Effect of methionine chelated Zn and Mn and corn particle size on Large White male turkey live performance and carcass yields

K. R. Flores ,* A. Fahrenholz,* P. R. Ferket,* T. J. Biggs,[†] and J. L. Grimes*,[1]

*Prestage Department of Poultry Science, North Carolina State University, Raleigh, NC 27695-7608, USA; and
[†]Global Animal Products, Inc. Amarillo, TX 79118, USA

ABSTRACT Most turkey research has been conducted with a regular corn particle size set through phase-feeding programs. This study's first objective was to determine the effect of increasing corn particle size through the feed phases on performance, processing yield, and feed milling energy usage in Large White commercial male turkey production. Zinc (**Zn**) and manganese (**Mn**) are essential microminerals for animals' healthy growth. The source in which these elements are supplied to the bird will determine their bioavailability, effect on bird growth, and subsequent environmental impact. This study's second objective was to measure both inorganic and chelated Zn and Mn sources on turkey performance, turkey carcass processing yields, and subsequent litter residues. Twelve hundred Nicolas Select male poults were randomly assigned to 48 concrete; litter-covered floor pens. The experimental design was a completely randomized block design with a 2 × 2 factorial arrangement of 2 sources of minerals (organic blend vs. inorganic) formulated to match breeder recommendations and 2 types of corn mean particle size (coarse corn [1,000−3,500 μm] vs. fine corn [276 μm]). The ASABE S319.4 standard was used to measure corn mean particle size. Bird performance, carcass processing yield, litter content of Zn and Mn, and pellet mill energy consumption were analyzed in SAS 9.4 in a mixed model. There was a reduction of pellet mill energy usage of 36% when coarse corn was added post-pelleting. Birds fed increasing coarse corn mean particle size were 250 g lighter on average in body weight (**BW**) than birds fed a constant control mean particle size. No difference was found in feed intake (**FI**) or feed conversion ratio (**FCR**). Birds fed methionine chelated Zn and Mn blended with inorganic mineral sources were 250 g heavier on average than birds fed only an inorganic source of minerals. In addition, feeding an organic blend of Zn and Mn resulted in greater breast meat yield. Litter from birds fed the control corn mean particle size, and inorganic minerals had a higher concentration of Zn in the litter but were not different when the chelated Zn/Mn were fed. In conclusion, increasing the corn mean particle size and adding it post pellet could save money during feed milling; however, birds might have a slightly lower BW. A combination of inorganic and chelated Zn and Mn may improve performance and increase total breast meat yields.

Key words: turkey, zinc, manganese, chelate, carcass yield

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INTRODUCTION

Enhanced poultry performance has been observed when feeding a coarser or whole-grain feed because of the increase in the gizzard's weight and functionality (Singh et al., 2014; Liu et al., 2015; Moss et al., 2017). By milling the grains, the gizzard's amount of work is reduced, thus reducing the gizzard's muscle mass (Ferket, 2000). Increasing the mean particle size or feeding whole corn increases the gizzard's muscle mass and may increase digestibility. This may be because the gizzard has been considered to be the "pace-maker" of gut motility (Duke, 1994) and regulates reverse peristalsis (Ferket, 2000). Increasing the mean particle size of ingredients can also reduce energy usage by the feed mill. Most studies in the literature compare a constant control and a high mean particle size of corn or whole-grain feeding through the feed phases (Portella et al., 1988; Ferket, 2000; Hetland et al., 2002; Charbeneau and Roberson, 2004; Favero et al., 2009; Svihus, 2011; Favero et al., 2012; Jankowski et al., 2013; Singh, 2013; Singh et al., 2014; Liu et al., 2015). This study's first objective was to understand how increasing the coarse corn mean particle size by 500 μm for each phase from the starter (1,000 μm) to the finisher 2 (3,500

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[1]Corresponding author: jgrimes@ncsu.edu

μm) affects live bird performance, carcass processing yields, and pellet mill energy consumption.

Zinc (**Zn**) is an essential mineral for growth, nutrient metabolism, immune system activity, disease control, reproduction, and also serves an antioxidant role (McDowell, 2003; Park et al., 2004; Suttle, 2010; Naz et al., 2016; Abd El-Hack et al., 2017). These functions are fulfilled, in part, by the requirement of Zn for regular physiological activity of over 200 enzymes (Ao and Pierce, 2013). Manganese (**Mn**) is needed for bone development, nervous system function, reproduction, cell structure, antioxidant systems, and nutrient metabolism (Suttle, 2010; Jankowski et al., 2018; Ognik et al., 2019). The poultry industry widely uses saline forms of Zn and Mn for their low cost and availability (Sandoval et al., 1997). Methionine chelated Zn and Mn have a higher bioavailability, less interaction with other molecules, and a higher cost (Vieira, 2008; Kratzer and Vohra, 2018). Most studies in the literature have specific sources that are not combined and are fed in a titration form to establish requirements that do not negatively affect performance or carcass yield (Bao et al., 2007; Nollet et al., 2007; Perić et al., 2007; Leeson et al., 2008; Bao and Choct, 2009; Ao and Pierce, 2013; Sahoo et al., 2014; Uniyal et al., 2017; Jankowski et al., 2018; Jóźwik et al., 2018; Jankowski et al., 2019a,b,c; Khatun et al., 2019; Patra and Lalhriatpuii, 2020). The second objective of this study was to evaluate the effect of feeding inorganic sources of Zn and Mn along with their chelated forms on bird live performance, carcass processing yields, and excretion as measured by litter residue. Aviagen Turkey mineral recommendations were used as the standard concentrations for this trial, as they are freely available.

MATERIALS AND METHODS

Treatments and Experimental Design

The experimental design was a completely randomized block design with a 2 × 2 factorial arrangement of 2 concentrations of corn mean particle size and 2 sources of mineral in the feed. The birds were fed diets that increased in mean particle size with each feed phase. The feed had either a control feed mean particle size of 100% of 276 μm or a mix of 276 μm with 2,595 μm or whole corn 10,000 μm (Table 2) to achieve the feed phase's desired mean particle size. The mineral sources used for the experiments were an organic source, Liqui-Trace ZM (Global Animal Products, Amarillo, TX), and an NCSU inorganic premix. All feed treatment mineral content was formulated based on the Aviagen male turkey minerals recommendations (Aviagen turkeys, Lewisburg, WV) (Aviagen, 2015).

Feed Manufacturing

Corn used for the treatments in each fed phase originated from the same batch of corn, however, in subsequent feed phases corn batches were different. Total corn used in each experimental treatment is presented in Table 1. Coarse corn was ground in a roller mill (Model C128889, RMS, Sea, SD), and fine corn was ground in a hammer mill (Model 1522, Roskamp Champion, Waterloo, IA). The settings used for the roller mill were 50% open for both the top and bottom roll pairs, yielding a corn mean particle size of 2,595 μm. The hammermill used numbers 6 and 8 screens to achieve a corn mean particle size of 276 μm. Both whole corn (10,000 μm) and 2,595 μm corn were combined post-pelleted to raise the mean corn to mean particle size in feed phases that

Table 1. Basal dietary ingredient composition in % for all treatments.

Ingredients	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Total corn[1]	19.50	26.00	34.80	40.20	42.85	47.55
Wheat	20.00	20.00	20.00	20.00	20.00	20.00
Soybean meal	38.00	31.65	23.45	18.25	16.25	12.00
Poultry meal	10.00	10.00	10.00	10.00	10.00	10.00
Calcium carbonate	1.24	1.17	0.96	0.89	0.83	0.64
Dicalcium phosphate	2.59	2.26	1.83	1.71	1.37	1.16
DL-Methionine[2,3]	0.42	0.36	0.24	0.24	0.19	0.18
L-Lysine[4]	0.46	0.39	0.32	0.30	0.18	0.16
Threonine	0.13	0.11	0.06	0.09	0.03	0.04
NaCl	0.15	0.15	0.15	0.15	0.15	0.15
Choline chloride 60%	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin mix[5]	0.20	0.20	0.20	0.20	0.20	0.20
Selenium mix 0.06%	0.05	0.05	0.05	0.05	0.05	0.05
Sodium bicarbonate	0.25	0.25	0.25	0.25	0.25	0.25
Poultry fat mixer	1.00	1.00	1.00	1.00	1.00	1.00
Poultry fat post pellet[6]	5.51	5.90	6.25	6.25	6.25	6.25
Ingredient total:	100	100	100	100	100	100

[1]Total corn in all treatments; this value represents 100% of corn for all treatments.
[2]Feed grade, DL-Methionine (99%), donated by Evonik North America.
[3]Supplemental methionine is reduced in organic blend diets by amounts supplied by the methionine chelates to be equal in all treatments.
[4]Feed grade L-Lysine monohydrochloride (98.5%). donated by Ajinomoto North America
[5]Donated by DSM Nutritional Products; vitamin premix provided the following per kg of diet: vitamin A, 26,455 IU; vitamin D3, 7,936 IU; vitamin E, 132 IU; vitamin B12, 0.08 mg; biotin, 0.51 mg; menadione, 8 mg; thiamine, 8 mg; riboflavin, 26.67 mg; pantothenic acid, 44 mg; vitamin B6, 16 mg; niacin, 220 mg; folic acid, 4 mg.
[6]Poultry fat added post pelleted in the mixer with post pelleting corn in the coarse corn treatments (Table 2) or by itself in fine corn treatments.

Table 2. Corn particle size mixing ratios for both fine and coarse corn treatments (%).[1]

	Fine corn	Coarse corn		
Feed phase	HM corn[2]	HM corn[3]	RM corn[4]	Whole corn[5]
Starter 1	19.50	8.20	11.30	NA[4]
Starter 2	26.00	20.05	20.00	NA[4]
Grower 1	34.80	3.50	31.30	NA[4]
Grower 2	40.20	NA[4]	40.20	NA[4]
Finisher 1	42.85	NA[4]	39.00	3.85
Finisher 2	47.55	NA[4]	37.55	10.00

[1]Corn inclusion as a percentage of total feed.

[2]Corn hammers milled with screens size 6 &8, the average particle size of 276 μm, added post pelleted with poultry fat post pellet (Table 1) to only coarse corn treatments at the specified amount.

[3]Corn rollers milled with a gap of 50/50 between rolls, the average particle size of 2,500 μm, added post pelleted with poultry fat post pellet (Table 1) to only coarse corn treatments the specified amount.

[4]Corn with no milling intervention, the average length of 10,000 μm, added post-pelleting to only coarse corn treatments at the specified amount.

[5]Non-applicable.

required a corn mean particle size above 2,595 μm. The maximum amount of whole corn used in the formulation was 10% of the total ratio (Table 2).

The minerals used for the experiment were from both inorganic and organic sources. All treatments were formulated to meet the Aviagen nutritional recommendations for minerals. The North Carolina State University Feed Mill Education Unit standard mineral premixes were used as the inorganic source. The starter 1&2 feed phases were supplemented with copper using a premix of 4% copper sulfate and 96% corn at 0.067 and 0.083% of the diet, respectively. No copper supplementation was added to the remaining feed phases.

Feed treatments labeled as "organic blend" were formulated using both an inorganic premix as a base and organic premix (LiquidTrace ZM, Global Animal Products) to supplement Zn and Mn (Table 3). The organic premix was formulated for each feed phase, using different concentrations of iron sulfate, copper sulfate, calcium iodate, and ground corn. LiquidTrace ZM (Global Animal Products) was included at 10% of the amount of all feed phases' organic premixes and included to supply 40 mg/kg Zn and Mn. The inclusion of supplemental DL-methionine was decreased in organic blend mineral diets according to that supplied by LiquiTrace ZM, such that all treatment diets were equal in sulfur-containing amino acids.

All of the fine corn, mineral sources, and other ingredients were batched and mixed in a 2-ton counterpoise ribbon mixer (Model TRDB126060, Hayes & Stolz, Fort Worth, TX) for 3 min of a dry mix followed by 90 s of a wet mix. All treatments were then conditioned for 30 s at 175°F in a single pass conditioner (Model C18LL4/F6, California Pellet Mill, Crawfordsville, IN). The feeds then were pelleted by a 30 HP pellet mill (Model PM1112-2, California Pellet Mill), using a 4.37 mm (11/64") × 34.93 mm (1 3/8") pellet mill die. Each treatment's pellets were cooled in a counterflow cooler (Model VK09 × 09KL, Geelen Counterflow USA, INC, Orlando, FL). The starter 1 was then crumbled (Model 624s, Roskamp Champion). After crumbling or pelleting the feed, coarse corn, and post-pellet fat were added to the 2-ton counterpoise ribbon mixer and mixed for 90 s (Figure 1). This process yielded 4 feed treatments per feed phase, 2 of which had the coarse corn added after the feed was pelleted.

Housing and Management

This study was conducted in a curtain-sided house with a concrete floor. There were 48 total pens (8.4 m^2/pen), 8 pens per treatment, and 25 birds per pen. All pens were bedded with fresh pine shavings. Nicholas Select (Aviagen Turkeys, Lewisburg, WV) male poults (1,200) were placed on the day of hatching. Poults were beak conditioned at the hatchery as it is standard practice for tom poults in the industry. Each pen of poults was weighed at placement. The birds were weighed individually with a digital scale (A&D Company, AND HV-200KGL, San Jose, CA) at 5 wk and then every 3 wk until 18 wk of age. The weight of each pen of birds plus culls and mortalities was used to determine the feed conversion ratio (**FCR**). Feed and water were offered ad libitum throughout the study. All animal handling

Table 3. Mineral sources used for both the inorganic and organic blend treatments (%).[1]

	Inorganic mineral treatment		Organic mineral blend treatment	
Feed phase	Inorganic premix[2]	Copper premix[3]	Inorganic premix[4]	LiquiTrace premix[5]
Starter 1	0.27	0.07	0.20	0.86
Starter 2	0.23	0.08	0.17	0.86
Grower 1	0.23	NA[6]	0.17	0.86
Grower 2	0.23	NA[6]	0.17	0.86
Finisher 1	0.20	NA[6]	0.13	0.86
Finisher 2	0.20	NA[6]	0.13	0.86

[1]Mineral sources inclusion as a percentage of total feed.

[2]The mineral premix provided the following per kg to *inorganic mineral treatments* in phase order: manganese, 160,140,140, 140, 140, 120 mg; zinc, 160,140,140, 140, 120, 120 mg; iron, 106.6, 93.4, 93.4, 93.4, 80, 80 mg; copper, 13.3, 11.7, 11.7, 11.7, 10, 10 mg; iodine, 3.3, 2.9, 2.9, 2.9, 2.5, 2.5 mg.

[3]Copper premix to supplement only starter 1&2 of the *inorganic mineral treatments*, provided the following per kg of starter 1&2 respectively: copper 6.67, and 8.32 mg.

[4]The mineral premix provided the following per kg of *organic blend treatments* in phase order: manganese, 120, 99.9, 99.9, 99.9, 80.1, 80.1 mg; zinc, 120, 99.9, 99.9, 99.9, 80.1, 80.1 mg; iron, 80, 66.6, 66.6, 66.6, 53.4, 53.4 mg; copper, 10, 8.3, 8.3, 8.3, 6.7, 6.7 mg; iodine, 2.5, 3.33, 3.33, 3.33, 1.7, 1.7 mg.

[5]LiquiTrace ZM premix formulated and provided by Global Animal Products, Amarillo, TX, then mixed with corn and other inorganic minerals at NC State feed mill and supplied the following per kg of diet: *organic blend treatments* in phase order: manganese (all phases), 39.9 mg; zinc (all phases), 39.9 mg; Iron, 26.6, 26.8, 26.8, 26.8, 26.6, 26.6 mg; copper, 10, 11.67, 3.35, 3.35, 3.33, 3.33 mg; Iodine, 0.84, 0.84, 0.84, 0.84, 0.83, 0.83 mg.

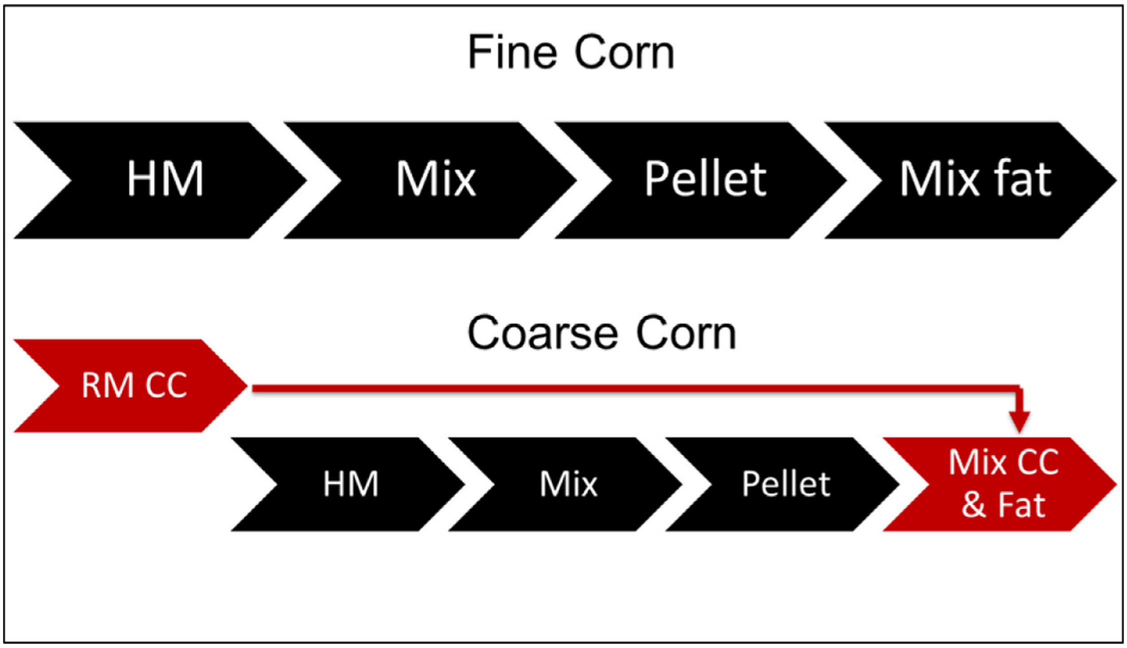

Figure 1. Fine corn and coarse corn treatment feed process. Corn for the fine corn treatment was hammer milled. Then it was mixed with all ingredients, pelleted and then mixed with post pellet poultry fat in the mixer. Corn for the coarse corn treatments had three sources, hammer milled corn, roller milled corn, and whole corn. Hammer milled corn was added at the basal with other ingredients in the coarse corn treatment and was manufactured similarly to the fine corn treatment until the last step. In the last step for coarse corn treatment, the roller mill corn and the whole con were mixed in, along with post pellet poultry fat in the mixer, by-passing the pellet mill.

procedures were approved by the NCSU Institutional Animal Care and Use Committee.

Feeding Program

The birds were fed 6 feed phases (starter 1, starter 2, grower 1, grower 2, finisher 1, and finisher 2) on a feed weight per bird feeding program (Table 1). Feed weight was recorded when added to feeders. At 5, 8, 11, 14, and 18 wk, feeders plus unconsumed feed were weighed to calculate feed disappearance as intake (FI) was used to determine FCR.

Feed Analysis

Proximate analysis was outsourced to a lab that uses the Association of Official Agricultural Chemists International (AOAC International) methodologies (Horwitz and Latimer, 2005). The nutrients analyzed were moisture (AOAC 930.15), crude protein (AOAC 990.03), crude fat (AOAC 920.39), ash (AOAC 942.05), phosphorus (AOAC 965.17), calcium (AOAC 968.08), sodium (AOAC 968.08), and zinc and manganese (AOAC 2011.14). All analyses were done in single samples (250 g) of each dietary treatment in every phase by an external lab (Carolina Analytical Services, Bear Creek, NC).

Pellet Mill Energy Consumption Estimates

The pellet mill motor load (kW) was recorded by the automation system (Repete, Sussex, WI) for each diet and feed phase. Using the time spent (H) to pellet each diet and the batch's total production in tonnes of feed, an estimated production rate (tonnes/H) was calculated. Energy consumption (kW × Hr/tonnes) was subsequently estimated. The feed phase data were collected for grower 2 and finishers 1 & 2.

Each of the four4 diets in each feed phase required different run times to be manufactured. Thus, it was agreed to average all the 5-s values into one true replicate per feed manufacturing run. In every feed phase, there were 4 runs (experimental unit), with 2 true replicates (average of the 5 s kW values) per the main effect. The feed phases served as a random block (time) effect in a Proc mixed model in SAS 9.4.

Pellet Durability Index

The Holmen pellet durability test (durability tester Model NHP100, Holmen Group, Stockholm, Sweden) was used to determine pellet durability. One representative sample was divided into four 100 g subsamples from each feed phase and treatment were agitated for 30 s (2 subsamples) and 60 s (2 subsamples), whole remaining pellets were weighed, and Pellet Durability Index (**PDI**) was calculated as the percentage of pellets (by weight) remaining after the test. For the statistical analysis, all subsamples were averaged into one true replicate, the original feed sample (experimental unit). Similar to the statical analysis of the pellet mill energy consumption, the feed phases served as a random block (time) effect in a Proc mixed model in SAS 9.4.

Corn Mean Particle Size Determination

Ground corn means particle size and variation calculations were determined using the American Society of Agricultural and Biological Engineers standard methodologies (ASABE, 2008). Treatment composite samples were collected from each feed bag. Three subsamples were collected from each composite sample after being homogenized. From each subsample, 100 g of feed and 0.5 g of sieve aid were weighed for sieve analysis. The sieves used were U.S. sieves 4, 6, 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, 200, 270, and a collection pan. The sieves' groups were shaken in a sieve shaker (Ro-Tap Model RX-29, W.S. Tyler Industrial Group, Mentor, OH) for 15 min. The feed present on each sieve was weighed in grams and analyzed per formulas described in ASABE S319.4 for the log-normal mean particle size and standard deviation.

The procedure described above was not viable for whole corn particle size determination. The sieve used in the method described above was too small to measure whole corn particle size. Whole corn particle size was estimated on the average length of whole corn samples. The value of 10,000 μm presented herein is an estimation of the whole corn from the batches used for the diets.

Processing

At 18 wk, two randomly chosen birds per pen were processed at the North Carolina State University poultry processing plant. Live, hot carcass, gizzard, and cold carcass weights were recorded. The hot carcasses were chilled overnight in unstirred ice-chilled water. The resulting cold carcasses were then weighed and cut into thighs, legs, wings, major and minor breasts, abdominal fat, and frame. The frame weight included the breast skin. The percentage of total yield was based on a hot and cold carcass. The parts percentage yield was calculated based on the cold carcass weight. Statistical analysis was conducted using SAS 9.4 using a proc mixed model. The mean of the 2 subsamples per pen was used as the experimental unit (pen average), and the block was the random effect. The block (spatial) was a quarter section of the total 48 pens in the house, thus a row with 12 pens in which each main effect was completely randomized 3 times.

Tibia Strength, and Calcium, Zinc, and Manganese Content

Freshly thawed bones were cleaned of all flesh. Fibula (perone) was left in place and was accounted for in all the analyses. The tibial bone strength at the ultimate stress point (Crenshaw et al., 1981) was measured with a TA-HD plus texture analyzer (Texture Technologies Co, South Hamilton, MA) with a size load cell of 250 kg. Tibias were fat extracted before ashing. Bones were wrapped in cheesecloth and then submerged in petroleum ether for 72 h. They were then placed in a ventilated hood for 1 d before they were dried for 24 h at 60°C in a Blue M drying oven (General Signal, Blue Island, IL).

Upon close inspection after completing this procedure, it was determined that the turkey tibias had some fat residues remaining. It was decided that a second fat removal step was needed. Bones were reduced in size with a mallet to increase the samples' surface area, the process described above was repeated, and the bones were then determined to be ready for ashing. Known weights of samples were placed in labeled ceramic crucibles with known weights and placed overnight in a furnace at 600°C. One gram of tibial ash was taken per pen to be analyzed for calcium, zinc, and manganese. The samples were hydrated with 2 mL of distilled water and boiled with 4 mL of hydrochloric acid 6 normal (HCL6N) for 5 min. Another 4 mL of HCL6N was used before the solution was filtered with ashless paper and diluted with 200 mL of distilled water. One single sample per experimental unit (1 bird per pen) of 15 mL was then analyzed for the specified minerals by the Department of Crop and Soil Science laboratory (North Carolina State University, Raleigh, NC). The external lab read the 15 mL digested samples on the ICP-OES (Ion-Coupled Plasma-Optical Emissions Spectrometer). The ICP-OES that read the samples was a Perkin Elmer Optima 8000 (PerkinElmer, Waltham, CT). The readings obtained from the ICP-OES, in mg/L, were multiplied by 0.015 L (15 mL solution) to achieve an mg/g unit for calcium. The ICP-OES, in mg/L, were multiplied by 0.015 L and 1,000 (15 mL solution times a 1,000 mg to μg factor) to achieve a μg/g unit for zinc and manganese values.

Zinc and Manganese Litter Residues

Clean new pine shavings were used for bedding at placement. Besides clean shavings, after a drinker overflowing, no other treatment activity or substance was added to the litter. At 18 wk, one pooled sample per pen was taken and then analyzed for Zn and Mn content on an as-is basis. The pooled sample was taken in a zig-zag manner inside the pen, avoiding the drinker and feeder area. All single samples were analyzed by the Environmental Analysis Laboratory, Department of Biological and Agricultural Engineering, NC State University, Raleigh, NC 27695-7625. Litter moisture was not measured. The lab incinerated the as is littler samples at 550C and dissolved them in 2 mol/L HCl, then measured these metals using the Perkin Elmer 3100 Atomic Absorption Spectrometer (PerkinElmer).

Performance Statistical Analysis

This experiment had a completely randomized block design. All parameters measured were analyzed using the PROC MIXED procedure from SAS 9.4. (SAS Institute, Cary, NC). A block (spatial) was a one-quarter

Table 4. Calculated nutrient contents (%) for all dietary treatment in each feeding phase.

Nutrient	Starter 1	Starter 2	Grower 1	Grower 2	Finisher 1	Finisher 2
Crude protein	29.00	26.37	22.99	20.93	20.00	18.31
ME (kcal/Kg)	3,050.00	3,149.00	3,275.00	3,336.00	3,369.00	3,427.00
Crude Fat	9.11	9.60	10.07	10.15	10.20	10.27
Lysine	1.75	1.54	1.29	1.14	1.00	0.88
Methionine[1,2]	0.80	0.71	0.56	0.44	0.48	0.45
Methionine + Cysteine[1,2]	1.13	1.01	0.83	0.79	0.72	0.67
Tryptophan[1]	0.32	0.28	0.24	0.21	0.20	0.18
Isoleucine[1]	1.07	0.96	0.81	0.72	0.68	0.61
Threonine[1]	1.01	0.90	0.74	0.70	0.62	0.57
Arginine[1]	1.89	1.57	1.34	1.10	1.13	1.01
Valine[1]	1.31	1.05	0.91	0.82	0.79	0.71
Calcium	1.49	1.38	1.20	1.14	1.04	0.92
Available phosphorus	0.76	0.69	0.60	0.57	0.51	0.46
Sodium	0.19	0.19	0.19	0.19	0.18	0.18
Chloride	0.27	0.26	0.26	0.25	0.24	0.24
Zinc (ppm)	160.00	140.00	140.00	140.00	120.00	120.00
Manganese (ppm)	160.00	140.00	140.00	140.00	120.00	120.00

[1]Calculated as digestible amino acids.
[2]Supplemental methionine is reduced in organic blend mineral diets by amounts supplied by the methionine chelates to be equal in all treatments.

side of a 48-pen house (12 pens), in which each main effect was completely randomized 3 times. All 4 blocks were considered a random variable in all analyses. Significant differences in main effects were separated using the Tukey HSD test. A value of $P \leq 0.05$ was used to set a significant difference between the main and interaction effects of the parameters analyzed.

RESULTS

Feed Analysis

The ingredient composition of diets is shown in Table 1. The calculated nutrient composition of treatment formulations is presented in Table 4. The nutrient wet lab analysis of all treatments is presented as-is in Table 5. The targeted dietary concentrations of Zn and Mn levels were met (Table 1). In each feed phase, the concentrations of Zn and Mn were similar across treatments. As planned, concentrations of Zn and Mn decreased in each subsequent feed phase.

Feed Mill Energy Consumption Estimates

The pellet mill motor load and estimated pellet mill energy consumption for the treatments with coarse corn were lower than those with fine corn. There was also a higher estimated production rate for the coarse corn runs in comparison to those with the fine corn (Table 6).

Pellet Durability Index

When corn was added post pellet in a coarse form, the PDI decreased when compared to diets formulated with fine corn (Table 7). This was observed both when PDI was measured at 30 s or 60 s. At 60 s the difference in PDI between corn particle treatments was higher. No statistical difference was observed when comparing the mineral treatments in PDI.

Performance Parameters

There was no statistical difference in cumulative bird mortality for any treatment during the experiment. No first-order interaction was found between the corn mean particle size and mineral source treatments for any performance variable at any point of the study. Birds fed coarse corn had a similar BW when compared to birds fed the fine corn until 8 wk (Table 8). From 11 wk to 18 wk, the birds fed coarse corn had a lower BW than the birds fed fine corn. From 8 to 11 wk, there was a single period where there was a significant difference in BWG and FI. The birds fed coarse corn had a lower BWG and FI in that period than the birds fed fine corn (Table 8). The organic blend resulted in a higher bird BW overall at 18 wk compared to birds fed the all-inorganic mineral treatment. At 11 wk bird BWG was statistically different due to feed mineral treatment. The organic blend resulted in significantly higher bird BWG at 11 wk compared to birds fed the total inorganic mineral treatment. At 5 wk, the birds fed the organic blend had significantly lower FI and improved FCR compared to the birds fed the total inorganic mineral treatment feed. There was also an improvement in FCR at 14 wk, but not at 18 wk of age (Table 9) due to feeding the organic blend treatment feed.

Processing

No first-order interaction was found between treatments on processing variables. No differences in hot or cold carcass weights were found between treatments. Birds fed coarse corn had heavier gizzards and a higher gizzard/live weight ratio (Table 10). The wing percentage yield was lower for birds fed coarse corn when compared to fine corn. The minor and total breast yield was higher, while frame yield was lower when birds were fed the organic blend of minerals compared to the birds fed solely the inorganic source (Table 10).

Table 5. Nutrient analyses (%) of experimental diets fed to turkeys.[1]

Nutrient	Starter 1				Starter2			
	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]
Moisture	12.17	12.90	11.99	12.71	11.40	11.97	12.09	12.27
Fat	9.020	8.60	9.22	8.39	8.99	7.96	8.92	8.72
Protein	28.02	28.68	29.32	28.62	27.86	26.51	27.95	26.88
Ash	6.77	6.57	6.61	6.59	5.74	5.8	6.29	6.16
Phosphorus[6]	1.08	1.04	1.07	1.01	1.02	0.85	1.12	0.99
Calcium	1.55	1.48	0.64	1.41	1.56	1.21	1.67	1.49
Sodium	0.18	0.17	0.18	0.16	0.19	0.15	0.19	0.17
Zinc (ppm)	216	239	222	216	205	188	227	198
Manganese (ppm)	183	164	195	165	168	155	229	150
	Grower 1				Grower 2			
	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]
Moisture	11.04	11.39	11.49	12.56	11.52	11.81	12.32	12.70
Fat	9.86	9.21	10.32	9.08	9.92	10.78	10.49	9.83
Protein	22.60	23.39	23.66	23.91	21.61	19.97	21.86	21.66
Ash	5.13	5.24	5.46	5.31	5.22	4.91	5.41	5.17
Phosphorus[6]	0.85	0.85	0.96	0.88	0.71	0.70	0.77	0.73
Calcium	1.26	1.20	1.52	1.28	0.99	1.06	1.07	1.04
Sodium	0.18	0.16	0.22	0.18	0.16	0.17	0.19	0.17
Zinc (ppm)	194	219	189	264	139	169	183	258
Manganese (ppm)	146	152	175	155	144	138	166	170
	Finisher 1				Finisher 2			
	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]	CC ORG[2]	CC INO[3]	FC ORG[4]	FC INO[5]
Moisture	11.77	11.19	11.94	12.53	11.42	11.00	12.28	12.00
Fat	11.81	10.10	10.11	9.91	11.04	11.42	12.40	11.09
Protein	20.99	20.67	22.00	21.06	19.65	19.16	19.05	19.34
Ash	4.82	4.61	4.85	4.89	4.78	4.21	4.34	4.34
Phosphorus[6]	0.63	0.70	0.77	0.70	0.66	0.66	0.63	0.69
Calcium	0.87	0.96	1.10	1.02	0.95	1.04	0.86	0.89
Sodium	0.17	0.17	0.18	0.21	0.17	0.20	0.15	0.19
Zinc (ppm)	223	117	152	176	140	196	139	167
Manganese (ppm)	132	118	133	134	125	173	124	142

[1]Feed analysis was performed by Carolina Analytical Services (17570 NC Highway 902, Bear Creek, NC 27207).
[2]Coarse corn with an organic blend of Zn and Mn feed treatment.
[3]Coarse corn with inorganic minerals feed treatments.
[4]Fine corn with an organic blend of Zn and Mn feed treatment.
[5]Fine corn with inorganic minerals feed treatments.
[6]Total phosphorus in diet treatments.

Tibia Strength, and Calcium, Zinc, and Manganese Content

No statistical difference was observed due to treatment in 18-wk-old turkey tibia bone strength at the ultimate stress point or bone calcium, zinc, or manganese content (Table 11).

Zinc and Manganese Litter Residues

There was a first-order interaction between treatments in the concentrations of Zn residues in the litter. When birds were fed fine corn and inorganic minerals, the Zn concentration was increased in the litter by 21% overall for other treatment combinations (Table 12). No

Table 6. Effect of treatments on production and energy estimates with each phase as a block.

Corn particle size	Mineral source	Motor load (kw)	Estimated production (ton/h)	Estimated energy consumption (KW × H/ton)
Coarse[1]		47.03[b]	4.64[a]	7.54[b]
Fine[2]		64.13[a]	4.08[b]	11.71[a]
SEM[3]		4.05	0.18	0.46
P-value		0.002	0.04	<0.0001
	Inorganic[4]	55.04	4.36	9.49
	Organic[5]	56.14	4.36	9.76
	SEM[3]	4.05	0.18	0.46
	P-value	0.77	0.98	0.58

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Coarse corn treatments increased the corn's average corn particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[2]Fine corn treatments were formulated in each feed phase with corn with an average particle size of 276 μm.
[3]The standard error of the mean (SEM) n = 6 feed manufacturing runs per the main effect, and the feed phase as the block (time).
[4]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[5]Blend of organic (chelated)/inorganic sources of the Zn and Mn.

Table 7. PDI[1] for feed treatments using the Holmen method for 30 and 60 s (%).

Corn particle size	Mineral source	PDI 30 s	PDI 60 s
Coarse[2]		78.30[b]	55.30[b]
Fine[3]		86.75[a]	74.46[a]
SEM[4]		1.55	4.13
P-value		0.001	0.001
	Inorganic[5]	84.78	68.29
	Organic[6]	81.40	61.50
	SEM[4]	1.55	4.13
	P-value	0.08	0.10

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Pellet durability index.
[2]Coarse corn treatments increased the corn's average corn particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[3]Fine corn treatments were formulated in each feed phase with corn with an average particle size of 276 μm.
[4]The standard error of the mean (SEM) n = 8 feed samples per the main effect, and the feed phase as the block (time).
[5]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[6]Blend of organic (chelated)/inorganic sources of the Zn and Mn.

interaction or main effects were found for Mn residues in the litter.

DISCUSSION

Most reported studies on feed mean particle size in turkeys were completed at early stages of age (Charbeneau and Roberson, 2004; Santos et al., 2006; Favero et al., 2009, 2012) with whole grain and single-mean particle size through all feed phases (Ferket and Veldkamp, 1999; Jankowski et al., 2013; Singh, 2013; Singh et al., 2014) which is different from the study herein. However, it has been postulated that, generally, in poultry, an increase in feed mean particle size results in increased digestibility and performance as measured by FCR (Favero et al., 2009). In this study, increasing the corn mean particle size through the feed phases resulted in a cumulative FCR that was not different at market age. However, a difference in BW at 18 wk was observed due to feeding corn mean particle size, with birds fed fine corn being heavier than those fed coarser corn.

Before and after that 8 to 11 wk period, there was no significant change in BWG due to coarse and fine corn treatments. Flores et al. (2020a) reported a similar pattern of feed quality treatments effects on male commercial turkeys during this same period of growth. Therefore, the 8 to 11 wk period may be crucial for developing male turkeys raised for the market. During this period, relatively more muscle and less skeletal growth may occur. The resulting BW difference at 18 wk could be related to a reduction of gelatinization, a mismatch of mean particle size for bird age, or pellet quality (abundance of fines) for the 8 to 11 wk period reduction in BWG for birds fed a coarse corn treatment.

The decrease in BWG during the 3-wk period (8−11 wk) may be due to decreased starch gelatinization in non-conditioned corn. Gelatinization of starch adds a specific amount of water and heat to disorganized starch molecules inside the starch granules (Moran, 1982b; Svihus, 2014). Starch gelatinization is regarded as a positive process for starch digestibility in poultry. It increases the dissolubility of starch with α-amylase (Mercier and Guilbot, 1974; Moran, 1982b; Svihus, 2014; Massuquetto et al., 2020). Mercier and Guilbot (1974) postulated that the combination of steam conditioning and die friction in the pelleting process will increase gelatinization and significantly affect starch's digestibility. However, in more recent studies summarized by Svihus (2014), it

Table 8. Effect of corn mean particle size on male turkey cumulative performance (kg/bird).

	Turkey age in weeks					
Corn mean particle size	0	0−5	0−8	0−11	0−14	0−18
		(Bodyweight)				
Coarse[1]	0.057	1.75	4.42	8.37[b]	13.18[b]	20.38[b]
Fine[2]	0.059	1.73	4.43	8.56[a]	13.37[a]	20.63[a]
SEM[3]	0.002	0.03	0.03	0.06	0.06	0.086
P-value	0.650	0.50	0.93	0.01	0.02	0.04
		(Bodyweight gain)				
Coarse[1]	NA[4]	1.69	2.68	3.94[b]	4.81	7.20
Fine[2]	NA[4]	1.67	2.70	4.14[a]	4.81	7.26
SEM[3]	NA[4]	0.03	0.03	0.06	0.05	0.06
P-value	NA[4]	0.52	0.56	<0.001	0.94	0.40
		(Feed intake)				
Coarse[1]	NA[4]	2.38	6.92	14.48[b]	25.50	43.22
Fine[2]	NA[4]	2.42	6.98	14.79[a]	25.66	43.24
SEM[3]	NA[4]	0.02	0.06	0.19	0.19	0.28
P-value	NA[4]	0.22	0.31	0.05	0.44	0.97
		(Feed conversion ratio)				
Coarse[1]	NA[4]	1.354	1.639	1.796	1.970	2.162
Fine[2]	NA[4]	1.366	1.652	1.776	1.962	2.158
SEM[3]	NA[4]	0.009	0.018	0.012	0.015	0.017
P-value	NA[4]	0.098	0.298	0.220	0.562	0.849

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Coarse corn treatments increased the corn's average corn mean particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[2]Fine corn treatments were formulated in each feed phase with corn with an average mean particle size of 276 μm.
[3]The standard error of the mean (SEM) n = 24 pens per the main effect with 25 birds per pen at placement.
[4]Non-applicable.

Table 9. Effect of mineral source on male turkey cumulative performance (kg/bird).

	Turkey age in weeks					
Mineral source	0	0–5	0–8	0–11	0–14	0–18
			(Bodyweight)			
Inorganic[1]	0.057	1.74	4.43	8.42	13.23	20.38[b]
Organic[2]	0.057	1.74	4.42	8.51	13.32	20.63[a]
SEM[3]	0.002	0.02	0.03	0.06	0.06	0.086
P-value	0.690	0.96	0.90	0.21	0.25	0.05
			(Bodyweight gain)			
Inorganic[1]	NA[4]	1.68	2.69	3.99[b]	4.81	7.16
Organic[2]	NA[4]	1.68	2.69	4.09[a]	4.82	7.31
SEM[3]	NA[4]	0.03	0.03	0.06	0.05	0.06
P-value	NA[4]	0.96	0.93	0.04	0.92	0.07
			(Feed intake)			
Inorganic[1]	NA[4]	2.43[a]	7.01	14.68	25.67	43.29
Organic[2]	NA[4]	2.37[b]	6.89	14.59	25.48	43.17
SEM[3]	NA[4]	0.02	0.06	0.19	0.19	0.28
P-value	NA[4]	0.017	0.07	0.54	0.37	0.74
			(Feed conversion ratio)			
Inorganic[1]	NA[4]	1.372[a]	1.656	1.799	1.980[a]	2.170
Organic[2]	NA[4]	1.347[b]	1.635	1.773	1.951[b]	2.149
SEM[3]	NA[4]	0.009	0.018	0.012	0.015	0.017
P-value	NA[4]	0.001	0.099	0.116	0.049	0.380

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[2]Blend of organic (chelated)/inorganic sources of the Zn and Mn.
[3]The standard error of the mean (SEM) n = 24 pens per the main effect with 25 birds per pen at placement.
[4]Non-applicable.

has been shown that only a limited amount (5–30%) of the starch is gelatinized in the pelleting process. It also has to be considered that α-amylase is produced in vast amounts by poultry to digest the untreated starch (Moran, 1982b; Svihus, 2014). Most problems with starch digestibility come with the dietary addition of wheat rather than corn. This may be due to the different types of starch granules in the cereals. Corn has small unimodal granules, while wheat has relatively large bimodal granules (Svihus, 2014). However, Hetland et al. (2002) reported a 0.98 starch digestibility coefficient when feeding 44% whole wheat. Massuquetto et al. (2020) postulated a solution for the low gelatinization of corn during the pelleting process by the high-temperature short-time process of expanding the corn before pelleting. Expanding the corn before adding it post-pelleting could be a future research opportunity. After expanding at 105°C average temperature, 3.5% steam addition, and 96 kgf/cm^2 pressure during 4 s, the corn can be milled to the desired mean particle size (Massuquetto et al., 2020).

The mismatch of mean particle size fed to the birds could be another reason for a lower BWG during the 8 to 11 wk of age for birds fed coarse corn. The mean mean particle size of 2,595 μm was fed to the coarse corn treatment turkeys during the 3 wk period. The mean particle size could have been a promotor to decrease feed intake at that age by not matching the beak size.

Table 10. Turkey processing carcass yields as a percentage of cold carcass weight.

Corn mean particle size	Mineral source	HCY[1]	CCY[2]	MAJ[3]	MIN[4]	TOT[5]	Wing	Thigh	Leg	Frame[6]	Fat[7]	Gizzard
Coarse[8]		82.67	84.63	25.67	5.94	31.57	0.99[b]	1.62	1.14	2.95	0.86	1.01[a]
Fine[9]		82.50	84.46	25.46	5.81	31.20	1.02[a]	1.60	1.15	2.96	0.86	0.81[b]
SEM[10]		0.19	0.23	0.21	0.08	0.17	0.12	0.19	0.10	0.20	0.05	0.03
P-value		0.47	0.61	0.38	0.11	0.12	0.05	0.38	0.58	0.55	0.98	<0.0001
	Inorganic[11]	82.50	84.54	25.37	5.70[b]	31.05[b]	1.00	1.61	1.15	2.99[a]	0.87	9.18
	Organic[12]	82.67	84.54	25.75	5.98[a]	31.73[a]	1.00	1.61	1.14	2.91[b]	0.85	8.95
	SEM[10]	0.19	0.23	0.21	0.08	0.17	0.12	0.19	0.10	0.20	0.05	0.03
	P-value	0.47	1.00	0.12	0.01	0.01	0.78	1.00	0.58	0.02	0.75	0.36

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Hot carcass yield.
[2]Cold carcass yield.
[3]Pectoralis major with no skin.
[4]Pectoralis minor.
[5]Total pectoralis (breast) weights
[6]Frame includes breast skin.
[7]Abdominal fat pad.
[8]Coarse corn treatments increased the corn's average corn mean particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[9]Fine corn treatments were formulated in each feed phase with corn with an average mean particle size of 276 μm.
[10]The standard error of the mean (SEM) n = 24 pens (true replicates) per the main effect with 2 birds processed (subsamples).
[11]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[12]Blend of organic (chelated)/inorganic sources of the Zn and Mn.

Table 11. Treatment effect on tibial ultimate stress, bone ash, and bone Zn and Mn content.

Corn mean particle size	Mineral source	Ultimate stress point (kg)[1]	Bone ash (%)	Bone Ca (mg/g)[2]	Bone Zn (μg/g)[3]	Bone Mn (μg/g)[4]
Coarse[5]		88.72	49.83	31.86	19.95	0.86
Fine[6]		84.75	50.33	31.19	19.35	0.90
SEM[7]		2.87	0.35	0.66	0.30	0.03
P-value		0.33	0.87	0.31	0.23	0.28
	Inorganic[8]	87.75	50.04	31.58	19.95	0.86
	Organic[9]	85.72	49.71	31.47	19.50	0.93
	SEM[7]	2.88	0.35	0.66	0.30	0.03
	P-value	0.62	0.50	0.86	0.43	0.16

[1]Tibial bone strength at the ultimate stress point (Crenshaw et al., 1981) was measured with a TA-HD plus texture analyzer (Texture Technologies Co, South Hamilton, MA) with a size load cell of 250 kg.
[2]Digested bone ash content of calcium in milligrams per gram of tibial ash.
[3]Digested bone ash content of zinc in micrograms per gram of tibial ash.
[4]Digested bone ash content of manganese in micrograms per gram of tibial ash.
[5]Coarse corn treatments increased the corn's average corn mean particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[6]Fine corn treatments were formulated in each feed phase with corn with an average mean particle size of 276 μm.
[7]The standard error of the mean (SEM) n = 24 pens (true replicates) per the main effect with 2 birds processed (subsamples).
[8]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[9]Blend of organic (chelated)/inorganic sources of the Zn and Mn.

No information was found on the optimal corn mean particle size to beak size relationship for that turkey age. It is known that the mechanoreceptors in the beak are of great importance for the ability to prehend feed and affect FI behavior (Moran, 1982a). In broilers, as the bird ages, a preference for increased feed mean particle size also increases (Portella et al., 1988). However, it is possible that the corn particle size (2,000 μm) at 8 to 11 wk fed in the study herein was not of optimal size to prehend with these bird's beak trimmed beak. Another reasoning for a change in BWG is selective feeding of the birds. The reasoning is that birds could select for only corn or pellet feed depending on their preference.

Table 12. Treatment effect on litter content of Zn and Mn at 18 wk of age (mg/kg[1]).

Corn mean particle size	Mineral source	Manganese	Zinc
Coarse[2]		566	1,057[b]
Fine[3]		565	1,171[a]
SEM[4]		11	26
P-value		0.98	0.004
	Inorganic[5]	569	1,157[a]
	Organic[6]	561	1,071[b]
	SEM[4]	11	26
	P-value	0.62	0.03
Coarse	Inorganic	560	1,031[b]
Fine	Inorganic	579	1,281[a]
Coarse	Organic blend	571	1,082[b]
Fine	Organic blend	551	1,061[b]
SEM[7]		16	37
P-value		0.22	0.001

[a,b]Means within a column lacking a common superscript differ ($P \leq 0.05$).
[1]Analysis done on as-is basis samples by the Environmental Analysis Laboratory, Department of Biological and Agricultural Engineering, NC State University, Raleigh, NC 27695-7625.
[2]Coarse corn treatments increased the corn's average corn mean particle size in 500 μm every period from 1,000 μm at 5 wk to 3,500 μm at 18 wk.
[3]Fine corn treatments were formulated in each feed phase with corn with an average mean particle size of 276 μm.
[4]The standard error of the mean (SEM) n = 24 pens per the main effect with 25 birds per pen at placement.
[5]Inorganic mineral source treatments got 100% of their mineral from an inorganic premix.
[6]Blend of organic (chelated)/inorganic sources of the Zn and Mn.
[7]The standard error of the mean (SEM) n = 12 pens per first-order interaction with 25 birds per pen at placement.

However, in the study herein feed was manually placed in tube feeders in each pen. Subsequent feed was added as the present feed in each tube feeder was consumed.

Overall, the coarse corn feed strategy used herein resulted in a 21% increased gizzard weight ($P < 0.001$) over the birds fed fine corn, potentially increasing feed digestibility. In multiple reports, there appears to be agreement that there should be improved digestion, gut motility, and reverse peristalsis with a heavier gizzard (Ferket, 2000; Hetland et al., 2002; Charbeneau and Roberson, 2004; Santos et al., 2006; Favero et al., 2009, 2012; Jankowski et al., 2013; Moss et al., 2017; Truong et al., 2017). However, there may be a need to fine-tune the feeding scheme to optimally match corn mean particle size to the bird's age and size. Moss et al. (2017), using an equilateral triangle design, demonstrated in broilers that for an optimum FCR of 1.446, a mix of 28.67% ground wheat, 42.66% pre-pellet whole wheat, and 28.67% post-pellet whole wheat was needed. This idea of fine-tuning the 8 to 11 wk corn mean particle size is challenged by Santos et al. (2006), who reported no effect on feeding 3,000 μm corn to 28-day-old poults. However, Ferket (2000) reported that the gizzard grinding of grains has an energy cost to the bird, and there is a need to balance the benefits of the gizzard and the energy used by milling. This cost in bird performance in this study was observed in BW but not in FCR at market age. In addition, this reduction in BW would need to be analyzed with cost-benefit analysis in each operation concerning the feed milling energy savings and potential increased feed production. Accounting for energy usage by the feed mill is essential to controlling production costs in integrated production. The reduction in pellet mill motor load and estimated time per tonne produced, and therefore a lower kilowatt hour per tonne of production, by adding corn post pelleting are logical. There is a reduction of ingredients (corn) to be pelleted, and there is a decrease in milling energy usage when corn is ground coarser and is added post pelleting.

Pellet quality (abundance of fines) should be carefully monitored when adding ingredients after pelleting.

When corn is added post pelleting, the feed quality may change because a change in the proportions of ingredients can increase or decrease the pellet durability achieved during the pelleting process. The wheat percentage in the basal mix will increase, but so will the amount of fat. The mechanism in which corn is added to the pelleted basal is of great importance as this could be done by putting it back into the mixer (as was the case for the current study) or by blending it into the pelleted basal while loading the feed truck. The form and quality of the pellets are vital for higher performance in the early stages of turkey production because of the birds' prehension capacities (Flores et al., 2020b). A high abundance of fines significantly increases FI (or feed disappearance) and FCR at market age (Flores et al., 2020a). The high abundance of feed fines could be one of the reasons that affected the birds that consumed coarse corn particle size treatments in the herein study. The PDI for the coarse corn treatment was significantly lower when compared to fine corn treatments across feed phases. This decrease in PDI is directly related to a high fine abundance (feed quality) and its decrease in the 8 to 11 wk BWG by birds that consume this low-quality feed (high abundance of fines or low PDI). Similar effects were reported by Flores et al. (2020a), where birds fed a high abundance of feed fines had a lower BWG at 8 to 11 wk of age. Thus there is the hypothesis for future research that high PDI or low abundance of feed is critical for male turkeys in the 8 to 11 wk growth period. Another research opportunity is to determine how to include coarse corn in the diets following pelleting while maintaining a high PDI. One potential research opportunity could be to formulate basal diets that are pelleted without a great amount of corn. Adding the corn after pelleting increases the percentage of the fat in the basal diet that is pelleted.

The idea of adding an ingredient following the pelleting process is not new. In Australia, 15 to 20% of whole grains are added post pelleting to enhance broiler performance while offsetting the feed milling cost (Moss et al., 2017; Truong et al., 2017). Usage of whole wheat in feed is common in European countries, Australia, and Canada (Singh et al., 2014; Liu et al., 2015). Jankowski et al. (2013) recommended adding up to 25 to 30% replacement of ground wheat with post-pelleted whole wheat. No study was found where coarse corn alongside whole corn was increasingly added in turkey rations. The study herein has shown no effect on adding post pellet whole corn (21%) alongside coarse corn on FCR.

Micro minerals are mostly supplemented in their saline forms in the poultry industry (Vieira, 2008). For example, at one time, zinc oxide was responsible for 80 to 90% of the industry supplementation of zinc in the poultry industry (Sandoval et al., 1997). The high use of zinc oxide is due to the low cost of Zn and Mn oxide forms compared to sulfate and chelated forms (Bao and Choct, 2009; Suttle, 2010; Singh et al., 2014; Patra and Lalhriatpuii, 2020). Although the cost may be higher, chelated minerals do not interact with other molecules due to increased stability (Kratzer and Vohra, 2018). The decrease in interaction cannot be claimed for sulfated minerals, which are highly reactive and can generate free metal ions (Patra and Lalhriatpuii, 2020). These free metal ions can degrade vitamins, fats, and oils (Batal et al., 2001).

There is generally an over-supplementation of Zn and Mn in the poultry industry. The Zn can be fed at high concentrations due to high tolerance by many animals (Alkhtib et al., 2020). High concentrations of Zn, Cu, and Mn have been used as a possible coccidiosis mitigation strategy in poultry (Bortoluzzi et al., 2020). Likewise, the lack of mineral requirement knowledge in poultry may also result in over-supplementing these minerals. The latest National Research Council (**NRC**) Poultry requirement guidelines were released in 1994 (NRC, 1994) and may be outdated. The out-of-date information may prompt the producer to increase the concentrations of cheap Zn and Mn oxide to have a safety net to prevent any nutritional deficiency or disease challenge. This action may or may not be prudent. The current study used the primary breeder recommended Zn and Mn concentrations, which are about 120 to 80 mg/kg higher than the NRC recommended concentrations for Zn and Mn. The low cost and the lack of clarity of the requirement of minerals requirements may lead producers to oversupply low-cost inorganic minerals, thus increasing the excretion to the environment (Bao et al., 2007; Bao and Choct, 2009; Ao and Pierce, 2013; Bratz et al., 2013; Singh et al., 2014; Singh et al., 2015; Jankowski et al., 2019b,c; Bortoluzzi et al., 2020; Patra and Lalhriatpuii, 2020). However, the study herein has shown that other factors affect Zn's excretion, precisely corn mean particle size. Feeding turkeys a combination of fine corn and inorganic mineral treatments increased the amount of Zn excreted into the litter at 18 wk. Thus, this may reflect the importance of mineral source bioavailability, amount of minerals fed, and the interaction with the corn particle size and its effect on reverse peristalsis in the bird.

The environmental impact is not the only reason to consider the potential over-supplementation of microminerals. Ao and Pierce (2013) offered 3 reasons for the reduction of microminerals in inorganic forms. The first is to reduce detrimental interrelationships between minerals (Suttle, 2010). The antagonistic relationships of minerals can reduce absorption, transport, and even excretion of the minerals, creating a mineral imbalance (Powell et al., 2010; Joshua et al., 2016). The second reason is to avoid the formation of soluble fractions with phytate, thus reducing phytase efficiency (Maenz et al., 1999; Ondracek et al., 2002; Banks et al., 2004). The order in which the microminerals ions inhibit phytase hydrolysis is $Zn^{2+} > Fe^{2+} > Mn^{2+} > Fe^{3+} > Ca^{2+} > Mg^{2+}$ (Maenz et al., 1999). A third reason offered by Ao and Pierce (2013) is the environmental burden (Blanco-Penedo et al., 2006).

The concentrations of Zn and Mn used in the study herein were taken from the primary breeder recommendations, which are 160 mg/kg for both Zn and Mn in the starter to 120 mg/kg in the finisher. During the whole trial, the methionine chelated source of minerals was at a constant, replacing 40 mg/kg Zn and Mn from inorganic sources. Thus, the organic blend treatment had both the inorganic and organic sources through the trial. The methionine chelated Zn and Mn portions increased from 25% in the starter to 33.33% in the finisher. The increased contribution of the chelated Zn and Mn was associated with increased BW and increased breast muscle compared to the birds fed only the inorganic source of Zn and Mn. Most studies in turkeys follow the trend of decreasing the commercial, NRC, or European breeder recommendations. In Europe, Zn's concentration as an inorganic source is about 144 mg/kg, which is 100 mg/kg higher than the recommend NRC concentration (Jankowski et al., 2019a). Mn is also used above its estimated requirement in Europe, with concentrations around 100 mg/kg to the extent that the amount can even cause cellular apoptosis (Jankowski et al., 2019c). Though Zn and Mn concentrations could be reduced to 10 mg/kg without affecting performance, the authors recommended reducing it to 50 mg/kg (Jankowski et al., 2019a,c). Additional research is needed to compare sources of minerals, including Zn and Mn, to reduce feed mineral usage further.

In conclusion for corn particle size treatments, feeding turkeys and increasing coarse corn mean particle size in 500 μm increments from the starter (1,000 μm) to the finisher 2 (3,500 μm) decreased bird BW by 250 g. However, there was no difference in FI, FCR, or carcass yields. Feed quality, as an abundance of fines in pelleted feed, needs to be closely researched. The reduction in market BW could be attributed to corn gelatinization, a mismatch of corn particles size with the bird's beak size, or a high abundance of fines in the feed during this phase. This is the second study conducted in this lab where BWG at 8 to 11 wk is reduced by a high abundance of feed fines when compared with a diet that yields a low abundance of feed fines (Flores et al., 2020a). Reducing feed fines by adding coarse corn post pellet reduced the pellet mill's energy usage by 36% in Kw × H/tonne.

In conclusion for mineral source treatments, birds fed a combination of methionine chelated Zn and Mn with their saline forms had a higher BW and improved breast meat yield at market age compared to birds only fed the inorganic forms. Feeding feed with fine corn particle size containing inorganic Zn increased litter Zn. The ratios of the blend of chelated Zn and Mn with inorganic sources and reducing the total feed mineral content is advisable for further study.

DISCLOSURES

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