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Effect of including canola meal in diets of slaughter ostriches (*Struthio camelus* var. *domesticus*)

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Abstract

Canola meal (CM) is a locally produced protein source that may be less expensive than soybean meal (SBM). This study evaluated the effects of replacing 0%, 25%, 50%, 75%, and 100% SBM with CM in diets for slaughter ostriches. The CM was added at the expense of SBM and other concentrates, with minor changes in other ingredients. Birds (n = 15 per treatment) were reared from 77 to 337 days old on the trial diets, which were supplied ad libitum for starter, grower, and finisher phases. Bodyweights and feed intake were measured during these phases. No differences (P >0.05) were found between treatments for live weight at the end of each phase, dry matter intake (DMI), average daily gain (ADG) and feed conversion ratio (FCR) over all the growth phases. Although no differences were observed in live weight at the end of each phase, the birds reared on the diet with 50% CM were heaviest at slaughter, and birds reared with 100% CM were lightest (P <0.05). Differences (P <0.05) between diets were observed for the weight at slaughter, weights of the liver and thyroid glands and the pH of the cold carcass. However, no differences (P >0.05) were observed between diets for fat pad weight, dressing percentage, and weights of thighs and *Muscularis gastrocnemius*. The results indicate that CM could replace SBM in the diets of slaughter ostriches without affecting production traits and slaughter yields.

Keywords: alternative protein, average daily gain, canola, dry matter intake, feed conversion ratio, growth, ostrich nutrition, production

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Introduction

Nutrition is the most important and greatest expense in any livestock industry (Brand & Jordaan, 2011), and cannot be neglected, because it has a direct influence on the growth and production of the animals. The only feasible approach to reducing feeding costs is to identify alternative local raw materials that can be incorporated in the diets of ostriches. Research into the influence of these alternative raw materials on production characteristics is essential to ensure profitability.

Protein makes up a large component of ostrich feed, and thus represents a large portion of the feeding costs (Carstens, 2013; Dalle Zotte *et al.*, 2013). The price of protein sources is increasing as protein becomes more and more scarce owing to a rapid rise in the human population (Brand *et al.*, 2000a; Brand *et al.*, 2004a). Currently, SBM is the main protein source in animal feeds in South Africa (Dalle Zotte *et al.,* 2013; Snyman, 2016). The current demand for soybean in the country is higher than production, therefore large quantities are imported, which leads to increased feed prices (Sihlobo & Kapuya, 2016; AFMA, 2017). Although protein is expensive and scarce, there is little information about the nutritive values of alternative sources for ostrich diets (Brand *et al.*, 2000a) and the effects they might have on production. It is thus important to quantify the nutritive value of alternative protein sources by formulating diets that fit the needs of ostriches without compromising production.

South Africa produces a large quantity of canola, especially in the Western Cape. Canola is used predominantly to produce vegetable oil. Canola meal (CM) is the by-product after the extraction of oil from

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the seeds (Zheng *et al.*, 2017). It has a protein content of approximately 36% and is potentially useful as a protein source in animal feed (Newkirk, 2009). However, anti-nutritional factors, including glucosinolates, in feed that contains CM influence DMI when it is provided to birds in a free choice feeding system over a limited period (Brand *et al*., 2018; Niemann, 2018; Van der Merwe, 2019). Therefore, the current study was conducted to evaluate the replacement of SBM with CM in the diets of slaughter ostriches.

Materials and Methods

Ethical clearance for the current study was obtained from Elsenburg Departmental Ethics Committee (DECRA R14/108). During the trial, all birds were monitored every day to ensure their wellbeing. The Code of Conduct for the Commercial Production of Ostriches (2011) of the South African Ostrich Business Chamber for rearing, handling, vaccinating and transporting was followed throughout the trial.

The 230 South African Black ostriches that were used in this trial were hatched in November 2016 at Oudtshoorn Research Farm. The trial ran until November 2017, when the remaining 197 ostriches were slaughtered. Post-mortem evaluations were conducted by an experienced veterinarian on dead ostrich chicks to determine the cause of death and to establish whether mortalities were related to nutrition. If nutrition had been identified as the cause of death, the trial would have been terminated immediately.

After hatching, the chicks were stratified by weight and divided into five groups, which represented the treatments, with equal numbers of chicks and an average chick weight of 0.894 ± 0.007 kg. These groups were sub-divided into three sub-groups, resulting in fifteen small groups (± 15 chicks per group, with the male to female ratio being equal among the treatments). Thus, there were three replicates per dietary treatment. Each of the fifteen groups was allocated to a similar camp of 10 x 5 m with adequate shelter and indoor housing (5 x 3 m). All groups received the same pre-starter diet (Table 1) up to 76 days old. Water and feed were provided ad libitum at all times. At 84 days old, all chicks were vaccinated against Newcastle disease.

Five experimental diets were formulated for each of the phases according to the model developed by Gous and Brand (2008) using Mixit$^{®}$ 2+ feed formulation software, namely starter (Table 2), grower (Table 3), and finisher (Table 4). All diets were formulated to be isonutritious in terms of energy and essential amino acids, that is, lysine, and total sulphur-containing amino acids threonine, tryptophan, and arginine. Each diet had a different inclusion level of CM, which replaced soybean meal in the increments of 0%, 25%, 50%, 75% and 100%. In an attempt to keep the diets isonutritious, changes in the grain components of the diets were inevitable.

The trial feeds were milled and pelleted on Oudtshoorn Research Farm. Approximately one kilogram was sampled from each batch of feed and sent for laboratory analysis to ensure uniform nutrient composition between the batches. The methods of the Association of Official Analytical Chemists (AOAC, 2012) were followed to determine dry matter (method 934.01), crude protein (method 990.03), crude fibre (Goering & Van Soest, 1970), detergent fibre, and neutral detergent fibre (Van Soest *et al.*, 1991). The guidelines of Agri Laboratory Association of South Africa (AgriLASA, 1998) were followed to determine the calcium and phosphorous values (method 6.1.1).

The glucosinolate concentration of the dry CM was determined by liquid chromatography-mass spectrometry (LC-MS). The samples were prepared by extracting 1 g of the CM with 25 mL of 50% MeOH/1% formic acid with vortexing and ultrasonification. After extraction, the sample was centrifuged and the clear supernatant was transferred to glass vials for analysis by LC-MS (Taylor, M.J.C., pers. comm., Central Analytic Facilities, Stellenbosch University, Stellenbosch, 7600, South Africa, October 2018). The glucosinolate contents of each of the trial diets are presented in Table 5.

Table 1 Ingredient and chemical composition of pre-starter diet fed to ostrich chicks at 0 - 76 days old (as-fed basis)

Ingredients	Amount (kg/ton)
Maize (yellow grain)	504.36
Lucerne meal, 17% crude protein	100.87
Soybean meal, 44% crude protein	172.82
Fish meal	75.65
Canola meal, 34% crude protein	50.44
Canola oil	50.44
Limestone, ground	24.31
Monocalcium phosphate	4.01
Sodium chloride	10.09
Vitamin and mineral premix[1]	5.04
Lysine-HCl	1.97
Nutrients (as formulated)	
Dry matter (g/kg)	907.40
Metabolizable energy ostrich (MJ/kg feed)[2]	14.36
Crude protein (g/kg)	205.68
Crude fibre (g/kg)	54.31
Crude fat (g/kg)	78.46
Calcium (g/kg)	15.18
Phosphorous (g/kg)	6.03

[1] Vitamin A: 15 000 000 IU, Vitamin D_3: 4 000 000 IU, Vitamin E: 60 000 mg, Vitamin K_3: 3 000 mg, Vitamin B_1: 5000 mg, Vitamin B_2: 10 000 mg. Vitamin B_6: 8 000 mg, Vitamin B_{12}: 100 mg, Niacin: 100 000 mg, Pantothenic acid: 15 000 mg, Folic acid: 3 000 mg, Biotin: 300 mg, Choline: 800 000 mg, Magnesium: 50 000 mg, Manganese: 120 000 mg, Iron: 30 000 mg, Zinc: 120 000 mg, Copper: 8 000 mg, Cobalt: 300 mg, Iodine: 2 000 mg, Selenium: 300 mg, Antioxidant: 125 000 mg; incorporated into the ration at 2.5 kg per ton.

[2] ME ostrich = 6.35 + 0.645 × ME poultry (Gous & Brand, 2008); ME: metabolizable energy

Table 2 Ingredient and chemical composition of five starter diets with increasing levels of canola meal fed to ostrich chicks from 76 to 146 days old (as-fed basis)

Ingredients (kg/ton)	Diets expressed as percentage of soybean meal that was replaced by canola meal				
	0%	25%	50%	75%	100%
Yellow maize	572.16	529.12	486.08	443.04	400.00
Soybean meal, 44% crude protein	179.51	134.63	89.76	44.88	0.00
Canola meal, 34% crude protein	0.00	78.20	156.40	234.60	312.80
Lucerne meal, 17% crude protein	123.97	125.48	126.99	128.50	130.00
Molasses meal	38.14	38.61	39.07	39.54	40.00
Fat, animal	28.61	35.31	42.01	48.70	55.40
Limestone, ground	11.47	11.43	11.39	11.34	11.30
Monocalcium phosphate	21.47	21.40	21.34	21.27	21.20
Bentonite clay	9.54	9.66	9.77	9.89	10.00
Sodium chloride	9.54	9.66	9.77	9.89	10.00
Vitamin and mineral premix[1]	3.34	3.38	3.42	3.46	3.50
Lysine-HCl	2.26	2.10	1.93	1.77	1.60
Nutrient composition (laboratory analysis)					
Dry matter (g/kg)	900.70	895.45	891.58	899.43	899.20
Metabolizable energy ostrich (MJ/kg feed)[2]	10.89	10.72	10.50	10.60	10.32
Crude fibre (g/kg)	78.13	80.05	90.73	93.53	116.78
Acid detergent fibre (g/kg)	110.05	113.30	122.45	134.05	170.53
Neutral detergent fibre (g/kg)	149.28	151.45	160.15	165.98	209.70
Calcium (g/kg)	12.15	12.20	14.55	15.45	17.35
Phosphorous (g/kg)	8.80	9.20	10.55	10.45	10.25
Amino acid composition (formulated)					
Lysine (g/kg)	0.93	0.95	0.97	0.99	1.01
TSAA[3] (g/kg)	0.70	0.71	0.73	0.74	0.76
Threonine (g/kg)	0.69	0.70	0.72	0.73	0.75
Tryptophan (g/kg)	0.19	0.20	0.20	0.20	0.21
Arginine (g/kg)	0.89	0.91	0.93	0.95	0.97

[1] Vitamin A: 15 000 000 IU, Vitamin D_3: 4 000 000 IU, Vitamin E: 60 000 mg, Vitamin K_3: 3 000 mg, Vitamin B_1: 5000 mg, Vitamin B_2: 10 000 mg. Vitamin B_6: 8 000 mg, Vitamin B_{12}: 100 mg, Niacin: 100 000 mg, Pantothenic acid: 15 000 mg, Folic acid: 3 000 mg, Biotin: 300 mg, Choline: 800 000 mg, Magnesium: 50 000 mg, Manganese: 120 000 mg, Iron: 30 000 mg, Zinc: 120 000 mg, Copper: 8 000 mg, Cobalt: 300 mg, Iodine: 2 000 mg, Selenium: 300 mg, Antioxidant: 125 000 mg; incorporated into the ration at 2.5 kg per ton.

[2] ME ostrich = 6.35 + 0.645 × ME poultry (Gous & Brand, 2008); ME: metabolizable energy

[3] TSAA: total sulphur-containing amino acids

Table 3 Ingredient and chemical composition of five grower diets with increasing levels of canola meal fed to ostrich chicks from 147 to 230 days old (as-fed basis)

Ingredients (kg/ton)	Diets expressed as percentage of soybean meal that was replaced by canola meal				
	0%	25%	50%	75%	100%
Wheat grain	583.64	571.40	559.17	546.93	534.69
Oats hulls	171.20	155.97	140.74	125.50	110.27
Soybean meal, 44% crude protein	134.58	100.94	67.29	33.65	0.00
Canola meal, 34% crude protein	0.00	50.02	100.05	150.07	200.09
Molasses meal	40.00	40.00	40.00	40.00	40.00
Lucerne meal, 17% crude protein	0.00	12.50	25.00	37.50	50.00
Monocalcium phosphate	26.66	26.25	25.84	25.42	25.01
Limestone, ground	17.09	16.22	15.35	14.48	13.61
Bentonite clay	10.00	10.00	10.00	10.00	10.00
Sodium chloride	10.00	10.00	10.00	10.00	10.00
Vitamin & mineral premix[1]	5.00	5.00	5.00	5.00	5.00
Lysine-HCl	1.83	1.71	1.58	1.46	1.33
Nutrient composition (laboratory analysis)					
Dry matter (g/kg)	903.98	901.58	901.33	883.03	884.00
ME[2] ostrich (MJ/kg feed)	10.42	10.34	10.29	10.01	10.02
Crude fibre (g/kg)	82.55	81.55	84.27	87.57	97.07
Acid detergent fibre (g/kg)	105.15	118.23	119.35	118.33	132.45
Neutral detergent fibre (g/kg)	177.87	204.25	205.07	213.57	230.62
Calcium (g/kg)	12.67	12.13	13.17	18.63	16.57
Phosphorous (g/kg)	8.73	9.50	10.30	10.40	10.03
Amino acid composition (formulated)					
Lysine (g/kg)	0.71	0.71	0.71	0.71	0.71
TSAA[3] (g/kg)	0.41	0.45	0.48	0.52	0.55
Threonine (g/kg)	0.44	0.46	0.48	0.50	0.53
Tryptophan (g/kg)	0.18	0.18	0.18	0.17	0.17
Arginine (g/kg)	0.68	0.68	0.68	0.68	0.68

[1] Vitamin A: 12 000 000 IU, Vitamin D3: 3 000 000 IU, Vitamin E: 45 000 mg, Vitamin K3: 3 000 mg, Vitamin B1: 3 000 mg, Vitamin B2: 8 000 mg, Vitamin B6: 6 000 mg, Vitamin B12: 100 mg, Niacin: 80 000 mg, Pantothenic acid: 12 000 mg, Folic acid: 2 000 mg, Biotin: 200 mg, Choline: 600 000 mg, Magnesium: 50 000 mg, Manganese: 120 000 mg, Iron: 25 000 mg, Zinc: 80 000 mg, Copper: 8 000 mg, Cobalt: 300 mg, Iodine: 1 000 mg, Selenium: 300 mg, Antioxidant: 125 000 mg; incorporated into the ration at 2.5 kg per ton.

[2] ME ostrich = 6.35 + 0.645 × ME poultry (Gous & Brand, 2008); ME: metabolizable energy

[3] TSAA: total sulphur-containing amino acids

Table 4 Ingredient and chemical composition of five finisher diets with increasing levels of canola meal fed to ostrich chicks from 231 to 337 days old (as-fed basis)

Ingredients (kg/ton)	Diets expressed as percentage of soybean meal that was replaced by canola meal				
	0%	25%	50%	75%	100%
Wheat grain	463.82	447.44	431.07	414.69	398.31
Oats hulls	322.98	314.51	306.04	297.56	289.09
Soybean meal, 44% crude protein	104.86	78.65	52.43	26.22	0.00
Canola meal, 34% crude protein	0.00	49.84	99.69	149.53	199.37
Molasses meal	40.00	39.97	39.94	39.90	39.87
Lucerne meal, 17% crude protein	0.00	2.49	4.99	7.48	9.97
Monocalcium phosphate	27.04	26.63	26.21	25.80	25.38
Limestone, ground	16.80	16.25	15.69	15.14	14.58
Bentonite clay	10.00	9.99	9.99	9.98	9.97
Sodium chloride	10.00	9.99	9.99	9.98	9.97
Vitamin and mineral premix[1]	3.50	3.50	3.50	3.49	3.49
Lysine-HCl	1.01	0.76	0.51	0.25	0.00
Nutrient composition (laboratory analysis)					
Dry matter (g/kg)	892.92	901.97	916.90	916.50	915.57
ME[2] ostrich (MJ/kg feed)	10.08	10.35	10.40	10.31	10.35
Crude fibre (g/kg)	98.47	104.52	112.78	119.52	125.50
Acid detergent fibre (g/kg)	129.27	136.88	153.92	162.87	178.30
Neutral detergent fibre (g/kg)	240.82	251.82	262.67	281.15	288.32
Calcium (g/kg)	14.57	13.07	13.30	13.47	13.50
Phosphorous (g/kg)	9.13	9.63	10.10	10.13	9.93
Amino acid composition (formulated)					
Lysine (g/kg)	0.55	0.55	0.55	0.55	0.55
TSAA[3] (g/kg)	0.35	0.39	0.43	0.47	0.50
Threonine (g/kg)	0.37	0.40	0.42	0.45	0.48
Tryptophan (g/kg)	0.16	0.16	0.16	0.16	0.16
Arginine (g/kg)	0.56	0.58	0.59	0.61	0.62

[1] Vitamin A: 8 000 000 IU, Vitamin D3: 2 000 000 IU, Vitamin E: 40 000 mg, Vitamin K3: 2 000 mg, Vitamin B1: 2 000 mg, Vitamin B2: 5 000 mg, Vitamin B6: 4 000 mg, Vitamin B12: 50 mg, Niacin: 60 000 mg, Pantothenic acid: 12 000 mg, Folic acid: 1 500 mg, Biotin: 100 mg, Choline: 300 000 mg, Magnesium: 50 000 mg, Manganese: 100 000 mg, Iron: 40 000 mg, Zinc: 100 000 mg, Copper: 10 000 mg, Cobalt: 500 mg, Iodine: 2000 mg, Selenium: 300 mg, Antioxidant: 125 000 mg; incorporated into the ration at 2.5 kg per ton.

[2] ME ostrich = 6.35 + 0.645 × ME poultry (Gous & Brand, 2008) ME: metabolizable energy

[3] TSAA: total sulphur-containing amino acids

Table 5 Glucosinolate content (as-is basis) of treatment diets in which soybean meal was gradually replaced by canola meal

Glucosinolate compound (µmol/g feed)	Percentage of soybean meal that was replaced by canola				
	0%	25%	50%	75%	100%
Starter diet (CM inclusion levels)	0%	7.8%	15.6%	23.5%	31.2%
Progoitrin	0.00	0.11	0.21	0.32	0.43
Sinigrin	0.00	0.00	0.01	0.01	0.01
Glucobrassicin	0.00	0.03	0.06	0.09	0.12
Gluconapin	0.00	0.09	0.18	0.27	0.36
4-hydroxyglucobrassicin	0.00	0.28	0.55	0.83	1.11
Epiprogoitrin	0.00	0.19	0.37	0.56	0.74
Gluconapoleiferin	0.00	0.01	0.02	0.03	0.04
Glucobrassicanapin	0.00	0.10	0.20	0.31	0.41
Gluconasturtin	0.00	0.01	0.02	0.03	0.04
Total (µmol/g)	0.00	0.81	1.63	2.44	3.26
Grower diet (CM inclusion levels)	0%	5%	10%	15%	20%
Progoitrin	0.00	0.07	0.14	0.20	0.27
Sinigrin	0.00	0.00	0.00	0.01	0.01
Glucobrassicin	0.00	0.02	0.04	0.06	0.07
Gluconapin	0.00	0.06	0.11	0.17	0.23
4-hydroxyglucobrassicin	0.00	0.18	0.35	0.53	0.71
Epiprogoitrin	0.00	0.12	0.24	0.36	0.48
Gluconapoleiferin	0.00	0.01	0.01	0.02	0.03
Glucobrassicanapin	0.00	0.07	0.13	0.20	0.26
Gluconasturtin	0.00	0.01	0.01	0.02	0.03
Total (µmol/g)	0.00	0.52	1.04	1.56	2.08
Finisher diet (CM inclusion levels)	0%	5%	10%	15%	20%
Progoitrin	0.00	0.07	0.14	0.20	0.27
Sinigrin	0.00	0.00	0.00	0.01	0.01
Glucobrassicin	0.00	0.02	0.04	0.06	0.07
Gluconapin	0.00	0.06	0.11	0.17	0.23
4-hydroxyglucobrassicin	0.00	0.18	0.35	0.53	0.71
Epiprogoitrin	0.00	0.12	0.24	0.36	0.47
Gluconapoleiferin	0.00	0.01	0.01	0.02	0.03
Glucobrassicanapin	0.00	0.07	0.13	0.20	0.26
Gluconasturtin	0.00	0.01	0.01	0.02	0.03
Total (µmol/g)	0.00	0.52	1.04	1.56	2.08

CM: canola meal

With the onset of the starter phase, the chicks were moved to fifteen larger pens (25 x 6 m) at 77 days old. At this point, the trial began, and the birds received their starter diets (Table 2). During the starter phase, the birds, feed, and orts were weighed each week to determine growth and feed intake. The chicks entered the grower phase at 147 days old and were given the grower trial diets (Table 3). During this phase, the groups were moved to larger camps (40 x 30 m) to allow for growth and reduce the risk of skin damage. Owing to the risk of injuries to the birds and the handlers, each bird and the orts were weighed every three weeks. The finisher diets (Table 4) were fed from 231 days old until slaughter. Before the ostriches were slaughtered at 337 days old, the fifteen experimental groups were sorted into the five treatment groups and relocated to five large quarantine camps for 27 days as obligated by European Union (EU) meat quality standards (DAFF, 2017). During quarantine, the birds were treated for possible external parasites, and blood samples were collected to test for avian influenza (AI). The birds tested negative for AI and could thus be taken to the abattoir for slaughter. One day prior to slaughter, the birds were moved according to protocol to Klein Karoo International Abattoir, where they were kept in lairage. They received no feed but had ad libitum access to fresh water.

Procedures for slaughter were similar to those described in Hoffman (2012). The birds were stunned electrically and exsanguinated and the weights of the dead birds were recorded. This bled weight was taken as the slaughter weight. After the birds had been exsanguinated, the feathers were plucked by hand and placed in marked bags. The carcasses were then skinned. Each skin was marked and sent for tanning to Klein Karoo International Tannery. After evisceration, the abdominal fat (fat pad) was removed and weighed. The weights of the liver and thyroid glands were recorded to determine whether the diets (specifically their glucosinolate content) had influenced the development and function of these organs. The carcasses were then chilled overnight in a cold room at 0 - 2 °C. The cold carcass weight was obtained the next morning (± 24 hours post-mortem) before deboning. These weights were used to calculate the dressing percentage by dividing the cold carcass weight by the bled-out weight, multiplied by 100. The pH of the *Muscularis gastrocnemius* was measured prior to deboning. The right thigh of each bird was weighed to obtain the contribution of the thighs to the whole carcass. It was assumed that the weight of the right thigh would be the same as that of the left thigh.

SAS enterprise guide (version 9.4, SAS Institute Inc., Cary, North Carolina, USA) was used to analyse the production and slaughter data statistically. The general linear model procedure was used to test for significant differences between the treatments at P ≤0.05 level. Detailed treatment differences were investigated with Fisher’s least significant difference t-test. In the analyses, camps were considered the experimental units and thus were the random replicates of the dietary treatments. The production traits of the birds were analysed in each of the phases and over the entire production period. The end weight of the previous feeding phase was taken as a covariate, starting weight, for the traits that were analysed in the next phase. Regression models were fitted to the data to describe the trends shown for each production trait in response to the level of CM in the diet. The growth curves for ostriches on each of the trial diets were developed by applying the nonlinear Gompertz function:

$$W_t = ae^{-be^{-ct}}$$

Where: W represents the weight of the ostrich at time,
t represents the asymptotic mature weight,
b sets the displacement along the age-axis,
c sets the growth rate, and
e is Euler’s number (2.71828...).

A one-way analysis of variance (ANOVA) was used to test for differences in the parameter estimates between the treatments.

Results

The overall mortality rate of ostriches in this trial was 14.8%. Most of these mortalities (11.3%) occurred during the starter phase. Post-mortem analyses indicated that the main cause of deaths in this phase was prolapses owing to the ingestion of sticks and gravel. The mortalities in the grower phase (2.5%) were also caused by gravel in the stomach and leg injuries. In the finisher phase, a mortality rate of 1% was observed as a result of ostriches injuring themselves in the fencing. The mortalities occurred across treatments, so it was determined that they were not the result of the treatments. Mortality rates were well below the industry norm of 40% (Brand, 2016).

The production traits of ostriches that were reared on diets in which CM replaced SBM incrementally as the primary source of protein are given in Table 6. The starting weight of each phase was used as a covariate to adjust statistically for any differences between treatments in the initial weight for each phase. The average starting weights of the birds on the starter, grower and finisher diets were 4.53 kg, 42.06 kg and 77.65 kg, respectively. Dry matter intake (DMI) did not vary between the diets in each of the feeding phases or over the entire rearing period (P >0.05). The DMI averages during the starter, grower and finisher phases were 1.34, 1.89 and 2.65 kg/bird/day, respectively, with the overall average DMI being 2.02 kg/bird/day. Differences were observed for the ADG of ostriches in the starter phase, with birds on the 75% CM diet (0.43 kg/bird/day) exhibiting higher growth rates (P =0.031) than birds on the 0% (0.38 kg/bird/day), 25% (0.36

Table 6 Effect of replacing soybean meal with increasing levels of canola meal in diets of slaughter ostriches on production traits in different production phases, presented as least square means ± standard error (LSM ± SE)

Production traits	Phase	Percentage of soybean meal replaced by canola meal					*P*-value
		0%	25%	50%	75%	100%	
Dry matter intake (kg/bird/day)	Starter	1.25 ± 0.08	1.26 ± 0.08	1.37 ± 0.08	1.55 ± 0.08	1.25 ± 0.08	0.155
	Grower	1.89 ± 0.15	1.86 ± 0.16	1.84 ± 0.16	2.02 ± 1.20	1.86 ± 0.19	0.364
	Finisher	2.62 ± 0.13	2.62 ± 0.14	2.59 ± 0.13	2.75 ± 0.14	2.66 ± 0.13	0.834
	Overall	1.98 ± 0.09	1.96 ± 0.09	1.98 ± 0.10	2.19 ± 0.90	1.97 ± 0.10	0.491
Average daily gain (g/bird/day)	Starter	378.49^{a} ± 13.68	364.93^{a} ± 13.68	388.61^{ab} ± 13.68	426.53^{b} ± 13.68	353.92^{a} ± 13.68	0.031
	Grower	437.31 ± 20.56	412.94 ± 20.56	392.47 ± 20.56	397.51 ± 20.56	439.44 ± 20.56	0.397
	Finisher	284.96 ± 15.50	312.05 ± 15.50	296.02 ± 15.50	302.12 ± 15.50	271.93 ± 15.50	0.450
	Overall	389.88 ± 11.35	384.97 ± 11.35	388.59 ± 11.35	399.42 ± 11.35	376.78 ± 11.35	0.722
Feed conversion ratio (feed in kg/weight gain in kg)	Starter	3.31 ± 0.21	3.47 ± 0.21	3.53 ± 0.21	3.64 ± 0.21	3.49 ± 0.21	0.857
	Grower	4.28^{a} ± 0.30	4.51^{a} ± 0.30	4.78^{ab} ± 0.30	5.38^{b} ± 0.30	4.05^{a} ± 0.30	0.078
	Finisher	9.21 ± 0.49	8.43 ± 0.49	8.73 ± 0.49	9.10 ± 0.49	9.91 ± 0.49	0.327
	Overall	5.08 ± 0.21	5.10 ± 0.21	5.14 ± 0.21	5.50 ± 0.21	5.18 ± 0.21	0.646
End weight (kg)	Starter	41.76^{ab} ± 1.36	40.72^{b} ± 1.36	43.17^{ab} ± 1.40	45.53^{a} ± 1.36	39.12^{b} ± 1.42	0.042
	Grower	78.37 ± 2.36	77.10 ± 2.47	76.88 ± 2.46	76.27 ± 3.07	79.61 ± 2.95	0.126
	Finisher	101.75^{ab} ± 1.30	103.91^{ab} ± 1.33	103.80^{ab} ± 1.30	104.41^{c} ± 1.35	100.76^{a} ± 1.31	0.005
	Overall	102.13 ± 2.33	102.49 ± 2.33	104.74 ± 2.40	106.18 ± 2.33	99.11 ± 2.43	0.458

^{a,b,c} Within a row, means with a common superscript do not differ at *P* =0.05

kg/bird/day) and 100% CM (0.35 kg/bird/day) diets, which did not differ (*P* >0.05). The ADG in the other phases did not differ between the diets, with average ADG for the grower phase being 0.41 ± 0.02 kg/bird/day. For the finisher phase it was 0.29 ± 0.02 kg/bird/day.

The feed conversion ratio of grower ostriches (5.38 ± 0.30) was highest for the diet with 15% CM and 33.7% SBM (75% replacement diet). It did not differ from the diet with 10% CM inclusion (50% replacement of SBM) (4.78 ± 0.30), but differed from the diets that had CM inclusion levels of 0% (4.28 ± 0.30), 25% (4.51 ± 0.30), and 100% (4.05 ± 0.30).

Differences in end weights were observed during the starter and finisher phases. The starter phase had the highest end weight in birds that were reared on the 75% CM diet (45.53 ± 1.36 kg for the starter phase and 104.41 ± 1.35 kg for the finisher phase) and the lowest end weight in birds that received the diet with 100% CM inclusion (39.12 ± 1.42 kg for the starter phase and 100.76 ± 1.31 kg for the finisher phase). The average end weight for the grower phase was 77.65 ± 2.66 kg.

To describe possible trends with increasing levels of CM replacing SBM in the diets of ostriches, the production traits were analysed by fitting the most appropriate regression models to the data during the three growth phases (Table 7).

Table 7 Regression models fitted to data of production traits of slaughter ostriches describing trends because of change in canola meal inclusion in the diets in each production phase and the overall period (x = canola meal as percentage of total protein source in the diet)

Production traits (*y*)	Phase	Equation	R^2	*P* value
Dry matter intake (g/bird/day)	Starter	$y = -3 \cdot 10^{-6}x^3 + 0.0004x^2 - 0.0096x + 1.2604$	0.4997	NS[1]
	Grower	$y = 0.0004x + 1.8756$	0.2400	NS[1]
	Finisher	$y = 0.0008x + 2.6068$	0.0299	NS[1]
Average daily gain (g/bird/day)	Starter	$y = -8 \cdot 10^{-7}x^3 + 0.0001x^2 - 0.003x + 0.3799$	0.5951	0.016
	Grower	$y = -4 \cdot 10^{-5}x + 0.4182$	0.0020	NS[1]
	Finisher	$y = -0.0001x + 0.3006$	0.0385	NS[1]
Feed conversion ratio (feed in g/weight gain in g)	Starter	$y = 0.0022x + 3.3788$	0.0572	NS[1]
	Grower	$y = -1 \cdot 10^{-5}x^3 + 0.0014x^2 - 0.0297x + 4.313$	0.5053	0.045
	Finisher	$y = 0.0083x + 8.6642$	0.1182	NS[1]
End weight (kg)	Starter	$y = -7 \cdot 10^{-5}x^3 + 0.0086x^2 - 0.2295x + 41.833$	0.5984	0.042
	Grower	$y = 0.0056x + 77.365$	0.3559	NS[1]
	Finisher	$y = -0.0012x^2 + 0.1176x + 101.68$	0.7866	NS[1]

[1] Not significant (*P* >0.05)

For dry matter intake, the *P* values of the models in each feeding phase were non-significant, with low R^2 values being obtained (<0.50) (Table 7). Figure 1 depicts a cubic regression fitted between the ADG and the CM inclusion level during the starter phase, describing 59.5% of the variation among the data (*P* =0.016). The trend shows a slight decrease in ADG as the CM inclusion level increased from 0% to 7.8%. With the rise in CM levels, the ADG increased to reach the highest ADG for the diet with 23.5% CM inclusion. This diet differs from all the others, except that with 15.6% CM inclusion. There is a sharp decrease in ADG from the 23.5% CM diet to the 31.3% CM diet, where the ADG was lowest at 0.35 ± 0.01 kg/bird/day. Figure 2 shows that a similar cubic regression trend (R^2 = 50.5%) could be drawn between FCR and the inclusion level of CM in the grower phase (*P* =0.045). As the CM level increased from 0% to 5%, there was a slight decrease in FCR, after which FCR increased until it reached its peak at 15% CM inclusion. Again, the FCR of this diet differed from all the other diets, except those in which 50% CM replaced SBM. A sharp decrease in FCR was observed when the CM level increased from 75% to its maximum of 100%. The weights of each diet at the end of the starter phase fitted a similar cubic regression (Figure 3), which described 59.8% of the variation in the data (*P* =0.042). Similar to the regression of these figures, the trend decreased slightly with the increase of CM from 0% to 7.8%, after which the weights increased to reach their maximum at the 23.5% CM inclusion. There was a sharp decrease in end weight when the CM inclusion level increased from 23.5% to 31.3%.

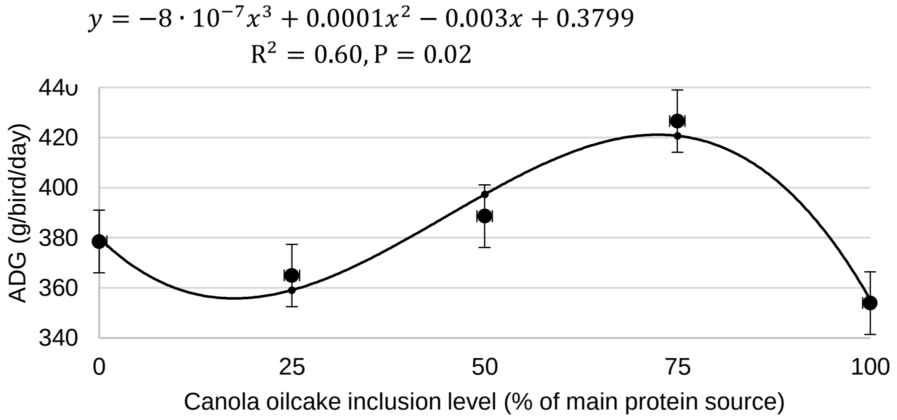

Figure 1 Cubic function fitted to least square mean average daily gain of slaughter ostriches in starter phase with varying levels of canola meal in the diets

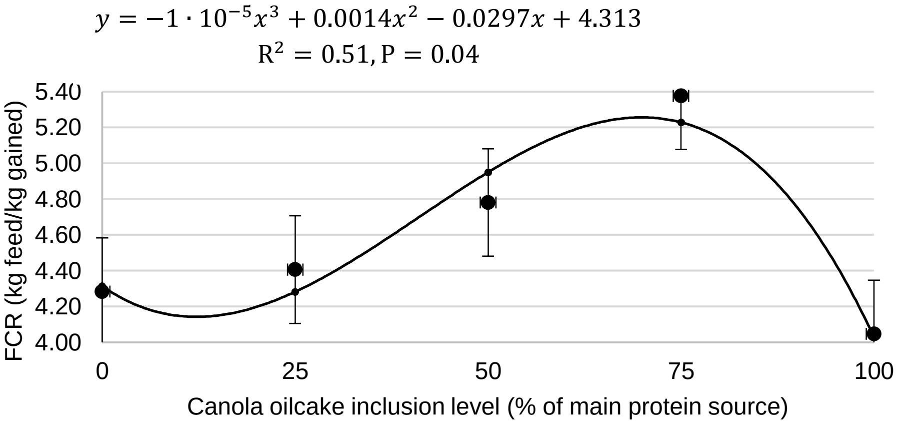

Figure 2 Cubic function fitted to least square mean feed conversion ratios of slaughter ostriches in grower phase with varying levels of canola meal in the diets

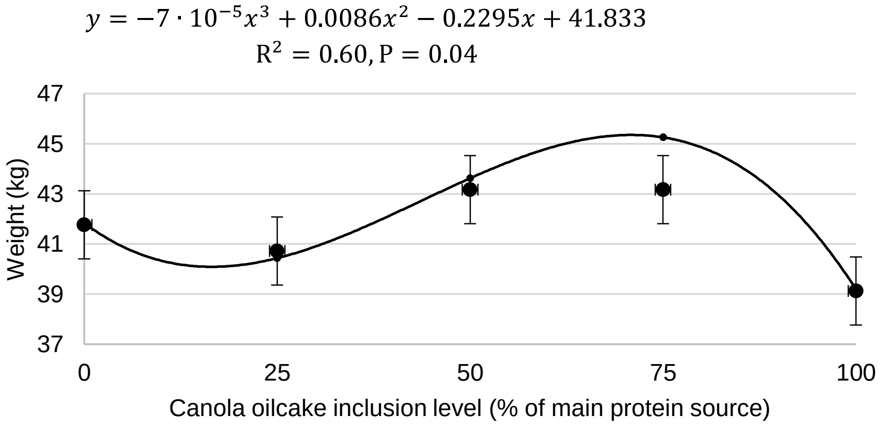

Figure 3 Cubic function fitted to least square mean of end weights of slaughter ostriches in the starter phase with varying levels of canola meal in the diets

The sigmoidal Gompertz growth curves from hatching to slaughter, as presented in Figure 4, explain 94% of the variation in the growth data (Table 8). No differences (*P* ≥0.05) were observed between diets among the parameters.

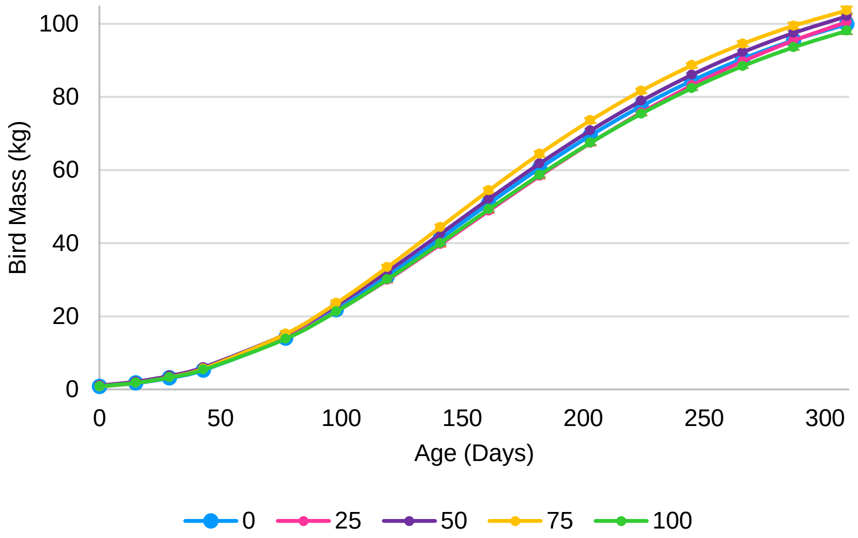

Figure 4 Gompertz growth curves fitted to mean bodyweights (kg) of slaughter ostriches that consumed diets with varying levels of canola meal over the growth period from 0 to 337 days old

Table 8 Estimates of parameters of the Gompertz growth curve (± SE) of slaughter ostriches fed diets with varying levels of canola meal replacing soybean meal as the primary source of protein

Parameter	Diets expressed as percentage canola meal in the experimental diets					*P*-value
	0%	25%	50%	75%	100%	
a	119.32 ± 3.60	125.21 ± 3.60	121.89 ± 3.60	119.97 ± 3.60	116.30 ± 3.60	0.531
b	0.01 ± 0.0007	0.01 ± 0.0007	0.01 ± 0.0007	0.01 ± 0.0007	0.01 ± 0.0007	0.605
c	145.79 ± 4.39	155.23 ± 4.39	146.60 ± 4.39	141.01 ± 4.39	147.23 ± 4.39	0.313
R^2	0.936	0.940	0.951	0.938	0.944	-

a = mature weight (kg)
b = maturing rate (growth coefficient)
c = age at maximum growth (days)

Differences (*P* <0.05) were observed in slaughter weights, with the heaviest birds being reared on the 50% CM (93.60 ± 2.00) diet and the lightest birds on the diet with 100% (83.38 ± 2.00) CM. No differences (*P* >0.05) between diets were observed for the weight of the abdominal fat pad, warm and cold carcass weights, dressing percentage, and weights of the right thigh and *Muscularis gastrocnemius*.

The smallest liver weight (1.26 ± 0.04 kg) was observed for the 100% CM diet and the heaviest for the 25% diet (1.61 ± 0.04 kg). The liver weights for the rest of the diets did not differ. The lightest thyroid gland weight was measured in the diet with 75% CM replacement (36.48 ± 2.92 g), which did not differ from that with 100% CM inclusion (39.05 ± 2.92 g), but differed from the rest of the diets (0%: 44.86 ± 2.92 g, 25%: 58.57 ± 2.92 g, and 50%: 49.50 ± 2.92 g) (Table 9).

Table 9 Least squares means (± SE) for carcass traits of ostriches fed diets in which increasing amounts of canola meal replaced soybean meal when they were slaughtered at 337 days old

Trait	Diets expressed as percentage canola meal (CM) replacing soybean meal in the experimental diets					*P*-value
	0%	25%	50%	75%	100%	
Slaughter weight[1] (kg)	91.30^{a} ± 2.00	90.36^{a} ± 2.00	93.60^{a} ± 2.00	89.01^{ab} ± 2.00	83.38^{b} ± 2.00	0.045
Abdominal fat pad weight (kg)	5.36 ± 0.37	5.66 ± 0.37	5.88 ± 0.37	4.88 ± 0.37	4.40 ± 0.37	0.101
Liver weight (kg)	1.40^{b} ± 0.04	1.61^{a} ± 0.04	1.42^{b} ± 0.04	1.34^{bc} ± 0.04	1.26^{c} ± 0.04	0.0007
Thyroid gland weight (g)	44.86^{bc} ± 2.92	58.57^{a} ± 2.92	49.20^{b} ± 2.92	36.48^{c} ± 2.92	39.05^{c} ± 2.92	0.0024
Warm carcass weight[3] (kg)	45.51 ± 1.14	45.97 ± 1.14	46.43 ± 1.14	45.27 ± 1.14	42.27 ± 1.14	0.161
Cold carcass weight (kg)	44.60 ± 1.11	44.82 ± 1.11	45.39 ± 1.11	44.30 ± 1.11	41.31 ± 1.11	0.156
Dressing percentage (%)	51.80 ± 0.39	51.99 ± 0.39	51.43 ± 0.39	52.47 ± 0.39	52.53 ± 0.39	0.309
Right thigh weight (kg)	16.51 ± 0.41	16.59 ± 0.41	16.76 ± 0.41	16.39 ± 0.41	15.24 ± 0.41	0.137
Muscularis gastrocnemius weight (kg)	1.14 ± 0.03	1.16 ± 0.03	1.14 ± 0.03	1.12 ± 0.03	1.03 ± 0.03	0.069
Muscularis gastrocnemius contribution to right thigh weight (%)	6.88 ± 0.08	6.96 ± 0.08	6.75 ± 0.08	6.82 ± 0.08	6.76 ± 0.08	0.342
Cold carcass pH	5.72^{a} ± 0.03	5.57^{b} ± 0.03	5.62^{b} ± 0.03	5.61^{b} ± 0.03	5.65^{ab} ± 0.03	0.028

^{a,b,c} Within a row, means with a common superscript do not differ at $P = 0.05$

[1] Bled out weight, feathers and skin still attached

[3] Bled out weight, feathers removed, but skin still attached, just before evisceration

Discussion

Ostrich rearing is one of the smallest and youngest commercial agricultural animal industries in South Africa. Therefore knowledge of ostrich nutrition is limited. Alternative dietary ingredients need to be investigated to determine their influence on growth and production. The biggest challenge that livestock producers face lies in reducing expenses to maximize profit margins (Al-Harthi & Attia, 2016; Al-Harthi *et al*., 2018). This is also the reason for identifying and investigating alternative raw materials that can be used in livestock diets. Although SBM is currently the most common source of protein in feeding ostriches, CM is high in protein and currently costs less per ton. Canola meal is also available locally, whereas large quantities of SBM need to be imported (De Kock & Agenbag, 2009; DAFF, 2016b; Nega & Woldes, 2018).

One concern in using CM as raw material in animal feeds is its glucosinolate content. Glucosinolates are anti-nutrients that cause feed to be unpalatable. These anti-nutrients are concentrated in CM after the extraction of oil from the seeds (Zeb, 1998). In the current study, the highest glucosinolate concentration was found in the starter diet when the SBM was replaced completely with CM. However, this had no clear effect, because no differences were detected in DMI and no significant trends were observed. Growth rate and end weight of the birds in the starter phase that received the 100% replacement diet were lower than those that were recorded for the other treatments. However, these values did not differ from those of the 0% replacement diet. This suggests that the levels of anti-nutrients in the 100% replacement diet are below the critical level that would affect the feed intake and production of the ostriches negatively. The results obtained in a previous study in which SBM was replaced with full-fat canola showed that the diet with the highest glucosinolate content (2.156 µmol/g) did not influence the DMI, ADG, FCR, or end weight of the ostriches (Niemann *et al.*, 2018). In the current study, an even higher level of glucosinolates (3.26 µmol/g of feed in the 100% CM diet) did not affect DMI either. Quinsac *et al.* (1994) found that a higher glucosinolate content of15.8 µmol/g, that is, a level 4.8 times the highest level in the current study, did not have a detrimental effect on the feed intake of broilers.

Studies based on ostrich nutrition have revealed that, like all other animals, ostriches eat according to their nutritional requirements, especially the energy content of the feed (Bozinovic & Del Rio, 1996; Niknafs & Roura, 2018). All diets in this study were formulated to have similar energy levels so that the dietary intake of the birds was not influenced.

Most of the differences in production traits occurred in the starter phase. Birds that received the diet with 75% CM had the highest ADG and end weights, and the ostriches that received the diet with 100% CM had the lowest ADG and end weights. Although no significant differences were observed in the DMI between the diets, the higher ADG of the 75% CM replacement diet was probably because of the higher DMI of this diet.

The starter phase could be considered an adaptation phase. The chicks were used to the pre-starter diet, which contained only a small amount (5%) of CM, which was too small to affect the taste of the feed. Thus, during the starter phase the birds adapted to diets containing less SBM and more CM, which tasted different from the pre-starter diet.

In the grower phase, differences were observed between diets in FCR, but not in DMI or ADG. Likewise, the performances of the birds in the finisher phase were similar across diets. Thus, the birds that were subjected to the treatments adapted to their diets despite the inclusion levels of CM. Minimal differences between traits were observed in the overall performance levels. Nonetheless, the diet with 75% CM showed the highest DMI, ADG, FCR and end weights. The Gompertz growth curve showed that the birds in all groups grew according to similar sigmoidal patterns, with no differences in the model parameters being observed. It was previously reported that feed with a glucosinolate concentration above 8.0 µmol/g of feed would result in growth depression in broilers (Tripathi & Mishra, 2007). In the current study, the 100% CM diet of the starter phase had the highest glucosinolate concentration of 3.26 µmol/g of feed. Thus, the current ration with 100% CM is well below the threshold that produced an effect in chickens. The critical threshold for glucosinolate concentration in diets for ostriches has not yet been reached. Therefore, the CM inclusion levels in the diets in the present study were below that threshold.

The inclusion of CM in the diets had little effect on the slaughter yields and traits of ostriches. Because slaughter traits are influenced directly by the production traits, these slight differences were expected. The birds on the control diet were heaviest at slaughter. The birds that received the diet with 100% CM were lightest, and had the lowest ADG and end weight. The various carcass yields (dressing percentage, thigh and *Muscularis gastrocnemius* weights) did not differ between the diets.

The 25% CM diet produced the highest weights of liver and thyroid. Ibrahim and Hill (1980), Butler *et al.* (1982), Opalka *et al.* (2001), and Maroufyan and Kermanshahi (2006) indicated that chickens and pigs that were reared on canola meal and rapeseed meal with high levels of glucosinolates showed enlargement of the liver and thyroid. However, Roth-Maier *et al.* (2004) noted that various levels of canola meal in the diets of pigs had no influence on the weight of the thyroid.

Conclusion

Canola meal can be used as a replacement for SBM in the diets of ostriches. Overall, CM inclusion levels that are lower than 20% in the starter, grower and finisher diets of ostriches are not expected to affect production negatively. However, further research is warranted to evaluate the influence of CM inclusion in the diets on the quality of end products of the slaughter ostriches.

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Authors' Contributions

TSB contributed to concept and design; JVDM was involved in data collection and analysis and drafting the paper; LCH provided critical revision and final approval of the version to be published

Conflict of Interest Declaration

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this article.

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