Animal Nutrition 5 (2019) 396–406

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: http://www.keaipublishing.com/en/journals/aninu/

Original Research Article

Effect of protein sources on performance characteristics of turkeys in the first three weeks of life ☆

Megan L. Ross, Dervan D.S.L. Bryan *, Dawn A. Abbott, Henry L. Classen *

Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, S7N 5A8, Saskatchewan, Canada

ARTICLE INFO

Article history:
Received 7 February 2019
Received in revised form
10 August 2019
Accepted 5 September 2019
Available online 4 October 2019

Keywords:
Soybean meal
Corn gluten meal
Canola meal
Fish meal
Porcine meal
Turkeys

ABSTRACT

The effect of nutrition during the early life of turkey poults has a long-lasting impact on bird performance. This study assessed the digestibility of 5 high protein feed ingredients (soybean meal [SBM], corn gluten meal [CGM], canola protein concentrate [CPC], fish meal [FM], and porcine meal [PCM]) in broiler chickens, as well as their use in turkey pre-starter diets fed to 21 d of age. The first experiment (5 × 2 factorial arrangement) determined nitrogen corrected apparent metabolizable energy (AMEn) and apparent ileal amino acid digestibility (AIAAD) of each ingredient in broiler chickens at 5 and 21 d of age, using 6 replications of 30 and 8 chicks, respectively. In the second experiment (completely randomized design), 4 replication pens, containing 23 d-old poults, were randomly assigned to one of 5 dietary treatments. The diets were formulated based on the AMEn and AIAAD values derived in the first experiment, and consisted of a high SBM control diet, and 4 additional diets with either CPC, FM, PCM or CGM replacing 25% of the protein supplied by SBM in the control diet. Statistical analysis was completed using Proc Mixed in SAS 9.3. Planned contrasts were used to compare treatments in the second experiment. Trends were identified at $P < 0.10$ and significant differences identified at $P \leq 0.05$. Bird age did not affect CPC, FM, CGM, and SBM AMEn, but the PCM value at d 5 was higher than that at d 21. Apparent ileal amino acid digestibility increased with age for most amino acids (AA), but the response was AA and protein source dependent. The largest average increase in AIAAD between 5 and 21 d of age was observed for CGM. Inclusion of CPC, FM, PCM, or CGM increased body weight up to 14 d, in comparison to poults fed the SBM diet, but feed efficiency and water consumption were not affected. Terminal ileum digesta moisture values were higher for birds fed SBM when compared to those fed PCM. These results demonstrate that combining SBM with CPC, FM, PCM, or CGM improves poult performance during the first 14 d of life in comparison to feeding SBM alone.

1. Introduction

Turkey poults are severely protein depleted at hatch, as protein is preferentially used as an energy source during the hatching process. This is because gluconeogenesis from protein does not require oxygen, which is limited during the transition from chorioallantois to pulmonary respiration (Uni and Ferket, 2004). Additionally, protein digestion is impaired in young birds because of the transition from yolk sac nutrients, which are predominantly lipids, to a high protein exogenous feed (Noy and Sklan, 1997; Sklan, 2001). The transition from yolk to feed is compromised because of the immature state of the digestive tract in young poults, which leads to a reduced ability to digest and absorb protein. The ability to use dietary protein and amino acids (AA) at a young age is important as these nutrients are required for basic body function, muscle cell proliferation and subsequent meat production (Firman and Boling, 1998; Halevy et al., 2000, 2003; Moore et al., 2005). Due to protein depletion and the decreased ability of poults to digest protein, it is essential to provide birds with adequate levels of high quality dietary protein following hatch.

☆ Presented at the Poultry Science Annual Meeting, Kentucky, USA, July 27, 2015.

* Corresponding authors.
E-mail addresses: dervan.bryan@usask.ca (D.D.S.L. Bryan), hank.classen@usask.ca (H.L. Classen).

Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.aninu.2019.09.002

Currently, the most commonly used protein source in poultry diets is soybean meal (SBM) because its nutritional profile (energy, AA level and balance) is complimentary to that of cereal grains and the poult's requirements. The market for food products from vegetable fed animals has increased the level of SBM used in turkey diets. Despite the favorable nutritional profile of SBM, when used at high levels as the sole protein source in practical pre-starter diets, the effects of anti-nutritional factors (ANF) may be underestimated. These ANF include protease inhibitors, which impair protein digestion (Palliyeguru et al., 2011), lectins, which affect carbohydrate digestion, as well as disrupting and causing damage to the intestinal wall (Fasina et al., 2003), phytic acid, which interferes with mineral and protein absorption (Cowieson et al., 2004), and non-starch polysaccharides, which cause fluid retention, increased passage rate, and subsequent poor nutrient absorption when in high concentrations within the digestive tract (Stein et al., 2008). Although industrial processing reduces the level of protease inhibitors and lectins (Kumar, 1992), the high inclusion rates of SBM may result in diet levels that have adverse effects. Potassium levels in SBM may also have anti-nutritive effects, as high levels of potassium in SBM have been associated with increased water intake and as a result increased excreta moisture (Youssef et al., 2011).

Reducing the SBM levels in pre-starter feeds by including other protein sources could be advantageous because it dilutes the levels of SBM ANF present in the feed. Other protein sources may also provide beneficial effects due to their nutritional properties and potential bioactive compounds. Bioactive compounds provide biological benefits to the bird by improving physiological functions (Muir et al., 2013) and are present in both vegetable and animal protein sources. For example, animal tissue cells contain bioactive compounds called polyamines (Smith et al., 2000), which are synthesized from ornithine and methionine, and are essential for cell growth (Smith et al., 1996). The presence of these compounds in the feed due to the addition of animal protein may benefit the performance of poults.

Combining protein sources in turkey pre-starter diets may improve turkey performance due to a reduction in the effects of SBM ANF and/or positive effects of other high protein ingredients. Further, the age effect on digestibility may vary with diet protein source, which in turn will influence accuracy of feed formulation and the selection of ingredients. To increase the accuracy of diet formulation and provide additional digestibility data on high protein ingredients, their nutritive values (apparent ileal amino acid digestibility [AIAAD] and nitrogen corrected apparent metabolizable energy [AMEn]) were determined using 5 and 21 d-old broiler chicks. Subsequently, performance was compared for poults fed a diet containing SBM as the sole protein source to diets where 25% of the protein provided by SBM was replaced by one of 2 animal-based (rendered) products (fish meal [FM] and porcine meal [PCM]) or one of 2 plant-based protein sources (corn gluten meal [CGM] and canola protein concentrate [CPC]). It was hypothesized that protein source digestibility increases with age on an ingredient specific basis, that reducing SBM in pre-starter diets by including other protein sources improves poult performance, and birds fed PCM and FM diets will outperform those fed CPC and CGM.

2. Materials and methods

The experimental procedures used in this research were approved by the University of Saskatchewan Animal Research Ethics Board. Animals were cared for according to the Canadian Council on Animal Care guidelines On the Care and Use of Farm Animals in Research, Teaching, and Testing (CCAC, 2009).

2.1. Digestibility assay

2.1.1. Birds and housing

Male Ross 308 × 308 broiler chicks were obtained from a commercial hatchery at the day of hatch (Lilydale, Wynyard, Canada) and used to determine AMEn and AIAAD at 5 and 21 d of age. For 5 d AMEn and AIAAD, 1,080 birds were randomly assigned to 72 Jamesway battery brooder cages (50 cm wide × 85 cm long × 25 cm high) at the day of hatch (d 0). Each cage containing 15 birds was randomly assigned to one of 6 treatments, with 12 replication cages per treatment. An additional 288 birds used for d 21 digestibility were placed in a floor pen until random allocation to one of 72 battery cages (4 birds per cage) on d 5. Room temperature was initially set at 32 °C and then gradually decreased by 3 °C every week. Birds were exposed to 20 h of light at light intensity 20 lx and 4 h of dark during the experiment. Feed and water were supplied *ad libitum* throughout the experiment. Cages were checked daily for mortality.

2.1.2. Dietary treatments

The d-5 digestibility chicks were fed experimental diets from d 0 to 5. The d-21 digestibility chicks were fed a commercial starter diet from d 0 until 15, after which they were given the experimental diets. Six treatment diets were fed in this experiment (Table 1) and all protein concentrates were analyzed for AA and mineral content prior to diet formulations (Table 2). The protein sources used were SBM, CGM, CPC, FM and PCM. The CPC was an experimental ingredient created by solubilizing canola meal protein in water, treating with phytase to remove phytate and then filtering to remove hulls. Protein sources were included at 40% of the diet in exchange for corn, SBM, and canola oil in the basal diet. Diets were fed as a mash with 1.5% celite added as an indigestible marker.

Table 1
Ingredients and composition of test diets on an as-is basis for apparent ileal amino acid digestibility and AMEn (%).

Item	Diets					
	Basal	SBM	CGM	CPC	FM	PCM
Ingredients						
Corn	80.41	46.41	46.41	46.41	46.41	46.41
Soybean meal	13.31	47.68	7.68	7.68	7.68	7.68
CGM	–	–	40.00	–	–	–
CPC	–	–	–	40.00	–	–
FM	–	–	–	–	40.00	–
PCM	–	–	–	–	–	40.00
Canola oil	0.88	0.51	0.51	0.51	0.51	0.51
Dicalcium phosphate	1.63	1.63	1.63	1.63	1.63	1.63
Limestone	1.35	1.35	1.35	1.35	1.35	1.35
Celite	1.50	1.50	1.50	1.50	1.50	1.50
Vitamin/mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.32	0.32	0.32	0.32	0.32	0.32
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10
Calculated nutrient composition						
ME, kcal/kg	3,075	2,703	3,263	2,917	2,903	3,263
Crude protein	14.00	27.32	34.80	32.52	32.80	28.60
Calcium	1.05	1.05	1.05	1.14	1.57	2.48
Chloride	0.22	0.22	0.22	0.22	0.22	0.22
Available phosphorous	0.56	0.55	0.43	0.65	1.14	1.62
Potassium	0.51	1.09	0.43	0.40	0.64	0.43
Sodium	0.17	0.23	0.16	0.25	0.75	0.16

AMEn = nitrogen-corrected apparent metabolizable energy; SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal.

[1] Supplied per kilogram of diet: 11,000 IU vitamin A; 2,200 IU vitamin D_3; 300 IU vitamin E; 2.0 mg menadione; 1.5 mg thiamine; 6.0 mg riboflavin; 60.0 mg niacin; 4.0 mg pyridoxine; 0.02 mg vitamin B_{12}; 10 mg pantothenic acid; 0.6 mg folic acid; 0.15 mg biotin; 80 mg iron; 80 mg zinc; 80 mg manganese; 10 mg copper; 0.8 mg iodine; 0.3 mg selenium.

Table 2
Analyzed nutrient content of protein sources on an as-is basis (%).

Item	SBM	CGM	CPC	FM	PCM
Crude Protein	47.30	66.00	60.30	61.20	49.40
Alanine	1.99	5.19	2.82	3.88	3.69
Arginine	3.79	2.33	4.11	4.64	3.91
Cysteine	0.74	1.06	1.18	0.56	0.48
Glycine	1.80	1.66	3.32	4.07	6.28
Histidine	1.51	1.18	1.17	1.71	1.42
Isoleucine	2.21	2.45	2.91	2.84	1.79
Leucine	3.73	10.40	5.28	4.99	3.65
Lysine	2.98	1.03	3.41	5.68	3.52
Methionine	0.63	1.47	1.27	1.64	0.90
Phenylalanine	2.48	4.07	3.26	2.88	2.15
Proline	2.46	5.53	3.53	2.97	4.05
Serine	2.54	3.44	3.09	2.71	2.22
Threonine	1.88	2.19	2.38	2.68	1.67
Tyrosine	2.01	3.61	2.14	2.39	1.51
Valine	2.20	2.76	3.41	3.21	2.34
Minerals					
Calcium	0.38	0.14	0.97	3.81	6.43
Total phosphorus	0.54	0.28	1.06	2.25	3.92
Sodium	0.19	0.07	1.08	1.50	0.47
Potassium	2.27	0.26	0.40	0.88	0.53

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal.

2.1.3. Data collection

Body weight gain and feed consumption were measured on a cage basis from d 0 to 5 for d-5 digestibility and d 15 to 21 for d-21 digestibility. Excreta was collected 4 times over 48 h on plastic sheets placed under each cage beginning on d 3 for d-5 digestibility birds and on d 19 for d-21 digestibility birds. The samples were dried in a forced air oven at 55 °C, pooled on a cage basis, and ground (1.0-mm screen) using a Retsch grinder (Hann, Germany). Following grinding and prior to chemical analysis, samples from 2 cages were pooled to create a total of 6 replications per treatment for analysis. The samples were analyzed in duplicate for dry matter (AOAC, 2006) using method 930.15. Samples were analyzed for N using a Leco nitrogen analyzer (Model 601–500–100, Serial # 3211, Leco Corporation, St. Joseph, MA, USA) according to the AOAC (2006) combustion method 990.03, and N values were converted to crude protein using 6.25 as the conversion factor. Acid insoluble ash was determined as described previously (Vogtmann et al., 1975), and gross energy was determined with a bomb calorimeter (Parr 1261 bomb calorimeter, Parr Instruments Co., Moline, IL). Analyzed values were used to calculate AMEn of the ingredients at d 5 and 21 as described by Scott et al. (1998).

On d 5 and 21, the birds were euthanized by cervical dislocation and the contents were collected from the distal 50% of the ileum, following the removal of 1 cm adjacent to the ileo-caecal junction. The ileal contents were gently squeezed into collection vials, pooled on a cage basis, immediately frozen at −20 °C and then freeze-dried. Following freeze-drying, the samples were ground using a mortar and pestle and analyzed for dry matter, crude protein, AA (AOAC, 2006) and acid insoluble ash. Apparent ileal amino acid digestibility coefficients (AIAADC) were calculated for d 5 and 21 collections as proposed by Ten Doeschate et al. (1993).

2.2. Production trial

2.2.1. Birds and housing

The timing of actual poult hatch and initial feeding can affect digestive tract development. To reduce this influence on the experiment, poult hatch times were recorded to permit equal distribution of poults to treatments based on hatch time, and initial feeding 24 h after a 28 d incubation period. Hybrid converter turkey eggs (1,500) were obtained from a commercial hatchery (Lilydale, Edmonton, Canada) and hatched at the University of Saskatchewan Poultry Centre. At 11 d of incubation, the eggs were candled and eggs with no evidence of living embryos were removed. On d 25 of incubation, the eggs were transferred from the incubator to the hatchers. Beginning at 26 d + 10 h of incubation and ending at 28 d + 4 h, the hatchers were checked every 6 h for hatched poults. Poults completely emerged from the eggshell and greater than 80% dry, were placed in cardboard poult boxes until the time of placement. Poult vent temperature was monitored periodically from hatch removal to placement to confirm the temperatures were approximately 40 °C. All poults were individually wing banded and wing bands were recorded at time of hatch to allow for tracking of hatch time. Twenty-four hours following the 28 d incubation period, 460 poults (mixed sex) were randomly assigned to one of 20 pens (4.5 m^2), while ensuring that the proportion of poults from each hatch window was the same in all pens. Shavings were added to the pens at a minimum depth of 7.5 cm and a heat lamp was provided in each pen for the first 7 d. Room temperature was 32 °C at bird placement and subsequently decreased 0.5 °C each day. Light was provided for 23 h at an intensity of 20 lx for the first 7 d, after which birds received 18 h of light per day at an intensity of 10 lux. Water was provided *ad libitum* to the poults in 4 L plastic fount drinkers. One drinker was provided in each pen for the first 7 d, after which a second drinker of the same style was added for the remainder of the trial. Pens were checked for mortality and bird morbidity twice daily, and dead and culled poults were removed and sent for necropsy to determine cause of death or illness (Prairie Diagnostic Services, Western College of Veterinary Medicine, University of Saskatchewan). Feed was provided *ad libitum* in one tube feeder (36 cm diameter) per pen for the duration of the trial. Supplemental feed was provided in flip-top plastic feeders (10.16 cm × 50.80 cm × 7.62 cm) for the first 7 d.

2.2.2. Dietary treatments

Each pen was randomly assigned one of 5 treatment diets (Table 3) for the duration of the trial. A basal wheat-SBM diet was formulated to meet Hybrid requirements (Hybrid, 2013). Because the digestible AA requirements for turkey poults are based on digestibility values derived from older animals, the 21 d determined digestibility values were used in feed formulation. The decision to use d 21 values for the first 3 wk was made in order to create a practical, commercially applicable diet. The remaining 4 diets were formulated by calculating the percentage of protein being supplied by the SBM in the basal diet and mathematically substituting one of 4 alternative ingredients to replace 25% of the protein SBM was contributing. The alternative ingredients were CGM, CPC, FM and PCM. All diets were analyzed using AOAC International (2006) methods for the following nutrients: moisture (method 930.15), crude protein (method 990.03), and minerals (method 985.01), and analyzed minerals were calcium, phosphorus, potassium, sodium and chloride. All diets were formulated on a digestible AA basis and met the minimum values in the Hybrid requirements (Hybrid Turkeys, 2013). Analyzed diet nutrient values approximated calculated values shown in Table 3. An exception was the analyzed sodium value of 0.15% in the CPC diet which was 0.03% below the expected value. Diets were fed as a crumble.

2.2.3. Data collection

Feed intake (pen basis) was measured weekly for the duration of the trial. All water added to the drinkers was weighed and all drinkers were weighed every 24 h to determine daily water intake. Water consumption was corrected daily for evaporation loss using 4 drinkers placed outside of the pens throughout the barn. The evaporation values were an average of 130 g for wk 1, and 100 g for

Table 3
Ingredients and composition of test diets for the turkey production trial (%, as-is basis).

Item	Diets				
	SBM	CGM	CPC	FM	PCM
Ingredients					
SBM	46.97	35.23	35.23	34.69	35.23
Wheat	40.63	44.79	45.74	48.30	47.31
CGM	–	8.74	–	–	–
CPC	–	–	8.27	–	–
FM	–	–	–	8.00	–
PCM	–	–	–	–	9.59
Canola oil	4.23	2.8	3.11	2.52	2.20
Monophosphate dicalcium	2.74	2.77	2.35	1.66	0.98
Limestone	2.13	2.18	2.19	1.9	1.36
DL-methionine	0.47	0.35	0.38	0.4	0.46
Salt	0.39	0.38	0.16	0.11	0.28
Threonine	0.06	0.05	0.06	0.05	0.1
Lysine HCl	0.02	0.35	0.15	0.01	0.13
Celite	1.50	1.50	1.50	1.50	1.50
Ameri-Bond 2X[1]	0.50	0.50	0.50	0.50	0.50
Vitamin/mineral premix[2]	0.23	0.23	0.23	0.23	0.23
Choline chloride	0.10	0.10	0.10	0.10	0.10
Endofeed W[3]	0.03	0.03	0.03	0.03	0.03
Calculated nutrient composition					
AME, kcal/kg	2,850	2,850	2,850	2,850	2,850
Crude protein	27.7	28.6	28.6	28.5	28.8
Crude fat	5.40	4.20	4.40	4.50	4.10
Calcium	1.40	1.40	1.40	1.40	1.40
Chloride	0.29	0.28	0.18	0.17	0.31
Available phosphorus	0.75	0.75	0.75	0.75	0.75
Potassium	1.12	0.93	0.94	0.98	0.96
Sodium	0.18	0.18	0.18	0.19	0.18
Digestible arginine	1.85	1.68	1.79	1.81	1.81
Digestible lysine	1.62	1.62	1.62	1.62	1.62
Digestible methionine	0.78	0.74	0.74	0.79	0.79
Digestible methionine & cysteine	1.05	1.05	1.05	1.05	1.05
Digestible threonine	0.96	0.96	1.17	0.96	0.96
Dietary electrolyte balance, mEq/kg	340.3	286.1	284.4	288.9	277.2

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; AME = apparent metabolizable energy.
[1] Ameri-Bond 2X:100% lignosulphonate (Borregaard LignoTech Feed Additives, New Jersey, USA).
[2] Vitamin/mineral premix supplied per kilogram of diet: 14,885 IU vitamin A; 5460 IU vitamin D_3; 100 IU vitamin E; 3.65 mg menadione; 4.15 mg thiamine; 26.78 mg riboflavin; 124.5 mg niacin; 6.75 mg pyridoxine; 0.04 mg vitamin B_{12}; 26.50 mg pantothenic acid; 2.65 mg folic acid; 0.51 mg biotin; 80.05 mg iron; 120.07 mg zinc; 120.08 mg manganese; 18.76 mg copper; 2.10 mg iodine; and 0.30 mg selenium.
[3] Endofeed W (GNC Bioferm Inc, Box 6, Bradwell, SK, Canada). This enzyme contains a minimum of 700 U/g of beta-glucanase and a minimum of 2,250 U/g of xylanase.

wk 2 and 3. Birds were group weighed on a pen basis on d 0, 7, 14 and 21. At the end of the trial, a sample of 30 birds per treatment (10 birds from 3 replication pens) was used to determine individual sexed body weight and breast meat yield. These data were used exclusively for the meat yield calculations to ensure that differences in sex ratios were not skewing the results. Contents of the distal ileum (as described previously) were also taken to determine moisture and osmolarity. Moisture was determined by weighing samples immediately after collection and then again after drying at 55 °C for 48 h in a forced air oven. Sample weights before and after drying were used to calculate percent moisture. For testing osmolarity, approximately 5 g of ileal content were transferred to a microfuge tube and centrifuged at 35,217 × *g* for 7 min in a Beckman Microfuge E 329210 (Beckman Coulter, Inc., Mississauga, ON, Canada). The supernatant was removed and microfuged again for an additional 5 min to ensure no particulates remained in the sample. The supernatant was poured into a new tube and osmolality was measured in duplicate using an osmometer (Advanced Model 3250 Single-Sample Osmometer, Advanced Instruments Inc., Norwood, MA, USA). Finally, at the end of the trial, the remainders of the birds were sexed to establish the gender proportions in each pen.

2.3. Statistical analysis

All data were analyzed using Proc Mixed in SAS 9.3. Differences were considered significant when $P \le 0.05$ and trends were identified when $P < 0.10$. When significant differences were observed, mean separation was completed using the Tukey method.

Data for AMEn and AIAAD were analyzed as a completely randomized design with a 5 (5 protein sources) × 2 (days of age) factorial arrangement to examine main effects (diet and age), as well as their interactions. Data were checked for normality prior to analysis. Data for the production trial were analyzed as a one-way analysis of variance, with 5 treatments and 4 replications, in a completely randomized design, with diet as the main effect. Data were transformed using (log+1) prior to analysis when normality assumptions were not met. Priori contrasts were also used to compare the SBM control diet to the average of CGM, CPC, FM, and PCM (contrast #1), PCM to the average of SBM, CGM, CPC, and FM (contrast #2), and the addition of vegetable (CGM and CPC) and animal protein (FM and PCM) (contrast #3). A one-way analysis of variance was also used to determine the effect of hatch window on final body weights, with the treatment being seven 4-h hatch windows.

3. Results

3.1. Apparent nutrient digestibility

Except for PCM, age did not affect protein source AMEn; the AMEn of PCM was lower on d 21 than d 5 (Table 4). Overall, there was a significant effect of treatment and age on digestibility of all AA, and interactions of main effects were significant for all AA except cysteine and lysine (Table 5). The ingredient with the highest average digestibility coefficient was SBM (0.82), followed by CGM (0.80) and CPC (0.80), FM (0.77), and PCM (0.70). Overall, AA digestibility increased 7% from d 5 to 21. Digestibility of all AA in SBM, CGM, and FM increased from d 5 to 21 (Table 6), with an average increase of 8.17%, 19.27%, and 7.75%, respectively (Table 7). Except for cysteine and serine, digestibility of all AA increased from d 5 to 21 in CPC with an overall average increase of 4.22%. In PCM, AIAAD increased for all AA except for alanine, arginine, glycine, histidine, and proline, with an overall average increase of 9.14%. The largest increase in average AIAAD from d 5 to 21 was observed for CGM, while the smallest increase was observed for CPC.

Table 4
Effect of age on AMEn of protein sources as determined in broiler chickens (kcal/kg).[1]

Treatment	Days of age		Pooled SEM	*P*-value
	5	21		
SBM	2,415	2,368	35.8	NS
CGM	3,745	3,726	30.3	NS
CPC	2,553	2,424	43.8	NS
FM	3,069	2,951	45.5	NS
PCM	2,723[a]	2,550[b]	36.7	0.0043

AMEn = nitrogen-corrected apparent metabolizable energy; SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; NS = not significant.
[a, b] Means within the same row with no common superscript differ significantly ($P \le 0.05$).
[1] Means of 6 replications; pooled excreta of 30 (5 d) or 8 (21 d) birds per replicate.

Table 5
Effect of protein source and age on apparent ileal amino acid digestibility coefficients[1] in broiler chickens.

Item	Meal					Days of age		Pooled	ANOVA *P*-value		
	SBM	CGM	CPC	FM	PCM	5	21	SEM	Meal	Age	Meal × Sex
Alanine	0.82	0.84	0.80	0.81	0.77	0.77	0.84	0.007	<0.0001	0.0001	0.0342
Arginine	0.89	0.87	0.86	0.82	0.78	0.82	0.87	0.007	<0.0001	<0.0001	0.0022
Cysteine	0.48^{c}	0.78^{a}	0.77^{a}	0.55^{b}	0.39^{d}	0.55^{b}	0.64^{a}	0.022	<0.0001	<0.0001	NS
Glycine	0.81	0.80	0.77	0.77	0.73	0.75	0.80	0.006	<0.0001	<0.0001	0.0029
Histidine	0.87	0.84	0.84	0.77	0.70	0.78	0.83	0.010	<0.0001	<0.0001	0.0025
Isoleucine	0.84	0.83	0.80	0.77	0.70	0.75	0.83	0.010	<0.0001	<0.0001	0.0009
Leucine	0.82	0.86	0.82	0.79	0.74	0.76	0.85	0.009	<0.0001	<0.0001	0.0002
Lysine	0.87^{a}	0.86^{a}	0.83^{b}	0.76^{c}	0.72^{d}	0.78^{b}	0.83^{a}	0.009	<0.0001	<0.0001	NS
Methionine	0.88	0.88	0.88	0.98	0.74	0.84	0.90	0.011	<0.0001	<0.0001	<0.0001
Phenylalanine	0.84	0.85	0.82	0.79	0.74	0.77	0.85	0.009	<0.0001	<0.0001	0.0033
Proline	0.82	0.85	0.80	0.76	0.69	0.75	0.82	0.010	<0.0001	<0.0001	0.0004
Serine	0.83	0.14	0.77	0.71	0.62	0.55	0.67	0.034	<0.0001	<0.0001	<0.0001
Threonine	0.79	0.82	0.77	0.75	0.66	0.72	0.80	0.010	<0.0001	<0.0001	0.0125
Tyrosine	0.86	0.88	0.88	0.80	0.74	0.79	0.87	0.009	<0.0001	<0.0001	0.0160
Valine	0.82	0.83	0.65	0.76	0.70	0.72	0.79	0.011	<0.0001	<0.0001	0.0011
Average	0.82	0.80	0.80	0.77	0.70	0.74	0.81				

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; NS = not significant.
[a-d] Means within the same row and main effect with no common superscript differ significantly ($P \leq 0.05$).
[1] Means of 6 replications; pooled ileal samples from 30 (5 d) or 8 (21 d) birds per replicate.

3.2. Production trial

3.2.1. Performance data

Hatch time affected d-21 body weight, with body weight increasing with increasing incubation time (Fig. 1). Analysis of variance suggested there was no effect of diet on production parameters except for mortality corrected gain to feed ratio in wk 2 where poults fed CGM were more efficient than those fed CPC (Table 8). There were trends for an effect of diet for several aspects of growth. Body weight at 14 d was highest for PCM ($P = 0.0645$) and similarly weight gain was highest for PCM and lowest for SBM during wk 1 ($P = 0.0752$) and wk 2 ($P = 0.0547$), respectively. Feed consumption also tended to be highest for PCM and lowest for SBM during wk 2 ($P = 0.0564$), as well as feed consumption for the duration of the trial ($P = 0.0889$). Mortality corrected gain to feed ratio showed a tendency to be improved in CGM as compared to CPC for the duration of the trial ($P = 0.0748$). There was no effect of treatment on mortality.

A priori contrast #1 (SBM vs. average of CGM, CPC, FM and PCM) showed that poults fed SBM had lower body weights at d 7 and 14 (177.3 and 419.4 g, respectively) and lower gains during wk 1 (116.6 g) as compared to the average of birds fed the remaining treatments (183.5, 433.1, and 123.0 g). Poults fed SBM showed a trend for growing more slowly during wk 2 in comparison to birds in other treatments ($P = 0.0972$).

Contrast #2 (PCM vs. the average of SBM, CGM, CPC, and FM) showed that birds fed PCM had heavier body weights at d 14 and 21 (443.5 and 843.1 g, respectively) than the average of remaining treatments (427.0 and 810.5 g, respectively), with a trend for increased body weights for poults fed PCM at d 7 ($P = 0.0631$). Increased gains were observed for the PCM treatment during wk 1, 2, and 3 (125.8, 257.5 and 399.6 g, respectively) than the average of the other treatments (120.7, 245.7 and 383.5 g, respectively). The PCM treatment also resulted in increased feed consumption during wk 2 (324.6 vs. 310.6 g), with a trend for increased consumption during wk 1 ($P = 0.0979$).

Table 6
Effect of protein source on amino acid content and apparent ileal amino acid digestibility coefficients in 5- and 21-d-old broiler chickens.[1]

Item	SBM			CGM			CPC			FM			PCM		
	Concentration, %[2]	5 d	21 d	Concentration, %[2]	5 d	21 d	Concentration, %[2]	5 d	21 d	Concentration, %[2]	5 d	21 d	Concentration, %[2]	5 d	21 d
Crude protein	47.3			66.0			60.3			61.2			49.4		
Alanine	1.99	0.77^{b}	0.86^{a}	5.19	0.78^{b}	0.89^{a}	2.82	0.77^{b}	0.82^{a}	3.88	0.79^{b}	0.84^{a}	3.69	0.75	0.79
Arginine	3.79	0.87^{b}	0.91^{a}	2.33	0.82^{b}	0.93^{a}	4.11	0.84^{b}	0.87^{a}	4.64	0.80^{b}	0.84^{a}	3.91	0.76	0.80
Cysteine	0.74	0.45^{b}	0.52^{a}	1.06	0.72^{b}	0.84^{a}	1.18	0.76	0.79	0.56	0.50^{b}	0.61^{a}	0.48	0.33^{b}	0.45^{a}
Glycine	1.80	0.77^{b}	0.84^{a}	1.66	0.76^{b}	0.85^{a}	3.32	0.76^{b}	0.79^{a}	4.07	0.75^{b}	0.79^{a}	6.28	0.73	0.73
Histidine	1.51	0.84^{b}	0.90^{a}	1.18	0.79^{b}	0.90^{a}	1.17	0.84^{b}	0.85^{a}	1.71	0.75^{b}	0.80^{a}	1.42	0.68	0.72
Isoleucine	2.21	0.81^{b}	0.88^{a}	2.45	0.76^{b}	0.91^{a}	2.91	0.77^{b}	0.82^{a}	2.84	0.74^{b}	0.80^{a}	1.79	0.67^{b}	0.74^{a}
Leucine	3.73	0.78^{b}	0.86^{a}	10.4	0.78^{b}	0.94^{a}	5.28	0.80^{b}	0.84^{a}	4.99	0.76^{b}	0.83^{a}	3.65	0.70^{b}	0.77^{a}
Lysine	2.98	0.84^{b}	0.90^{a}	1.03	0.83^{b}	0.90^{a}	3.41	0.81^{b}	0.84^{a}	5.68	0.74^{b}	0.78^{a}	3.52	0.70^{b}	0.75^{a}
Methionine	0.63	0.84^{b}	0.92^{a}	1.47	0.82^{b}	0.94^{a}	1.27	0.86^{b}	0.89^{a}	1.64	0.97^{b}	0.98^{a}	0.90	0.71^{b}	0.78^{a}
Phenylalanine	2.48	0.80^{b}	0.87^{a}	4.07	0.78^{b}	0.93^{a}	3.26	0.80^{b}	0.85^{a}	2.88	0.75^{b}	0.83^{a}	2.15	0.70^{b}	0.78^{a}
Proline	2.46	0.78^{b}	0.86^{a}	5.53	0.78^{b}	0.91^{a}	3.53	0.78^{b}	0.82^{a}	2.97	0.72^{b}	0.79^{a}	4.05	0.68	0.70
Serine	2.54	0.80^{b}	0.86^{a}	3.44	−0.02^{b}	0.31^{a}	3.09	0.76	0.79	2.71	0.67^{b}	0.75^{a}	2.22	0.57^{b}	0.67^{a}
Threonine	1.88	0.76^{b}	0.83^{a}	2.19	0.75^{b}	0.88^{a}	2.38	0.75^{b}	0.79^{a}	2.68	0.71^{b}	0.78^{a}	1.67	0.61^{b}	0.70^{a}
Tyrosine	2.01	0.84^{b}	0.89^{a}	3.61	0.82^{b}	0.93^{a}	2.14	0.86^{b}	0.90^{a}	2.39	0.76^{b}	0.83^{a}	1.51	0.70^{b}	0.78^{a}
Valine	2.20	0.79^{b}	0.86^{a}	2.76	0.77^{b}	0.90^{a}	3.41	0.64^{b}	0.66^{a}	3.21	0.73^{b}	0.79^{a}	2.34	0.67^{b}	0.74^{a}
Average		0.78	0.85		0.73	0.90		0.79	0.82		0.74	0.80		0.66	0.73

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal.
[a, b] Means within the same row and protein source with no common superscript differ significantly ($P \leq 0.05$).
[1] Means of 6 replications; pooled ileal samples from 30 (5 d) or 8 (21 d) birds per replicate.
[2] Concentration of nutrient in protein source samples.

Table 7
Increases[1] of apparent ileal amino acid digestibility coefficients[2] of protein sources from d 5 to 21 (%).

Item	Treatment				
	SBM	CGM	CPC	FM	PCM
Alanine	10.47	12.34	6.10	5.95	5.06
Arginine	4.40	11.83	3.45	4.76	5.00
Cysteine	13.46	14.29	3.80	18.03	26.67
Glycine	8.33	10.59	3.80	5.06	0.00
Histidine	6.67	12.22	1.18	6.25	5.56
Isoleucine	7.95	16.48	6.10	7.50	9.46
Leucine	9.30	17.02	4.76	8.43	9.09
Lysine	6.67	7.78	3.57	5.13	6.67
Methionine	8.70	12.77	3.37	1.02	8.97
Phenylalanine	8.05	16.13	5.88	9.64	10.26
Proline	9.30	14.29	4.88	8.86	2.86
Serine	6.98	102.30	3.80	10.67	14.92
Threonine	8.43	14.77	5.06	8.97	12.86
Tyrosine	5.62	11.83	4.44	8.43	10.26
Valine	8.14	14.44	3.03	7.59	9.46
Average[3]	8.17	19.27	4.22	7.75	9.14

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal.
[1] Percentage increase calculated as: (d 21 digestibility − d 5 digestibility)/d 21 digestibility × 100.
[2] Means of 6 replications; pooled ileal samples from 30 (5 d) or 8 (21 d) birds per replicate.
[3] Average percentage increase of apparent ileal amino acid digestibility coefficients of CGM is 13.34%, when serine is removed from the calculation.

Body weight, body weight gain, feed consumption, mortality corrected gain:feed ratio, and mortality were not affected by feeding a vegetable (CGM and CPC) vs. an animal (FM and PCM) protein source (contrast #3). There was a trend for animal protein treatments to produce increased gain (393.4 vs. 382.1 g) during wk 3 of the trial ($P = 0.0868$).

Breast meat yields on an absolute weight and a percentage of live weight basis are presented in Table 9. On an absolute basis, males had heavier total breast meat and breast meat portions than females. Contrast #2 (PCM vs. the average of SBM, CGM, CPC, and FM) demonstrated that PCM resulted in heavier total breast and pectoralis major values (153.4 and 124.5 g) in comparison to the means for the other protein treatments (147.3 and 119.1 g). Breast meat yield as a percentage of live weight was not affected by dietary treatment, but females showed increased yield of total breast and breast portions. A priori contrasts did not show a significant effect of dietary treatment on proportional breast meat yield.

3.2.2. Water consumption and terminal ileum digesta moisture content and osmolarity

Dietary treatment only affected evaporation corrected water consumption for wk 2, with poults fed CPC drinking more than those fed FM; all other treatments were intermediate and not different from the extreme values (Table 10). Water to feed ratio was affected by treatment for wk 2 with the CPC treatment resulting in a higher ratio compared to all treatments except FM. Further, the water to feed ratio was higher for SBM than the values recorded for CGM and PCM. For wk 3, the CPC treatment resulted in a higher water to feed ratio than SBM and FM, while CGM and PCM values were intermediate. For wk 2, CPC had the highest water to gain ratio, followed by SBM, and CGM, FM, and PCM treatments resulting in the lowest values. For wk 3, the CPC treatment water to gain ratio was higher than the SBM and PCM treatments; the values for CGM and FM were intermediate and not different than the previously mentioned treatments. The distal ileum digesta moisture content at d 21 was higher for SBM poults as compared to PCM birds, while CGM, CPC and FM values were intermediate and not different than SBM and PCM treatments. Terminal ileum digesta osmolarity at d 21 was not affected by treatment.

A priori contrast #1 revealed poults fed SBM had increased ileal digesta moisture at d 21 (81.1%) as compared to the other 4 treatments (79.8%). Identified trends were a decreased water to feed ratio during wk 3 ($P = 0.0912$) and an increased mortality corrected water to gain ratio during wk 2 ($P = 0.0672$) for the SBM treatment. No differences were observed between SBM and the remaining treatments for evaporation corrected water consumption, water to feed ratio during wk 1 and 2, mortality corrected water to gain ratio during wk 1 and 3, and terminal ileum digesta osmolarity at d 21.

Contrast #2 showed that PCM had a lower water to feed ratio (2.42) during wk 2, mortality corrected water to gain ratio in wk 2 (3.02), and terminal ileum digesta moisture at d 21 (78.8%), than the other 4 treatments (2.61, 3.29, and 80.4%, respectively). No difference was identified between PCM and the remaining treatments for evaporation corrected water consumption, water to feed ratio during wk 1 and 3, mortality corrected water to gain ratio during wk 1 and 3, and terminal ileum digesta osmolarity at d 21.

Contrast #3 revealed no difference between vegetable and animal protein for all water consumption parameters during the first week, as well as in terminal ileum digesta osmolarity at d 21. There was an effect during the second and third week of the trial. Evaporation corrected water consumption was increased during wk 2 and 3 in vegetable protein diets (843.8 and 1,301.7 g, respectively)

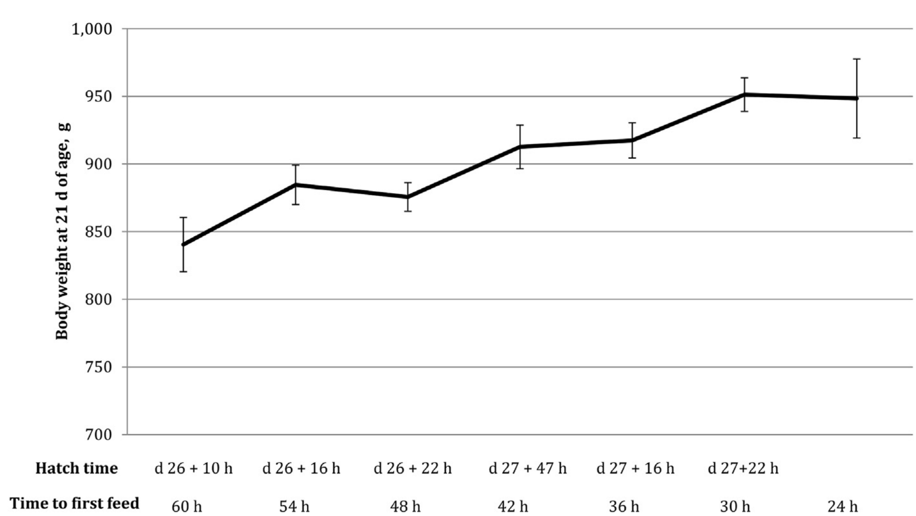

Fig. 1. Effect of hatch time on body weight of turkey poults at 21 d of age. d $n + n$ h = day and hour of incubation at hatch pull.

Table 8
Effect of treatment on production parameters in turkey poults from 0 to 3 wk of age.

Item	Meal					Pooled	ANOVA	Contrast[1] (*P*-values)		
	SBM	CGM	CPC	FM	PCM	SEM	*P*-value	#1	#2	#3
Body weight, g										
Week 0	60.7	60.9	60.7	60.3	60.2	0.0002	0.7064	NS	NS	NS
Week 1	177.3	183.0	183.3	181.5	186.0	0.0011	0.1065	0.0197	0.0631	NS
Week 2	419.4	432.9	431.7	424.1	443.5	0.0029	0.0645	0.0433	0.0173	NS
Week 3	801.9	814.2	814.6	811.2	843.1	0.0052	0.1111	NS	0.0125	NS
Average gain, g										
Week 1	116.6	122.2	122.7	121.2	125.8	0.0011	0.0752	0.0141	0.0396	NS
Week 2	242.1	249.8	248.3	242.6	257.5	0.0019	0.0547	0.0972	0.0112	NS
Week 3	382.5	381.3	382.9	387.1	399.6	0.0029	0.2494	NS	0.0328	0.0868
Week 1 to 3	741.3	753.3	753.9	751.0	782.9	0.0052	0.1035	NS	0.0113	NS
Feed consumption, g										
Week 1	128.7	130.0	135.7	133.6	136.7	0.0012	0.1213	NS	0.0979	NS
Week 2	304.6	311.5	322.3	303.9	324.6	0.0003	0.0564	NS	0.0421	NS
Week 3	532.4	530.4	556.2	540.1	551.9	0.0042	0.2055	NS	NS	NS
Week 1 to 3	965.7	971.9	1014.2	977.7	1013.3	0.0076	0.0889	NS	NS	NS
Mortality corrected gain to feed ratio										
Week 1	0.9034	0.9437	0.9036	0.9293	0.9192	0.0083	0.5009	NS	NS	NS
Week 2	0.7946[ab]	0.8022[a]	0.7708[b]	0.7988[ab]	0.7985[ab]	0.0037	0.0270	NS	NS	NS
Week 3	0.7183	0.7191	0.6889	0.7179	0.7241	0.0055	0.2657	NS	NS	NS
Week 1 to 3	0.7670	0.7757	0.7436	0.7730	0.7745	0.0049	0.0748	NS	NS	NS
Mortality, %										
Week 1	3.3	3.3	6.5	6.5	6.5	1.0685	0.7886	NS	NS	NS
Week 2	0.0	0.0	0.0	0.0	2.2	0.4348	0.4380	NS	NS	NS
Week 3	0.0	0.0	0.0	0.0	0.0	0.0000	–	–	–	–
Week 1 to 3	3.3	3.3	6.5	6.5	8.7	1.3110	0.7529	NS	NS	NS

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; NS = not significant.
[a, b] Means within the same row with no common superscript differ significantly ($P \leq 0.05$) with means of 4 replications of 23 birds per replicate.
[1] Contrast #1: SBM versus the average of CGM, CPC, FM, and PCM; contrast #2: PCM vs. the average of SBM, CGM, CPC, and FM; contrast #3: vegetable (CGM and CPC) vs. animal (FM and PCM) addition to SBM.

when compared to animal protein diets (732.3 and 1,190.5 g, respectively). The same effect was observed in water to feed ratio during wk 2 and 3 with 2.66 and 2.43, respectively for vegetable protein diets and 2.46 and 2.22, respectively for animal protein diets. This effect was also seen for mortality corrected water to gain ratio during wk 2 and 3 with 3.41 and 3.47, respectively, for vegetable protein diets and 3.03 and 3.13 for animal protein diets. Finally, birds consuming vegetable protein diets had higher terminal digesta moisture at d 21 (80.4%) than birds consuming animal protein diets (79.3%).

4. Discussion

4.1. Apparent nutrient digestibility

Bird age can impact nutrient digestibility, but the nature and extent of this effect is related to age in combination with the ingredients being assessed (Batal and Parsons, 2002; Adeola et al., 2018). Changes in digestibility due to age (from d 2 to 21) are shown in research on the AMEn of maize, wheat and sorghum-based diets in broiler chicks (Thomas et al., 2008). The AMEn was high following hatch, then decreased to d 6, and subsequently increased to d 21 (Thomas et al., 2008). Similar patterns of energy and amino acid digestibility were shown by Batal and Parsons (2002) for a maize-SBM based diet fed to broilers. These data demonstrate that age comparisons are affected by the specific ages being used and therefore comparisons of the present data with other research must keep this in mind. Lopez and Leeson (2008) reported no effect of age on SBM AMEn, which was confirmed in this study. However, the latter study compared 9- to 12- and 30- to 33-d-old chicks, and it is probable that full digestive capacity required for maximum digestibility had been attained at both ages (Batal and Parsons, 2002). In general terms, AMEn is high from hatch to 5 d, then decreases between d 6 to 8 and then increases until a plateau is reached at 14 d. This may explain why there was no effect of age on SBM AMEn in the current study, as

Table 9
Effect of protein source on breast meat yield of turkey poults at 3 wk of age.

Item	Meal					Sex		Pooled SEM	ANOVA *P*-value			Contrast[1] (*P*-values)		
	SBM	CGM	CPC	FM	PCM	Male	Female		Meal	Sex	Meal × Sex	#1	#2	#3
Total BM, g	147.0	146.1	148.7	147.2	153.4	152.8[a]	144.1[b]	1.23	NS	0.0005	NS	NS	0.0470	NS
P. maj., g	118.6	118.0	120.4	119.3	124.5	124.0[a]	116.4[b]	1.03	NS	0.0003	NS	NS	0.0356	NS
P. min., g	28.4	28.1	28.3	27.8	28.9	28.8[a]	27.8[b]	0.23	NS	0.0251	NS	NS	NS	NS
BM, as % LW	16.6	16.4	16.8	16.6	16.7	16.4[b]	16.9[a]	0.06	NS	0.0001	NS	NS	NS	NS
P. maj., as % LW	13.4	13.2	13.6	13.5	13.6	13.3[b]	13.6[a]	0.05	NS	0.0025	NS	NS	NS	NS
P. min., as % LW	3.2	3.2	3.2	3.1	3.2	3.1[b]	3.2[a]	0.02	NS	<0.0001	NS	NS	NS	NS

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; BM = breast meat; NS = not significant; P. maj. = pectoralis major; P. min. = pectoralis minor; LW = live weight.
[a, b] Means within the same row per main effect group with different superscripts are significantly different ($P < 0.05$) with means of 3 replications of 10 birds per replicate.
[1] Contrast #1: SBM versus the average of CGM, CPC, FM, and PCM; contrast #2: PCM vs. the average of SBM, CGM, CPC, and FM; contrast #3: vegetable (CGM and CPC) vs. animal (FM and PCM) addition to SBM.

Table 10
Effect of treatment on water consumption in turkey poults from 1 to 3 wk of age.

Item	Meal					Pooled	ANOVA	Contrast[1] (*P*-values)		
	SBM	CGM	CPC	FM	PCM	SEM	*P*-value	#1	#2	#3
Evaporation corrected water consumption, g/bird										
Week 1	432.7	444.9	467.0	438.2	449.0	6.91	NS	NS	NS	NS
Week 2	777.7[ab]	741.9[ab]	945.7[a]	684.3[b]	780.2[ab]	33.20	0.0149	NS	NS	0.0204
Week 3	1142.6	1232.5	1370.9	1175.1	1205.9	29.05	NS	NS	NS	0.0407
Water to feed ratio										
Week 1	3.39	3.44	3.45	3.36	3.33	0.046	NS	NS	NS	NS
Week 2	2.60[b]	2.43[c]	2.89[a]	2.50[bc]	2.42[c]	0.059	0.0002	NS	0.0006	0.0008
Week 3	2.12[b]	2.31[ab]	2.55[a]	2.20[b]	2.24[b]	0.052	0.0221	0.0912	NS	0.0152
Mortality corrected water to gain ratio										
Week 1	3.75	3.65	3.81	3.43	3.63	0.058	NS	NS	NS	NS
Week 2	3.29[b]	3.00[c]	3.82[a]	3.03[c]	3.02[c]	0.101	<0.0001	0.0672	0.0003	0.0001
Week 3	2.92[b]	3.22[ab]	3.72[a]	3.17[ab]	3.09[b]	0.098	0.0267	NS	NS	0.0311
Distal ileum digesta moisture at d 21, %										
	81.1[a]	79.7[ab]	81.0[ab]	79.7[ab]	78.8[b]	0.28	0.0303	0.0409	0.0143	0.0458
Distal ileum digesta osmolarity at d 21, mOsm/kg										
	411.1	389.6	388.6	396.3	394.3	4.59	NS	NS	NS	NS

SBM = soybean meal; CGM = corn gluten meal; CPC = canola protein concentrate; FM = fish meal; PCM = porcine meal; NS = not significant.
[a–c] Means within the same row with no common superscript differ significantly ($P \leq 0.05$) with means of 4 replications of 23 birds per replicate.
[1] Contrast #1: SBM versus the average of CGM, CPC, FM, and PCM; contrast #2: PCM vs. the average of SBM, CGM, CPC, and FM; contrast #3: vegetable (CGM and CPC) vs. animal (FM and PCM) addition to SBM.

AMEn values at d 5 (excreta collection from d 3 to 5) and d 21 (excreta collection from d 19 to 21) may be similar due to the timing of the decrease and subsequent increase of AMEn. Other factors which may contribute to differences in AMEn with age include digestive enzyme secretion and nutrient absorption capacity as the animal ages (Dibner et al., 1996; Sklan and Noy, 2000). Research on the effect of young age on AMEn might also be influenced by factors such as time from actual hatch (not hatch pull) and when feed is offered to the birds. This information is most often not included in publications, making comparisons less precise. The decrease in PCM AMEn value for 21-d-old broilers was unexpected in this study and does not agree with research reported by Adeola et al. (2018) for meat and bone meal where AMEn values had a quadratic response with age.

The AMEn values for FM, CGM, and SBM were similar to values reported in the literature (National Research Council, 1994). As there is no previous research examining PCM and this specific CPC in poultry, the AMEn values cannot be compared to previous literature. However, PCM and CPC have greater AMEn values than those reported for meat meal and canola meal (approximately 600 and 500 kcal/kg higher, respectively) in National Research Council (1994). The higher value for CPC is logical due to the higher protein and less fibre in this experimental product in comparison to CM.

The increase in AA digestibility with age reported by Huang et al. (2005) and Adedokun et al. (2008) was confirmed in our study. The variability observed between protein sources AA digestibility as the bird age also supports previous research findings (Huang et al., 2005; Adedokun et al., 2008). The increase in digestibility is likely attributed to the development of the gastrointestinal tract (GIT). The digestive capacity of birds after hatch is stimulated by feed consumption as indicated by rapid increases in digestive enzymes and nutrient transporters after the initiation of feed intake (Sklan and Noy, 2000). This significantly improves the bird's ability to hydrolyze dietary proteins and absorb resulting AA (Sklan and Noy, 2000). At a young age, the GIT is rapidly growing and its ability to effectively utilize diet nutrients similarly increases (Dibner et al., 1996). The combination of a maturing and functional GIT, and the rise in digestive enzymes works together to increase the ability of the bird to digest protein and therefore contributes to the increase in AA digestibility observed between d 5 and 21.

The 21 d digestibility coefficients in this study for FM, CGM, and SBM were similar to values found in the literature, as well as reference values (Degussa, 2005; Huang et al., 2005; Ravindran and Morel, 2006). Although the CPC was an experimental product, when the CPC digestibility values were compared to canola meal values, the results were similar (Huang et al., 2005). When PCM was compared to meat and bone meal values, the digestibility values for meat and bone meal tend to be higher than those found for PCM (Degussa, 2005; Huang et al., 2005). The reason for the digestibility difference between PCM and meat and bone meal is unknown, but is likely affected by the nature of raw material rendered and the rendering process itself.

The largest increase in AIAAD from d 5 to 21 was observed in CGM. This is an interesting observation because of the unique nature of CGM proteins. These unique properties, including low solubility in some solutions, are due to the presence of zein protein in corn (Shukla and Cheryan, 2001). Zein is difficult to solubilize in water, likely because it has a high proportion of non-polar AA and is lacking basic and acidic AA (Shukla and Cheryan, 2001). In addition, CGM was found to have a slower digestion rate than a variety of other protein sources in an *in vitro* digestion model (Bryan et al., 2018). Therefore, it is possible that CGM protein may be difficult to solubilize and digest in the immature digestive tract. Another response of interest in CGM is the negative digestibility value of serine at d 5. This response may be because serine is part of mucin and biliary acids (Cowieson et al., 2004; Horn et al., 2009), however, the same negative digestibility was not seen in other AA that make up mucin and biliary acids, such as cysteine, glycine, proline, and threonine. This result does not agree with previous research and there is no obvious reason for why this difference exists. A study by Kim et al. (2012) found serine digestibility in CGM to be between 85.3 and 92.4%, depending on the assay used, which is much higher than what was found in this research. Because of the negative digestibility value observed for serine at d 5, the overall age increase in AA digestibility in CGM is high at 19.3%. The increase, however, is still high when the serine digestibility is removed, with an overall increase in AA digestibility of 13.3%, remaining the highest increase when the 5 test ingredients are compared.

4.2. Production trial

4.2.1. Performance data

During the first 2 wk, birds fed SBM alone had lower body weights, decreased average gain and a trend for lower feed consumption for wk 1. This suggests that turkey poult growth is most susceptible to the negative effects of feeding high SBM diets during the first 14 d of life. The lack of difference between animal and vegetable protein sources for body weight, average gain, feed consumption, and mortality corrected gain to feed ratio indicates that regardless of the protein source being provided, supplementing a high SBM diet with a second protein source is beneficial to production parameters in turkeys. The results may also reflect the accuracy of amino acid availability data used to formulate experimental diets. The lack of protein source effect agrees with Vieira and Lima (2005) who did not observe a difference in performance between broilers fed all vegetable diets or diets containing meat meal.

The depressed performance observed with feeding high SBM levels could be attributed to the dietary concentration of ANF, such as protease inhibitors, lectins, non-starch polysaccharides, phytate, and potentially allergens. It has been demonstrated that protease inhibitors reduce broiler performance (Hoffmann et al., 2019) by inhibiting protein digestion (Palliyeguru et al., 2011), however, these compounds are heat labile and can be reduced during processing. There is minimal research into the critical level of protease inhibitors that will negatively affect poultry performance. However, a recent study by Hoffmann et al. (2019) suggested that dietary trypsin inhibitors levels above 2 mg/g reduce the performance of broilers fed heat-processed SBM. Lectins have the ability to bind dietary carbohydrates and enterocytes in the GIT (Fasina et al., 2003), potentially leading to an impairment of nutrient digestibility. Although protease inhibitors and lectins are drastically reduced during SBM processing, there are still residual levels present, which are highly dependent on the SBM processing temperature (Fasina et al., 2003). Phytate can also lead to impaired digestion and absorption of minerals (including phosphorus, calcium, magnesium, zinc, and iron), starch and protein by forming complexes that cannot be digested and absorbed (Selle et al., 2000). Phytate is not heat labile and would be present in the diet. The animal protein sources and CPC contain essentially no phytate, while CGM and SBM levels are approximately equal (She et al., 2015). The finding that early growth performance of CGM fed poults was higher than those fed SBM diet suggested phytate was not the factor responsible for slower growth in the latter treatment.

Performance could also be affected by imbalances in minerals or protein within the diet. All diets were balanced to the same calcium, phosphorus, sodium, and chloride levels. The most notable mineral difference was a higher potassium level for the SBM diet. The SBM diet contained 1.12% potassium, while the remaining diets ranged from 0.93% to 0.98% potassium. The dietary electrolyte balance ($Na^+ + K^+ - Cl^-$) in mEq/kg was calculated for all diets (Table 3). The electrolyte balance was higher in the SBM diet, due to the higher potassium levels in that diet, while values for the remaining diets were similar. The higher potassium level in the SBM feed may have caused poults to reduce their feed consumption, as they had the lowest overall consumption, which may have contributed to the reduced growth. This is, however, in disagreement with previous research conducted in broiler chickens (Borges et al., 2003; Ahmad et al., 2009), which concluded that increasing dietary electrolyte balance results in increased feed intake. The research concluded that an increase in the sodium levels in the diets is what is responsible for the increased dietary electrolyte balance, as well as causing the resulting increase in feed intake (Ahmad et al., 2009). This is different from the current study where an increase in potassium led to the increased dietary electrolyte balance and a reduced feed intake was observed. A second dietary factor that may have affected performance is a protein imbalance; however, all diets were balanced to have similar digestible arginine, lysine, methionine, methionine plus cysteine, and threonine levels (Table 3), so this should not have caused the negative impact on growth that was observed in the SBM diet. Further support for this interpretation is the lack of a diet effect on proportional breast meat yield.

4.2.2. Water consumption and terminal ileum digesta moisture content

The highest weekly and overall water consumption was seen for poults fed the CPC treatment. This treatment effect is difficult to explain, particularly because all diets were balanced to the same minimum mineral content. Sodium, calcium, phosphorus, and potassium were similar in the CPC, CGM, FM, and PCM treatments, yet water consumption was much higher in the CPC treatment. This indicates another component of the diet that was not assessed caused the birds on the CPC treatment to have a higher water intake.

Water consumption of poults on the SBM diet was not higher than birds fed PCM, which contradicts the finding that digesta moisture was significantly higher in SBM than PCM. This is also not in agreement with other research showing an increase in water intake and litter moisture for broiler chickens fed a diet containing only SBM in comparison to a diet with animal by-products (Vieira and Lima, 2005; Eichner et al., 2007). No effect on water intake may be partially explained by reduced body weight gain and feed intake for the SBM fed poults during wk 1 (contrast #1, $P = 0.0141$) and 2 (contrast #1, $P = 0.0972$). If CPC is excluded from the comparison, SBM had the numerically highest water to gain ratio for wk 1 (contrast #1, $P > 0.10$) and 2 (contrast #1, $P = 0.0672$), but the numerically lowest value for wk 3 (contrast #1, $P > 0.10$). It is possible that a factor or factors in SBM caused increased water consumption in the first 2 wk, but after that time poults were able to adapt. Despite the change in water to feed ratio, digesta moisture in the SBM treatment remained high at the end of wk 3. Possible reasons for the increased moisture content are higher levels of oligosaccharides (Graham et al., 2002) and potassium in SBM. The diets containing vegetable protein had increased water consumption, water to feed and water to gain ratios, and terminal ileum digesta moisture at d 21 in comparison to diets that included animal protein (contrast #3, $P < 0.05$). The elevated water consumption and excreta moisture in the vegetable fed diets was also observed by Vieira and Lima (2005).

Determining digestibility and energy levels for feed ingredients is the first step for their use in young turkey diets. The digestibility data from this study indicate that ingredients such as SBM and CPC provide highly digestible protein to poults. Choosing ingredients that are highly digestible for young turkey diets should be an advantage, because they should maximize early growth and development, while minimizing negative effects of indigestible protein. Large fractions of indigestible protein have been associated with poorer performance (Bryan et al., 2019) and impaired GIT development (Qaisrani et al., 2014; Apajalahti and Vienola, 2016). The digestibility data contradict the results from the performance trial in this study. Soybean meal inclusion at high levels reduced early poult growth, and increased water to gain ratio and digesta moisture, which can also have negative consequences. Adding a complementary protein source with SBM had a positive impact on performance, however, the best performance was observed when

PCM was added to SBM. This is an interesting result because PCM was one of the more poorly digestible ingredients tested. This research indicates that there are other factors in protein sources other than their digestibility which might be important when selecting high protein ingredients for young turkey diets.

4.3. Hatch window and early poult growth

This research was not designed to study hatch window effects on production. Rather, hatch window was equalized across treatments to reduce its impact on poult growth and digestive tract development. However, it was possible to see if hatch time affected growth rate. Fig. 1 clearly demonstrates that growth rate was negatively impacted by early hatch. These results are similar to research in meat-type chickens (Wyatt et al., 1985; Bergoug et al., 2013) and indicate that narrower hatch windows benefit early poult performance.

5. Conclusions

The AA digestibility of poultry protein sources (SBM, CGM, CPC, FM, and PCM) increased with broiler age in a protein source and specific amino acid manner, with the largest increase occurring for CGM. In contrast, AMEn values were either unaffected by age or showed a slight reduction at 21 d of age. The 21 d digestibility values were used to formulate diets containing only SBM or with 25% of the SBM protein replaced by one of the other protein sources, which were fed to turkey poults for 21 d after hatch. Growth rate of turkey poults during the first 2 wk of life was reduced when SBM was the only high protein source. Replacing 25% of the SBM protein improved poult growth, regardless of protein source choice or digestibility.

Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

Acknowledgements

The authors would like to acknowledge the Natural Sciences and Engineering Research Council of Canada (NSERC), Industrial Research Chair Program for financial support for this project (Grant No. IRCSA 452664-12). Funding for this program was derived from Aviagen, Canadian Poultry Research Council, Chicken Farmers of Saskatchewan, NSERC, Ontario Poultry Industry Council, Prairie Pride Natural Foods Ltd., Saskatchewan Egg Producers, Saskatchewan Hatching Egg Producers, Saskatchewan Turkey Producers, Sofina Foods Inc. and the University of Saskatchewan.

References

Adedokun SA, Adeola O, Parson CM, Lilburn MS, Applegate TJ. Standardized ileal amino acid digestibility of plant feedstuffs in broiler chickens and Turkey poults using a nitrogen-free or casein diet. Poult Sci 2008;87:2535–48.

Adeola O, Anwar MN, Abdollahi MR, Ravindran V. Age-related energy values of meat and bone meal for broiler chickens. Poult Sci 2018;97:2516–24.

Ahmad T, Mushtaq T, Khan MA, Babar ME, Yousaf M, Hasan ZU, Kamran Z. Influence of varying dietary electrolyte balance on broiler performance under tropical summer conditions. J Anim Physio An N 2009;93:613–21.

AOAC International. Official methods of analysis. 18th ed. Gaithersburg, MD: AOCA International; 2006.

Apajalahti J, Vienola K. Interaction between chicken intestinal microbiota and protein digestion. Anim Feed Sci Technol 2016;221:323–30.

Batal AB, Parsons CM. Effects of age on development of digestive organs and performance of chicks fed a corn-soybean meal versus a crystalline amino acid diet. Poult Sci 2002;81:1338–41.

Bergoug H, Burel C, Guinebretière M, Tong Q, Roulston N, Romanini CEB, Exadaktylos V, McGonnell IM, Demmers TGM, Verhelst R, Bahr C, Berckmans D, Eterradossi N. Effect of pre-incubation and incubation conditions on hatchability, hatch time and hatch window, and effect of post-hatch handling on chick quality at placement. World Poultry Sci J 2013;69:313–34.

Borges SA, Fischer da Silva AV, Ariki J, Hooge DM, Cummings KR. Dietary electrolyte balance for broiler chickens exposed to thermoneutral or heat-stress environments. Poult Sci 2003;82:42–435.

Bryan DDLS, Abbott DA, Classen HL. The influence of indigestible protein on the performance and meat quality of broilers vaccinated for coccidiosis. Poult Sci 2019;98:4815–28. https://doi.org/10.3382/ps/pez216.

Bryan DDLS, Abbott DA, Classen HL. Development of an in vitro protein digestibility assay mimicking the chicken digestive tract. Anim Nutr 2018;4:401–9.

CCAC. Guide Lines on the care and use of farm animals in research, teaching and testing. Ottawa, ON, Canada: Canadian Council on Animal Care; 2009. p. 1–162. https://www.ccac.ca/Documents/Standards/Guidelines/Farm_Animals.pdf. [Accessed January 2019].

Cowieson AJ, Acamovic T, Bedford MR. The effects of phytase and phytic acid on the loss of endogenous amino acids and minerals from broiler chickens. Br Poult Sci 2004;45:101–8.

Degussa. AminoDat 4.0. Evonik Degussa; 2005. http://animal-nutrition.evonik.com/product/feed-additives/en/services/analytical-services/aminodat/Pages/default.aspx. [Accessed December 2018].

Dibner JJ, Kitchell ML, Atwell CA, Ivey FJ. The effect of dietary ingredients and age on the microscopic structure of the gastrointestinal tract in poultry. J Appl Poult Res 1996;5:70–7.

Eichner G, Vieira SL, Torres CA, Coneglian JLB, Freitas DM, Oyarzabal OA. Litter moisture and footpad dermatitis as affected by diets formulated on an all-vegetable basis or having the inclusion of poultry by-product. J Appl Poult Res 2007;16:344–50.

Fasina YO, Classen HL, Garlich JD, Swaisgood HE, Clare DA. Investigating the possibility of monitoring lectin levels in commercial soybean meals intended for poultry feeding using steam-heated soybean meal as a model. Poult Sci 2003;82:648–56.

Firman JD, Boling SD. Lysine: ideal protein in turkeys. Poult Sci 1998;77:105–10.

Graham KK, Kerley MS, Firman JD, Allee GL. The effect of enzyme treatment of soybean meal on oligosaccharide disappearance and chick growth performance. Poult Sci 2002;81:1014–9.

Halevy O, Geyra A, Barak M, Uni Z, Sklan D. Early posthatch starvation decreases satellite cell proliferation and skeletal muscle growth in chicks. J Nutr 2000;130:858–64.

Halevy O, Nadel Y, Barak M, Rozenbloim I, Sklan D. Early posthatch feeding stimulates satellite cell proliferation and skeletal muscle growth in Turkey poults. J Nutr 2003;133:1107–8.

Hoffmann D, Thurner S, Ankerst D, Damme K, Windisch W, Brugger D. Chickens' growth performance and pancreas development exposed to soy cake varying in trypsin inhibitor activity, heat-degraded lysine concentration, and protein solubility in potassium hydroxide. Poult Sci 2019;98:2489–99. https://doi.org/10.3382/ps/pey592.

Horn NL, Donkin SS, Applegate TJ, Adeola O. Intestinal mucin dynamics: response of broiler chicks and White Pekin ducklings to dietary threonine. Poult Sci 2009;88:1906–14.

Huang KH, Ravindra V, Li X, Bryden WL. Influence of age on the apparent ileal amino acid digestibility of feed ingredients for broiler chickens. Br Poult Sci 2005;46:236–45.

Hybrid Turkeys. Commercial nutrient guidelines calculator. 2013. http://resources.hybridturkeys.com/nutrition/commercial-guidelines. [Accessed December 2018].

Kim EJ, Utterback PL, Parsons CM. Comparison of amino acid digestibility coefficients for corn, corn gluten meal, and corn distillers dried grains with solubles among 3 different bioassays. Poult Sci 2012;91:3141–7.

Kumar R. Anti-nutritional factors, the potential risks of toxicity and methods to alleviate them. Pages 145-160 in Legume Trees and other Fodder Trees as Protein Sources for Livestock. FOA Animal Production and Health Paper; 1992.

Lopez G, Leeson S. Assessment of the nitrogen correction factor in evaluating metabolizable energy of corn and soybean meal in diets for broilers. Poult Sci 2008;87:298–306.

Moore DT, Ferket PR, Mozdziak PE. The effect of early nutrition on satellite cell dynamics in the young Turkey. Poult Sci 2005;84:748–56.

Muir WI, Lynch GW, Williamson P, Cowieson AJ. The oral administration of meat and bone meal-derived protein fractions improved the performance of young broiler chicks. Anim Prod Sci 2013;53:369–77.

National Research Council. In: Nutrient requirements of poultry. 9th rev. Washington, DC: Natl. Acad. Press; 1994.

Noy Y, Sklan D. Posthatch development in poultry. J Appl Poult Res 1997;6:344–54.

Palliyeguru MW, Rose SP, Mackenzie AM. Effect of trypsin inhibitor activity in soya bean on growth performance, protein digestibility and incidence of sub-clinical necrotic enteritis in broiler chicken flocks. Br Poult Sci 2011;52:359–67. https://doi.org/10.1080/00071668.2011.577054.

Qaisrani SN, Moquet PCA, van Krimpen MM, Kwakkel RP, Verstegen MWA, Hendriks WH. Protein source and dietary structure influence growth

performance, gut morphology, and hindgut fermentation characteristics in broilers. Poult Sci 2014;93:3053–64.
Ravindran V, Morel PCH. Ileal amino acid digestibility of some novel dietary protein sources for growing chickens. J Sci Food Agric 2006;86:2603–8.
Scott TA, Silversides FG, Classen HL, Swift ML, Bedford MR. Comparison of sample source (excreta or ileal digesta) and age of broiler chick on measurement of apparent digestible energy of wheat and barley. Poult Sci 1998;77:456–63.
Selle PH, Ravindran V, Caldwell A, Bryden WL. Phytate and phytase: consequences for protein utilization. Nutr Res Rev 2000;13:255–78.
She Y, Su Y, Liu L, Huang C, Li J, Li P, Li D, Piao X. Effects of microbial phytase on coefficient of standardized total tract digestibility of phosphorus in growing pigs fed corn and corn co-products, wheat and wheat co-products and oilseed meals. Anim Feed Sci Technol 2015;208:132–44.
Shukla R, Cheryan M. Zein: the industrial protein from corn. Ind Crops Prod 2001;13:171–92.
Sklan D. Development of the digestive tract of poultry. World Poultry Sci J 2001;57:415–28.
Sklan D, Noy Y. Hydrolysis and absorption in the small intestines of posthatch chicks. Poult Sci 2000;79:1306–10.
Smith TK, Mogridge JL, Sousadias MG. Growth-promoting potential and toxicity of spermidine, a polyamine and biogenic amine found in foods and feedstuffs. J Agric Food Chem 1996;44:518–21.
Smith TK, Tapia-Salazar M, Cruz-Suarez L, Ricque-Marie D. Feed-borne biogenic amines: natural toxicants or growth promoters? In: Cruz-Suarez LE, Ricque-Marie D, Tapia-Salazar M, Olvera-Novao MA, Civera-Cerecedo R, editors. Avances en Nutricion Acuicola V. Memorias del V Simposium Internacional de Nutricion Acuicola. Mexico: Merida, Yucatan; 2000. November 19 – 22, 2000.
Stein HH, Berger LL, Drackley JK, Fahey GC, Hernot DC, Parsons CM. In: Johnson LA, White PJ, Galloway R, editors. Nutritional properties and feeding values of soybeans and their co-products. Pages 613– 660 in Soybeans, Chemistry, Production, Processing, and Utilization. Urbana, IL: AOCS Press; 2008.
Ten Doeschate RAHM, Scheele CW, Schreurs VVAM, Van Der Klis JD. Digestibility studies in broiler chickens: influence of genotype, age, sex and method of determination. Br Poult Sci 1993;34:131–46.
Thomas DV, Ravindran V, Ravindran G. Nutrient digestibility and energy utilisation of diets based on wheat, sorghum or maize by the newly hatched broiler chick. Br Poult Sci 2008;49:429–35.
Uni Z, Ferket RP. Methods for early nutrition and their potential. World Poultry Sci J 2004;60:101–11.
Vieira SL, Lima IL. Live performance, water intake and excreta characteristics of broilers fed all vegetable diets based on corn and soybean meal. Int J Poult Sci 2005;4:365–8.
Vogtmann H, Friter P, Prabuck AL. A new method of determining metabolizability of energy and digestibility of fatty acids in broiler diets. Br Poult Sci 1975;67:641–6.
Wyatt CL, Weaver WDJ, Beane WL. Influence of egg size, eggshell quality, and posthatching holding time on broiler performance. Poult Sci 1985;64:2049–55.
Youssef IMI, Beineke A, Rohn K, Kamphues J. Effects of litter quality (moisture, ammonia, uric acid) on development and severity of foot pad dermatitis in growing turkeys. Avian Dis 2011;55:51–8.