie, MN). All birds were weighed on a per pen basis at 14, 28, 41 and 55 d of age and body weights (BW), adjusted feed conversion (FC) and mortality were determined.

At 21 d of age, two birds per pen were randomly chosen to assess femur breaking strength [5, 6]. At 41 d of age, two birds per pen were euthanized and segments of the intestines were removed to measure intestinal puncture strength and skin puncture strength [7].

Both at 42 and 56 d of age, 320 randomly selected birds (10 birds per pen) were processed at the Auburn University Poultry Science Department Processing Plant simulating commercial processing practices to assess the effect of treatments on carcass yield parameters. Carcasses were chilled for 1.5 h in static slush-ice. At 42 d of age, whole carcass, lean carcass and abdominal fat weights and yields were determined. Carcasses were graded for: wing bruises and fractures; drumstick bruises and fractures; thigh sores, scabs and scratches (SSS); back bruises and overall grading). At 56 d of age, whole carcass, abdominal fat, parts (wings, leg quarters) and deboned breast (fillet and tender) weights and yields were determined. At each market age, breast fillet from 3 birds

per pen were randomly selected for meat quality attributes. Deboned breast fillets (skinless *Pectoralis major* muscle) were individually bagged and stored at 4 C for drip loss (24 h and 48 h), cook loss, water holding capacity (WHC) [8] and color (L*, a* and b*) measurements [9].

The data were statically analyzed by the General Linear Models procedure for the ANOVA using SAS 9.1 software (SAS Institute, 2002-2003) [10]. All percentage data was transformed with arcsine values prior to analysis. The Tukey's test was used to compared and separate means when main effects were significant ($P<0.05$).

RESULTS AND DISCUSSION

Few differences were observed in live performance throughout the study. Total mortality at 55 d of age was higher than normal, but no differences ($P>0.05$) were detected in mortality between the treatments (Table 1). This could be attributed to high temperatures during the study period (summer: May and June). Zinc retention by broilers exposed to heat stress is reduced with increased zinc excretion. Heat stress has been associated with decreases in broiler weight gain, feed conversion and mineral retention [11]. Dietary treatments did not affect body weights ($P>0.05$) for any of the feeding periods (Table 1). Feed conversion was improved by IC+C-Zn+C-Mn treatment at 14 d of age, but not on later ages. The results were similarly to Hudson et al. [12], broiler breeder hens fed different Zn sources did not influence body weight, feed conversion and mortality from 18 to 30 d of age. However, Potter et al. [13] reported that birds fed Zn-methionine with 0.15% more methionine had better body weight at 14 and 28 d of age, and improved feed conversion from 14 to 56 d of age. Gorobets [14] showed an improved

growth rate in broiler chickens fed Zn chelated with amino acids. Body weight and feed efficiency are generally not influenced by feeding excessive supplementary Mn and/or Zn [15].

Femur bone breaking strengths were not significantly ($P>0.05$) affected by dietary treatments at 21 d of age (Table 2). Intestinal and skin puncture strength measurements at 41 d of age are presented in Table 3. No differences ($P>0.05$) were found in either intestinal or skin puncture strength among the dietary treatments. Although no significant differences in skin puncture strength was observed, birds fed complexed minerals showed numerical increases in load, displacement and energy at break point measurements. Another studies reported intestinal strength was improved in birds fed organic Zn [16].

Carcass and skin quality evaluation results are shown in Table 4. This trial utilized male broilers from a slow feathering strain and high placement density in an attempt to maximize skin defects in the birds on various feed treatments. No significant effect ($P>0.05$) due to dietary treatments were noted for overall grade A carcasses. There was a significant improvement in sores, scratches and scabs (SSS) on the back area where birds raised on IC+C-Zn treatment had a lower ($P<0.05$) incidence of SSS than other treatments. However, drumstick bruising increased with complexed mineral treatments as compared to the IC treatment. These results were contrary to our expectations based on the importance of Zn in wound healing. Zinc is necessary to promote protein synthesis, collagen formation, and for optimal enzyme activity. The greatest activity of Zn in wound healing occurs during epithelization when the large stores of Zn in the skin may be a convenient source of the metal [16]. Although collagen appears to be the major

determinant of skin strength, the rate of cross-liking and the state of maturation of the collagen may also play a role [7].

At 42 d of age, no differences between treatments in carcass (chilled and lean) and abdominal fat weights and yields were observed among the dietary treatments (Table 5). Similarly, carcass and parts (leg quarters and fillets, tenders and total breast) weights and yields were not affected by the dietary treatments at 56 d of age (Table 6, 7 and 8). Effect of complexed Zn and Mn on breast meat yield is inconsistent. McNaughton and Shugel [17] reported that feeding Zn-methionine and Mn-methionine increased breast meat yield in broilers. Bonomi et al. [18] reported that carcass and meat yields improved when ducks were fed chelated Zn and Mn complexes. However, Collins et al. [14] could not show improvements in breast yield when different levels of Zn and Mn were fed to broilers.

Meat quality attributes (drip loss, cooking loss, WHC and color) measured during this experiment were not influenced by Zn sources ($P>0.05$) at 56 d of age (Table 11 and 12). However, at 42 d of age, fillet cook loss was decreased with IC+C-Zn+C-Mn treatment as compared to the IC (Table 9 and 10). Although WHC was not different among treatments, there was a numerical trend of improvement with complexed mineral supplementation. At 42 d of age, color measurements showed increased a* value and decreased L* values with complexed minerals. However, fillet color did not vary among the treatments at 56 d of age. Response of broiler chickens to complexed trace mineral supplementation was variable and age dependent. Level and source of Zn and Mn had no influence on broiler live and processing performance.

CONCLUSIONS AND APPLICATIONS

1. Live and processing performance of broiler chickens were not affected by dietary treatments at 42 and 56 d of age.
2. Skin quality was significantly improved with organic Zn supplementation.
3. Complexed trace mineral supplementation reduced cook loss, increased redness, and decreased lightness of breast fillets at 42 d of age.

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5. **Femur bone breaking strength:** Two birds per pen were killed by carbon dioxide. One femur from each bird was removed, cleaned of all adhering tissue and frozen at -20 C until the day of testing. Bones were thawed to room temperature 2 h before testing. The center of each bone was aligned with the breaking probe (10 mm

diameter) which approach at 10 mm/sec using a 50 kg. load cell capacity on Texture Analyzer [9]. The supports for each bone were 30 mm apart. The breaking strength was determined from the break point (peak) of each loading curve

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Cooking Loss: After weighing for drip loss determination, left fillets were weighed and recorded. Fillets were numbered, arranged on wire oven racks and placed in a preheated (1 h) convection oven (177 C). Fillets were cooked to an internal temperature of 77 C, removed from oven and allowed to cool to an internal temperature of 24 C, and reweighed. Cooking loss (%) was calculated between raw and cooked fillet weight divided by raw fillet weight.

Water Holding Capacity: Ten grams sample of ground right fillet meat (composite from 3 fillets/pen) was weighed into 50 ml polycarbonate centrifuge tube. Sixteen milliliters of a 0.6 M NaCl solution was pipetted into each tube. Sample tubes were vortexed approximately 30 sec, allowed to incubate for 30 min at 4 C, and centrifuged at 7,000 g. for 25 min. Supernatant were decanted into a graduated cylinder

and volume recorded. Water holding capacity (ml/g of tissue) was calculated as 16 ml minus decanted volume divided by sample weight.

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Table 1. Influence of Zn sources on broiler live performance

Treatment[1]	1-14 d of age			1-28 d of age			1-41 d of age			1-55 d of age		
	BW (g)	FC[2]	% Mort	BW (g)	FC	% Mort	BW (g)	FC	% Mort	BW (g)	FC	% Mort
	NS[3]	0.0503	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IC	363	1.272[a]	0.1	1314	1.426	0.8	2355	1.680	1.1	3040	1.992	4.8
IC-C-Zn	367	1.206[ab]	0.4	1311	1.472	0.9	2358	1.674	1.1	3097	1.967	3.6
IC+C-Zn	369	1.206[ab]	0.4	1311	1.449	0.4	2372	1.651	0.6	3049	1.989	3.8
IC+C-Zn+C-Mn	382	1.183[b]	0.4	1344	1.427	0.9	2414	1.666	2.0	3141	1.978	4.9
SEM[4]	7.34	0.02	0.22	10.06	0.02	0.28	26.30	0.02	0.40	95.33	0.04	0.83

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]FC=Feed conversion adjusted for mortality.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 2. Influence of Zn sources on bone breaking strength at 21 d of age

Treatment[1]	Force (kg)
	NS[2]
IC	21.54
IC-C-Zn	19.84
IC+C-Zn	20.55
IC+C-Zn+C-Mn	20.94
SEM[3]	0.87

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant ($P>0.05$).

[3]SEM = Pooled Standard Error of the Mean.

Table 3. Influence of Zn sources on intestinal and skin puncture strength at 41 d of age

Treatment[1]	Intestinal strength			Skin strength		
	Load (kg)	Displacement (mm)	Energy at break point (kg/mm)	Load (kg)	Displacement (mm)	Energy at break point (kg/mm)
	NS[2]	NS	NS	NS	NS	NS
IC	0.707	12.508	2.139	7.514	15.070	28.472
IC-C-Zn	0.815	12.334	2.802	7.959	15.412	30.676
IC+C-Zn	0.787	11.003	2.468	8.272	15.881	30.661
IC+C-Zn+C-Mn	0.758	11.986	2.742	8.409	16.064	35.249
SEM[3]	0.051	0.888	0.255	0.483	0.757	2.411

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant ($P>0.05$).

[3]SEM = Pooled Standard Error of the Mean.

Table 4. Influence of Zn sources on carcass and skin quality at 42 d of age

Treatment[1]	Wing		Drumstick		Thigh	Back		Grade A
	Bruise	Broken	Bruise	Broken	SSS[2]	Bruise	SSS	
	NS[3]	NS	*	NS	NS	NS	*	NS
IC	6.3	5.6	1.3[b]	3.1	36.9	1.3	13.8[ab]	80.0
IC-C-Zn	10.1	7.6	7.6[ab]	0	35.4	3.9	10.4[ab]	77.2
IC+C-Zn	11.3	5.0	10.6[ab]	3.8	39.8	3.1	2.5[b]	76.9
IC+C-Zn+C-Mn	20.0	4.0	13.8[a]	1.3	45.3	1.3	16.4[a]	68.5
SEM[4]	4.37	3.13	3.10	1.92	5.80	2.03	3.14	5.12

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]SSS = Sores, scabs and scratches.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 5. Influence of Zn sources on chilled, lean carcass and abdominal fat weights and yields at 42 d of age

Treatment[1]	PSW[2]	Chilled Carcass		Lean Carcass[4]		Abdominal Fat	
		Weight	Yield[3]	Weight	Yield	Weight	Yield
	NS[5]	NS	NS	NS	NS	NS	NS
IC	2415	1785	73.9	1750	72.5	35	1.5
IC-C-Zn	2381	1755	73.7	1715	72.0	40	1.7
IC+C-Zn	2390	1759	73.6	1719	72.0	40	1.6
IC+C-Zn+C-Mn	2443	1815	74.3	1774	72.6	42	1.7
SEM[6]	27.26	23.47	0.55	23.25	0.57	2.22	0.09

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Pre-slaughter weight.

[3]As percent of pre-slaughter weight.

[4]Excluding abdominal fat.

[5]Not significant ($P>0.05$).

[6]SEM = Pooled Standard Error of the Mean.

Table 6. Influence of Zn sources on chilled, lean carcass and abdominal fat weights and yields at 56 d of age

Treatment[1]	PSW[2]	Chilled Carcass		Lean Carcass[4]		Abdominal Fat	
		Weight	Yield[3]	Weight	Yield	Weight	Yield
	NS[5]	NS	NS	NS	NS	NS	NS
IC	3146	2392	76.0	2324	73.9	67	2.1
IC-C-Zn	3203	2440	76.2	2372	74.1	68	2.1
IC+C-Zn	3797	2440	76.3	2373	74.2	67	2.1
IC+C-Zn+C-Mn	3243	2460	75.9	2394	73.8	67	2.1
SEM[6]	116.21	87.64	0.28	85.16	0.26	3.49	0.08

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Pre-slaughter weight.

[3]As percent of pre-slaughter weight.

[4]Excluding abdominal fat.

[5]Not significant ($P>0.05$).

[6]SEM = Pooled Standard Error of the Mean.

Table 7. Influence of Zn sources on wings and leg quarters weights and yields at 56 d of age

Treatment[1]	Wings		Legs	
	Weight	Yield[2]	Weight	Yield
	NS[3]	NS	NS	NS
IC	262	8.4	780	24.8
IC-C-Zn	266	8.3	789	24.6
IC+C-Zn	264	8.3	788	24.6
IC+C-Zn+C-Mn	269	8.3	802	24.8
SEM[4]	7.39	0.09	29.19	0.15

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]As percent of pre-slaughter weight.

[3]Not significant ($P>0.05$).

[4]SEM = Pooled Standard Error of the Mean.

Table 8. Influence of Zn sources on fillet and tender weights and yields at 56 d of age

Treatment[1]	Fillets		Tenders		Total Breast	
	Weight	Yield[2]	Weight	Yield	Weight	Yield
	NS[3]	NS	NS	NS	NS	NS
IC	581	18.5	127	4.04	707	22.5
IC-C-Zn	592	18.4	129	4.03	721	22.5
IC+C-Zn	598	18.7	130	4.06	727	22.7
IC+C-Zn+C-Mn	603	18.5	131	4.03	733	22.6
SEM[4]	26.58	0.22	5.09	0.07	31.28	0.25

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]As percent of pre-slaughter weight.

[3]Not significant ($P>0.05$).

[4]SEM = Pooled Standard Error of the Mean.

Table 9. Influence of Zn sources on meat quality attributes at 42 d of age

Treatment[1]	Drip Loss (%)		Cook Loss (%)	WHC (%)
	24 h	48 h		
	NS[2]	NS	*	NS
IC	1.2	2.8	29.7[a]	22.7
IC-C-Zn	1.2	2.9	26.2[ab]	26.2
IC+C-Zn	1.4	2.8	27.7[ab]	26.0
IC+C-Zn+C-Mn	1.3	2.7	22.3[b]	33.1
SEM[3]	0.23	0.38	1.61	3.82

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 10. Influence of Zn sources on color measurement at 42 d of age

Treatment[1]	Color measurement		
	L*	a*	b*
	**	*	NS[2]
IC	66.21[a]	4.60[a]	14.06
IC-C-Zn	64.90[ab]	5.43[ab]	15.05
IC+C-Zn	64.04[b]	6.06[b]	15.77
IC+C-Zn+C-Mn	63.68[b]	5.79[ab]	15.38
SEM[3]	0.54	0.33	0.48

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 11. Influence of Zn sources on meat quality attributes at 56 d of age

Treatment[1]	Drip Loss (%)		Cook Loss (%)	WHC (%)
	24 h	48 h		
	NS[2]	NS	NS	NS
IC	0.6	2.1	19.1	40.2
IC-C-Zn	0.5	2.5	19.6	35.4
IC+C-Zn	0.5	2.8	22.2	43.8
IC+C-Zn+C-Mn	0.6	2.5	20.3	41.7
SEM[3]	0.09	0.39	1.41	3.85

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant ($P>0.05$).

[3]SEM = Pooled Standard Error of the Mean.

Table 12. Influence of Zn sources on color measurement at 56 d of age

Treatment[1]	Color measurement		
	L*	a*	b*
	NS[2]	NS	NS
IC	63.96	6.12	14.11
IC-C-Zn	62.69	5.76	13.41
IC+C-Zn	63.16	6.21	16.23
IC+C-Zn+C-Mn	62.47	5.30	12.34
SEM[3]	0.10	0.40	0.65

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control, IC+C-Zn+C-Mn = 40 ppm complexed Zn and 40 ppm complexed Mn added on top of control.

[2]Not significant ($P>0.05$).

[3]SEM = Pooled Standard Error of the Mean.

V. EFFECT OF COMPLEXED ZINC SUPPLEMENTATION ON SKIN AND MEAT QUALITY IN BROILERS

SUMMARY

This study was conducted to determine the effects of supplemental dietary zinc (Zn) sources on broiler live and processing performance, carcass and deboning yields, carcass and skin quality, and meat quality attributes. A total of 1,920 male Ross x Ross 708 broilers were reared to 49 d of age using a four stage feeding program (60 birds/pen; 8 replicates/treatment). Three dietary treatments included: inorganic control (IC; 80 ppm $ZnSO_4$ and 80 ppm $MnSO_4$), complexed Zn (Availa-Zinc, Zinpro Corp., Eden Prairie, MN) replaced 40 ppm Zn in control diet (IC-C-Zn) and additional 40 ppm Zn from Availa-Zn on top of control (IC+C-Zn). Body weight, feed conversion and mortality were determined on days 14, 28 and 49. At 42 d of age, femur bone breaking strength, small intestine and skin puncture strength were determined. At 49 d of age, 10 birds per pen were processed to assess carcass yield, carcass, skin, paw, and meat quality attributes (drip loss, cooking loss, water holding capacity, color and rancidity).

At 41 and 48 d of age, body weight was significantly higher ($P<0.05$) in the IC-C-Zn treatment than IC treatment. Feed conversion was also improved ($P<0.05$) at 41 and 48 d of age with IC-C-Zn as compared to IC treatment. No differences ($P>0.05$) were

detected in mortality among the treatments. Bone breaking strength and skin puncture strength did not vary (P>0.05) between the dietary treatments. Intestinal strength (i.e. energy at break point) favored IC-C-Zn treatment. Birds fed IC-C-Zn had lower (P<0.05) incidence of thigh sores, scabs and scratches as compared to the IC treatment. Overall grade was not significantly (P>0.05) different among the treatments. Foot pad quality improved (P<0.05) with all treatments fed complexed Zn. At 49 d of age, fillets and total breast yields were significantly higher in birds fed IC+C-Zn than the IC treatment. Breast fillet drip loss, cook loss, WHC, pH, rancidity and color did not show any differences due to treatments. However, drip loss increased in fillets held for 48 vs. 24 h (2.1 vs. 0.9%). Level and source of dietary Zn had a significant influence on broiler live and processing performance in this study.

Key words: Broilers, complexed zinc, skin quality, foot pad quality, TBA

DESCRIPTION OF PROBLEM

The poultry industry has benefited from growing domestic and international markets. Appearance is the major criterion of evaluation of carcass and meat quality, and purchase for the consumers. Many production and processing factors contribute to carcass quality problems. Pododermatitis is a type of skin dermatitis in broiler chickens affecting the foot pads (also referred to paw burns or ammonia burns). Several factors contribute to the prevalence of pododermatitis in broilers, including nutrient deficiencies, litter type, moisture and high stocking density [1, 2, 3].

Zinc is a required micro mineral in many bodily processes including growth, skin quality and wound healing. Zinc is also involved in the synthesis of RNA and DNA [4].

Zinc plays a function in cross-linking of collagen and improves the tensile strength of skin [5]. Little information is available regarding the effects of complexed organic Zn sources on broiler carcass and meat quality.

The objective of this study was to evaluate live and processing performance, carcass, skin, foot pad and meat quality of broilers fed inorganic or organic sources of Zn.

MATERIALS AND METHODS

A total of 1,920 male Ross x Ross 708 broilers were raised in 24 floor pens to 49 d of age in new pine shaving litter-covered floor pens (8 pens/diet; 60 birds/pen or 15 birds/m^2). The experimental diets were provided on a four stage feeding program of starter (1-14 d of age), grower (15-28 d of age), finisher (29-42 d of age), and withdrawal (43-49 d of age). There were three dietary treatments: (1) Inorganic Control [IC; 80 ppm $ZnSO_4$ and 80 ppm Mn SO_4], (2) 40 ppm C-Zn [IC-C-Zn; complexed Zn replaced 40 ppm Zn from $ZnSO_4$], and (3) 40 ppm C-Zn [IC+C-Zn; complexed Zn provided additional 40 ppm Zn on top of control]. Complexed Zn was supplied from Availa-Zinc (Zinpro Corp., Eden Prairie, MN). Birds were weighed at 14, 28 and 49 d of age on a per pen basis and body weights (BW), adjusted feed conversion (FC) and mortality were determined.

At 42 d of age, two birds per pen were randomly chosen to assess femur breaking strength [8], intestinal and skin puncture strength [9, 10]. The incidence and severity of pododermatitis were scored on 48 d of age by using a visual ranking system [1]. At 49 d of age, 10 birds per pen (240 total) were processed at the Auburn University Poultry Science Department Processing Plant simulating commercial processing practices to

assess the effect of treatments on carcass yield parameters. Carcasses were chilled for 1.5 h in static slush-ice. Carcass and skin quality were determined by qualifying: wing bruises and fractures; drumstick bruise and fractures; thigh bruises, sores, scabs and scratches (SSS); back bruises and SSS and overall grade. Whole carcass, abdominal fat, parts (wings, drumsticks and thighs) and deboned breast (fillet and tender) weights and yields were determined. Breast fillets from three birds per pen were randomly selected to assess meat quality attributes. Deboned breast fillets (skinless *Pectoralis major* muscle) were individually bagged and stored at 4 C for drip loss (24 h and 48 h), cook loss, water holding capacity (WHC) [11], pH, Thiobarbituric acid test (TBA) at 0 and 7 d of storage [12] and color (L*, a* and b*) measurements [13].

The data were statically analyzed by the General Linear Models procedure for the ANOVA using SAS 9.1 software (SAS Institute, 2002-2003) [14]. All percentage data was transformed to arcsine values prior to analysis. The Tukey's test was used to compared and separate means when main effects were significant ($P<0.05$).

RESULTS AND DISCUSSION

Birds on organic trace minerals showed improvement in live performance over the inorganic control. The Zn sources had a significant effect ($P<0.05$) on body weights at 42 and 48 d of age, where birds raised with IC-C-Zn diet had higher body weights as compared to IC treatment (Table 1). Feed conversion was improved ($P<0.05$) with both C-Zn treatments at 41 and 48 d of age. No differences ($P>0.05$) were detected in mortality between the treatments throughout the study.

At 42 d of age, femur bone breaking strength or skin puncture strength were not significantly ($P>0.05$) affected by dietary treatments (Table 2 and 3). However, load at break point was highest with the IC-C-Zn treatment. No differences ($P>0.05$) in skin strength were observed among the treatments (Table 3).

Incidence and severity of pododermatitis was significantly ($P<0.05$) improved with all C-Zn treatments at 48 d of age (Table 4). The percentage of birds without foot pad lesions was highest for the C-Zn treatments. Also, mild and severe lesions were reduced when birds were fed C-Zn treatments as compared to the IC treatment. Foot pad quality depends on the ability of the broiler to maintain skin integrity when faced with irritation from friction and feces associated with the litter. Parson et al. [15] showed improvements in foot pad quality in broilers fed Zn complexes. In a similar study, Moore et al. [16] showed improvements in visual hoof scores in dairy cow fed Zn-methionine.

Carcass and skin quality evaluation results are shown in Table 5. This trial utilized a slow feathering strain and high placement density in an attempt to maximize skin defects in the birds on various feed treatments. No significant effect ($P>0.05$) due to treatments were noted for proportion of grade A carcasses. Thigh SSS were improved with organic trace minerals, particularly in the IC-C-Zn treatment. Most of the skin lesions are located on the thigh and pelvic back region of the broilers, where feathering is marginal. Skin strength has been shown to be different for fast feathering and slow feathering broiler crosses with the latter having less elastic skin than the former.

At 49 d of age, chilled carcass, wings and drumsticks weights and yields were not different among the dietary treatments. Thigh yield was highest on birds reared on IC-C-Zn treatment (Table 6 and 7). Breast fillet and total breast (fillet + tender) yields were

significantly higher in IC+C-Zn+C-Mn treatment as compared to the IC treatment (Table 8).

Meat quality attributes (drip loss, cooking loss, WHC, pH, TBA and color) measured during this experiment were not influenced by Zn sources (P>0.05) at 49 d of age (Table 9 and 10). Drip loss increased in fillets stored for 48 h and 24 h. TBA value increased numerically in fillets during 7 d storage at 4 C. Color measurements showed increased redness value in C-Zn treatments.

CONCLUSIONS AND APPLICATIONS

1. Body weights and feed conversions were improved with C-Zn supplementation of broiler diets.
2. Birds on organic Zn showed significant improvements in weight gain and feed conversion, breast yield, thigh SSS and pododermatitis incidence and severity.
3. Complexed Zn may improve redness color in meat fillet.

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8. **Femur bone breaking strength:** Two birds per pen were killed by carbon dioxide. One femur from each bird was removed, cleaned of all adhering tissue and frozen at -20 C until the day of testing. Bones were thawed to room temperature 2 h before testing. The center of each bone was aligned with the breaking probe (10 mm diameter) which approach at 10 mm/sec using a 50 kg. load cell capacity on Texture Analyzer [9]. The supports for each bone were 30 mm apart. The breaking strength was determined from the break point (peak) of each loading curve

9. The TA.XTplus Texture Analyzer, Texture Technologies Corporation, Scarsdale, NY.

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11. **Fillet Drip Loss Determination:** Breast fillets were individual weighed and recorded immediately after deboning, placed in plastic storage bags. Left fillets (12 h) and right fillets (48 h) were stored at 4 C, and then reweighed. Fillets were slightly blotted before reweighing. Fillets drip loss (%) was calculated as the difference between deboned and stored fillet weights divided by deboned weight.

Cooking Loss: After weighing for drip loss determination, left fillets were weighed and recorded. Fillets were numbered, arranged on wire oven racks and placed in a preheated (1 h) convection oven (177 C). Fillets were cooked to an internal temperature of 77 C, removed from oven and allowed to cool to an internal temperature of 24 C, and reweighed. Cooking loss (%) was calculated between raw and cooked fillet weight divided by raw fillet weight.

Water Holding Capacity: Ten grams sample of ground right fillet meat (composite from 3 fillets/pen) was weighed into 50 ml polycarbonate centrifuge tube. Sixteen milliliters of a 0.6 M NaCl solution was pipetted into each tube. Sample tubes were vortexed approximately 30 sec, allowed to incubate for 30 min at 4 C, and centrifuged at 7,000 g. for 25 min. Supernatant were decanted into a graduated cylinder and volume recorded. Water holding capacity (ml/g of tissue) was calculated as 16 ml minus decanted volume divided by sample weight.

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Table 1. Influence of Zn sources on broiler live performance

Treatment[1]	1-15 d of age			1-41 d of age			1-48 d of age		
	BW (g)	FC[2]	% Mort	BW (g)	FC	% Mort	BW (g)	FC	% Mort
	NS[3]	NS	NS	*	*	NS	**	**	NS
IC	481	1.177	0.3	2596[b]	1.643[a]	0.9	3140[b]	1.736[a]	1.4
IC-C-Zn	493	1.185	0.3	2670[a]	1.614[b]	1.4	3241[a]	1.701[b]	1.9
IC+C-Zn	481	1.186	0.3	2664[ab]	1.614[b]	1.3	3209[ab]	1.713[b]	1.5
SEM[4]	9.87	0.02	0.16	19.38	0.007	0.33	20.96	0.006	0.40

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]FC=Feed conversion adjusted for mortality.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 2. Influence of Zn sources on bone breaking strength at 42 d of age

Treatment[1]	Force (kg)
	NS[2]
IC	32.868
IC-C-Zn	32.672
IC+C-Zn	31.374
SEM[3]	1.354

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

Table 3. Influence of Zn sources on intestinal and skin puncture strength at 42 d of age

Treatment[1]	Intestinal strength			Skin strength		
	Load (kg)	Displacement (mm)	Energy at break point (kg/mm)	Load (kg)	Displacement (mm)	Energy at break point (kg/mm)
	NS[2]	NS	**	NS	NS	NS
IC	0.529	1.297	8.548[b]	7.886	34.332	16.177
IC-C-Zn	0.548	1.565	11.393[a]	6.975	31.106	17.273
IC+C-Zn	0.519	1.247	9.570[ab]	6.478	29.028	16.615
SEM[3]	0.024	0.107	0.653	0.429	2.041	0.570

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 4. Influence of Zn sources on the incidence and severity of pododermatitis (%) at 48 d of age

Treatment[1]	None[2]	Mild[3]	Severe[3]
	***	*	NS[4]
IC	30.5[b]	48.0[a]	21.6
IC-C-Zn	50.5[a]	34.6[b]	14.9
IC+C-Zn	53.9[a]	35.1[b]	11.0
SEM[5]	3.80	3.19	3.15

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]None = No lesion present; [3]Mild = Lesion < 1.5 cm; [4]Severe = Lesion > 1.5 cm.

[4]Not significant (P>0.05).

[5]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 5. Influence of Zn sources on carcass and skin quality (%) at 49 d of age

Treatment[1]	Wing		Drumstick		Thigh		Back		Breast	Grade A
	Bruise	Broken	Bruise	Broken	Bruise	SSS[2]	Bruise	SSS	Bruise	
	NS[3]	NS	NS	NS	NS	***	NS	NS	NS	NS
IC	4.7	24.7	6.5	2.6	0	42.7[a]	7.0	7.2	3.2	55.6
IC-C-Zn	9.9	17.5	7.1	0	1.4	9.6[b]	3.0	4.0	0	71.1
IC+C-Zn	18.4	16.2	1.3	0	0	26.3[ab]	4.7	4.4	1.6	63.9
SEM[4]	4.18	4.62	2.42	1.00	0.80	4.85	3.16	2.37	1.51	5.56

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]SSS = Sores, scabs and scratches.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 6. Influence of Zn sources on chilled, lean carcass and abdominal fat weights and yields at 49 d of age

Treatment[1]	PSW[2]	Chilled Carcass		Lean Carcass[4]		Abdominal Fat	
		Weight	Yield[3]	Weight	Yield	Weight	Yield
	NS[5]	NS	NS	NS	NS	NS	NS
IC	3153	2345	74.4	2290	72.6	55	1.7
IC-C-Zn	3200	2399	75.0	2345	73.3	54	1.7
IC+C-Zn	3156	2376	75.3	2323	73.6	54	1.7
SEM[6]	35.36	29.51	0.53	28.99	0.53	1.81	0.05

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]Pre-slaughter weight.

[3]As percent of pre-slaughter weight.

[4]Excluding abdominal fat.

[5]Not significant (P>0.05).

[6]SEM = Pooled Standard Error of the Mean.

Table 7. Influence of Zn sources on wings, drumsticks and thighs weights and yields at 49 d of age

Treatment[1]	Wings		Drumsticks		Thighs	
	Weight	Yield[2]	Weight	Yield	Weight	Yield
	NS[3]	NS	NS	NS	*	*
IC	239	7.6	297	9.4	431[ab]	13.7[ab]
IC-C-Zn	243	7.5	303	9.5	442[a]	13.8[a]
IC+C-Zn	238	7.5	299	9.5	416[b]	13.2[b]
SEM[4]	2.10	0.07	3.85	0.07	7.03	0.16

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]As percent of pre-slaughter weight.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 8. Influence of Zn sources on fillet and tender weights and yields at 49 d of age

Treatment[1]	Fillets		Tenders		Total Breast	
	Weight	Yield[2]	Weight	Yield	Weight	Yield
	NS[3]	**	NS	NS	NS	*
IC	572	18.1[b]	133	4.2	705	22.4[b]
IC-C-Zn	560	18.7[ab]	134	4.2	733	22.9[ab]
IC+C-Zn	600	19.0[a]	133	4.2	733	23.2[a]
SEM[4]	8.90	0.17	2.03	0.05	10.36	0.19

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]As percent of pre-slaughter weight.

[3]Not significant (P>0.05).

[4]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

Table 9. Influence of Zn sources on meat quality attributes at 49 d of age

Treatment[1]	Drip Loss (%)		pH	Cook Loss	WHC	TBA	
	24 h	48 h		(%)	(%)	0 d	7 d
	NS[2]	NS	NS	NS	NS	NS	NS
IC	0.9	2.1	6.29	27.5	33.1	0.38	0.72
IC-C-Zn	1.1	2.4	6.13	26.2	34.8	0.34	0.57
IC+C-Zn	0.9	2.5	6.12	27.6	35.0	0.32	0.52
SEM[3]	0.11	0.18	0.13	1.05	3.59	0.02	0.07

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]Not significant ($P>0.05$).

[3]SEM = Pooled Standard Error of the Mean.

Table 10. Influence of Zn sources on color measurement at 49 d of age

Treatment[1]	Color measurement		
	L*	a*	b*
	NS[2]	*	NS
IC	60.52	5.99[ab]	12.87
IC-C-Zn	60.54	6.39[a]	13.25
IC+C-Zn	60.34	6.23[ab]	13.11
SEM[3]	0.39	0.16	0.33

[1]Treatments: IC = Inorganic Control (80 ppm $ZnSO_4$, 80 ppm $MnSO_4$); IC-C-Zn = complexed Zn replaced 40 ppm Zn from $ZnSO_4$; IC+C-Zn = complexed Zn provided additional 40 ppm Zn on top of control.

[2]Not significant (P>0.05).

[3]SEM = Pooled Standard Error of the Mean.

[ab]Means within a column with difference superscripts differ significantly.

*(P<0.05); **(P<0.01); ***(P<0.001).

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