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Effect of varying levels of protein concentration on production traits of ostriches (*Struthio camelus* var. *domesticus*)

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Abstract

The ostrich industry is poised to recover from the recent lifting of the four-year export ban on fresh meat products to the European Union EU). However, during this period profit margins were severely affected and the need to minimize input costs was as important as it ever was, particularly nutrition. The aim of this study was to evaluate the influence of varying protein concentrations in the diets of slaughter ostriches on the production traits. Five treatment diets were formulated for each feeding phase (pre-starter, starter, grower and finisher), with a control diet, two diets that decreased in protein content and two diets that increased in protein concentration. There were three replications per treatment, resulting in 15 camps, which contained 20 chicks each. Differences were found in live weight of the birds at the end of each feeding phase, except for the finisher phase. Differences were found among the diets for dry matter intake (DMI), average daily gain (ADG), and feed conversion ratio (FCR). The control diet and the two diets that were formulated with higher protein concentrations had higher DMI values, better ADG, and more efficient FCR. Differences were found in cold carcass weights and thigh weights for the birds that were exposed to the treatment diets. The results indicated that the birds on the control diet and on the diets containing higher concentrations of protein, although not differing from each other, consistently outperformed the diets with lower concentrations of protein. From a financial standpoint it can be concluded that it does not make sense to increase the protein concentration in the diets beyond that currently used in the ostrich industry, while a decrease in protein concentration resulted in decreased production performance.

Keywords: amino acids, financial, growth, nutrition, slaughter

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Introduction

Ostriches are a recently domesticated species in relation to animals such as poultry and cattle, which leaves scope for dramatic advances in their production. In the Cape region of South Africa, the domestication process started in 1865 with 80 tame birds (Mellett, 1985). Consequently, the behaviour of ostriches, in particular their temperament, is volatile in comparison with other livestock species that are currently being produced worldwide. That being as it is, with domestication comes human control and influence over factors such as nutrition. Consequently, various studies have been conducted and the results successfully implemented to better understand the nutritional requirements of ostriches (Smit, 1963; Gandini *et al.*, 1986; Du Preez, 1991; Mellett, 1992; Ullrey & Allen, 1996; Cilliers *et al.*, 1998; Brand & Olivier, 2011).

Nutritionally, the source of protein in the diet of any livestock species is of significant importance. An estimated 70% - 80% of the input costs in a slaughter ostrich enterprise are attributed to the feeding of the birds (Brand & Gous, 2006). Slaughter ostriches generally receive four diets according to their age and physiological development, namely pre-starter, starter, grower and finisher diets. With protein constituting up to 22.9% of the diet fed to ostriches (Brand & Gous, 2006) depending on the feeding phase, optimizing and understanding the protein requirements of the birds becomes of paramount importance.

From a producer's point of view the most viable solution in terms of nutrition, without compromising the quality of the products, is the most desirable. Therefore in this study, the effects of the varying concentrations

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of protein in the diets of slaughter ostriches were evaluated for dry matter intake (DMI), average daily gain (ADG) and feed conversion ratio (FCR). The resultant growth response was also analysed, with the impact on the slaughter parameters.

Materials and Methods

This trial was conducted at Oudtshoorn Research Farm (situated 22˚20' E, 33˚58' S at an altitude of 307 m) in the Klein Karoo region of South Africa. The trial was structured with five treatments, including three replications per treatment. A total of 300 ostrich chicks were randomly assigned to the 15 separate groups, with each group containing 20 young growing chicks. The groups were kept in separate camps with adequate shelter and approximate dimensions of 20 m x 5 m, until they reached the age of 213 days. They were then transferred to larger camps of approximately 25 m x 25 m to accommodate their growth and prevent unnecessary damage to their skins that might be caused by overcrowded conditions.

The five groups received separate diets, which were formulated to contain various levels of essential amino acids with a specific profile (refer to protein level), namely diet 1 through diet 5. Diet 3 was formulated according to the optimization model developed by Gous & Brand (2008), and therefore acted as the control. Thus, in this trial the ostriches were fed according to standard practice, but with five treatments. The diets, which were formulated on a least cost basis, are presented in Tables 1 to 4. The chemical compositions of the diets are presented in Table 5, while the amino acid profiles are displayed in Table 6.

Table 1 Composition of the five treatment diets (as fed basis) in the pre-starter phase of slaughter ostriches (kg/ton) fed from 0 to 79 days old

Raw materials (kg)	Diet number (% crude protein)				
	1 (15.2%)	**2 (17.1%)**	**3 (19.0%) (control)**	**4 (20.9%)**	**5 (22.8%)**
Maize meal	575.00	550.00	525.00	500.00	475.00
Soybean oilcake meal	105.40	142.83	180.25	217.68	255.10
Fishmeal	50.00	62.50	75.00	87.50	100.00
Full fat soybean meal	50.00	40.53	31.05	21.58	12.10
Bentonite	25.00	25.00	25.00	25.00	50.00
Lucerne meal	50.00	43.75	37.50	31.25	25.00
Wheat bran	43.70	32.78	21.85	10.93	0.00
Plant oil	47.10	45.48	43.85	42.23	40.60
Monocalcium phosphate	24.00	23.73	23.45	23.18	22.90
Limestone	13.00	10.43	7.85	5.28	2.70
Salt	10.00	10.00	10.00	10.00	10.00
Synthetic lysine	1.80	1.75	1.70	1.65	1.60
Mineral and vitamin premix*	5.00	5.00	5.00	5.00	5.00

*Refer to Annexure A in Viviers (2015) for the composition of the vitamin and mineral premix

As mentioned, the middle diet (Diet 3) served as the control diet. Diets 1 and 2 were formulated to contain 20% and 10%, respectively, less protein than the control. The protein content was increased by 10% and 20% in diets 4 and 5, respectively, from that of the control diet. The energy contents of the diets were kept constant to investigate the effects that dietary protein would have on the production parameters of ostriches.

Table 2 Composition of the five treatment diets (as fed basis) in the starter phase of slaughter ostriches (kg/ton) fed from 80 to 157 days old

Raw materials (kg)	**Diet number (% crude protein)**				
	1 (13.1%)	**2 (14.3%)**	**3 (15.5%) (control)**	**4 (16.7%)**	**5 (17.8%)**
Maize meal	544.60	510.15	475.70	440.60	405.50
Soybean oilcake meal	100.00	132.50	165.00	198.00	231.00
Lucerne meal	100.00	100.00	100.00	100.00	100.00
Wheat bran	100.00	100.00	100.00	100.00	100.00
Bentonite	50.00	50.00	50.00	50.00	50.00
Molasses meal	40.00	40.00	40.00	40.00	40.00
Plant oils	15.50	17.75	20.00	22.50	25.00
Monocalcium phosphate	10.60	10.10	9.60	9.05	8.50
Limestone	22.00	22.00	22.00	22.00	22.00
Salt	10.00	10.00	10.00	10.00	10.00
Synthetic lysine	2.30	2.50	2.70	2.85	3.00
Mineral and vitamin premix*	5.00	5.00	5.00	5.00	5.00

*Refer to Annexure A in Viviers (2015) for the composition of the vitamin and mineral premix.

Table 3 Composition of the five treatment diets (as fed basis) in the grower phase of slaughter ostriches (kg/ton) fed from 158 to 241 days old

Raw materials (kg)	**Diet number (% crude protein)**				
	1 (13.1%)	**2 (13.28%)**	**3 (14.25%) (control)**	**4 (15.23%)**	**5 (16.20%)**
Maize meal	451.00	432.00	413.00	393.50	374.00
Soybean oilcake meal	37.90	63.65	89.40	115.15	140.90
Lucerne meal	444.87	438.33	431.78	425.74	419.70
Molasses meal	40.00	40.00	40.00	40.00	40.00
Monocalcium phosphate	18.30	17.70	17.10	16.50	15.90
Limestone	6.00	6.30	6.60	6.91	7.21
Salt	10.00	10.00	10.00	10.00	10.00
Synthetic lysine	1.25	1.29	1.32	1.35	1.38
Synthetic methionine	0.68	0.74	0.80	0.86	0.91
Mineral and vitamin premix*	5.00	5.00	5.00	5.00	5.00

*Refer to Annexure A in Viviers (2015) for the composition of the vitamin and mineral premix

The ostriches were fed their diets ad libitum, and had free access to clean fresh water. They were weighed once weekly on the same day for the duration of the trial, and their live weights were recorded to determine ADG. Feed intake per camp was measured weekly by weighing back the refusals for the week and subtracting the value from the quantity of feed offered during the week. FCR per treatment was then calculated by dividing the DMI by the ADG. The protein efficiency ratio (PER) was determined by using the percentage of protein in the diet as a factor of the daily intake per bird to give the protein intake (PI) in kilogrammes per kilogram weight gain per bird. Therefore, the calculation that yielded the PER was taken as the ADG of the birds divided by PI. Inclement weather resulted in the cancellation of three weighing sessions to prevent injury to the animals and the handlers. However, feed refusals could still be recorded.

Table 4 Composition of the five treatment diets (as fed basis) in the finisher phase of slaughter ostriches (kg/ton) fed from 242 to 360 days old

Raw materials (kg)	Diet number (% crude protein)				
	1 (11.8%)	2 (12.2%)	3 (12.6%) (control)	4 (13.0%)	5 (13.4%)
Maize meal	200.00	200.00	200.00	200.00	200.00
Soybean oilcake meal	0.00	12.50	25.00	37.50	50.00
Lucerne meal	250.00	250.00	250.00	250.00	250.00
Wheat bran	306.00	293.00	280.00	266.90	253.90
Oat bran	97.00	97.00	97.00	97.00	97.00
Molasses meal	50.00	50.00	50.00	50.00	50.00
Bentonite	50.00	50.00	50.00	50.00	50.00
Monocalcium phosphate	20.40	20.10	19.90	19.60	19.30
Limestone	10.70	10.80	10.90	10.90	11.00
Salt	10.00	10.00	10.00	10.00	10.00
Synthetic lysine	0.30	0.60	1.00	1.30	1.60
Synthetic methionine	0.60	1.00	1.40	1.80	2.20
Mineral and vitamin premix*	5.00	5.00	5.00	5.00	5.00

*Refer to Annexure A in Viviers (2015) for the composition of the vitamin and mineral premix

At 12 months old, the birds were placed into a quarantine camp for 14 days, as specified by the European Union (EU) meat quality standards (Department of Agriculture, 2013). At this point the birds all received a standard diet, because the facilities that were available, namely one large quarantine camp, dictated the decision. The birds were also tested for strains of avian influenza (AI), which resulted in positive sera screening for the H5N2 and the H6N2 strains. This meant that the slaughter of the ostriches would not be permitted until the whole flock was free of the strains of the virus, and they were reassigned into their trial camps for a further six weeks, when they received the treatment diets once more. Consequently, the ostriches were placed in the quarantine camp again for the mandatory 14 days before slaughter. The ostriches were again tested for AI. After a negative result, permission was granted to slaughter the birds. At this point the birds had attained the age of 13.5 months.

The birds were transported to Mosstrich Abattoir in Mossel Bay, approximately 100 kilometres from the research farm, owing to limited availability at the nearby abattoir in Oudtshoorn. The live weight of each animal was recorded and standard slaughtering procedures were followed (Hoffman, 2012), with the use of The Divac Ostrich Stunning box®.

Warm carcass weights were recorded once skinning and evisceration had taken place, then the carcasses were moved to the cold storage facility. The cold carcass weights were only measured after 72 hours because the slaughter day was at the end of the working week. The ostrich carcass comprises only the neck, wings, chest and thighs of the bird. The cold carcass weight is used to determine the dressing percentage as a proportion of live weight at slaughter. The right thigh weight of each ostrich was recorded and multiplied by two to indicate the proportion of the total weight of the carcass.

Table 5 Nutritional composition (as formulated basis) of experimental diets containing five levels of protein (diets 1, 2, 3, 4, and 5) fed to ostriches during the pre-starter (0 to 79 days) and starter (80 to 157 days) phases

	Diet number									
	Pre-starter					Starter				
	1	2	3 (control)	4	5	1	2	3 (control)	4	5
Nutrient										
ME[1] MJ/kg feed*	14.5	14.5	14.5	14.5	14.5	13.5	13.5	13.5	13.5	13.5
Dry matter (g/kg)	903.1	902.9	902.7	902.5	902.3	898.0	898.2	898.4	898.6	898.8
Crude protein(g/kg)	152.0	171.3	190.4	209.2	228.0	131.1	142.8	154.5	166.2	177.9
Crude ash (g/kg)	24.9	25.3	25.8	26.2	26.6	23.8	23.4	22.9	22.5	22.0
Crude fibre (g/kg)	40.4	40.9	41.4	41.9	42.3	55.5	57.1	58.6	60.2	61.7
Ether extract (g/kg)	84.0	80.4	76.7	73.0	69.5	45.5	46.8	48.1	49.4	50.7
Calcium (g/kg)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Phosphorus (g/kg)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Amino acids										
Protein %	152.0	171.3	190.4	209.2	228.0	131.1	142.8	154.5	166.2	177.9
Lysine	10.1	11.4	12.6	13.9	15.1	7.40	8.35	9.30	10.25	11.2
Methionine	3.50	3.95	4.40	4.85	5.30	2.60	2.95	3.30	3.65	4.00
Cysteine	1.00	1.10	1.20	1.30	1.40	0.80	0.90	1.00	1.10	1.20
TSAA[2]*	4.50	5.05	5.60	6.15	6.70	3.40	3.85	4.30	4.75	5.20
Threonine	5.80	6.50	7.20	7.90	8.60	4.30	4.85	5.40	5.95	6.50
Tryptophan	1.40	1.60	1.80	2.00	2.20	1.10	1.25	1.40	1.55	1.70
Arginine	9.50	10.7	11.9	13.1	14.3	7.10	8.00	8.90	9.80	10.7

*As formulated
[1]Metabolizable energy
[2]Total sulphur containing amino acids

Table 6 Nutritional composition (as formulated basis) of experimental diets containing five levels of protein (diets 1, 2, 3, 4 and 5) fed to ostriches during the grower (158 to 241 days) and finisher (242 to 360 days) phases

	Diet number									
	Grower					Finisher				
	1	2	3 (control)	4	5	1	2	3 (control)	4	5
Nutrient										
ME[1] MJ/kg feed*	11.5	11.5	11.5	11.5	11.5	10.7	10.7	10.7	10.7	10.7
Dry matter (g/kg)	909.4	909.1	908.9	908.6	908.5	908.3	908.4	908.5	908.6	908.6
Crude protein (g/kg)	123.5	133.1	142.7	152.3	161.9	117.7	121.9	126.0	130.1	134.1
Crude ash (g/kg)	49.0	48.1	47.3	46.5	45.6	54.7	53.8	53.0	52.3	51.5
Crude fibre (g/kg)	120.0	119.8	119.6	119.4	119.2	132.5	132.0	131.4	130.9	130.3
Ether extract (g/kg)	24.4	24.2	24.0	23.8	23.5	23.9	23.8	23.6	23.5	23.3
Calcium (g/kg)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Phosphorus (g/kg)	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Amino acids										
Protein %	123.5	133.1	142.7	152.3	161.9	117.7	121.9	126.0	130.1	134.1
Lysine	5.60	6.30	7.00	7.80	8.40	4.40	4.95	5.50	6.05	6.60
Methionine	2.00	2.25	2.50	2.75	3.00	1.50	1.70	1.90	2.10	2.30
Cysteine	0.70	0.80	0.90	1.00	1.10	1.50	1.55	1.60	1.65	1.70
TSAA[2]*	2.70	3.05	3.40	3.75	4.10	3.00	3.25	3.50	3.75	4.00
Threonine	3.40	3.80	4.20	4.60	5.00	3.60	3.75	3.90	4.05	4.20
Tryptophan	0.90	1.00	1.10	1.20	1.30	1.60	1.65	1.70	1.75	1.80
Arginine	5.40	6.10	6.80	7.50	8.20	5.90	5.93	5.95	5.98	6.00

*As formulated
[1] Metabolizable energy
[2] Total sulphur containing amino acids

Statistical analysis was done with SAS Enterprise Guide (version 9.2). A regression analysis was carried out per treatment diet over age to assess the weight gains by the birds. The Gompertz growth model was fitted to the curves of the diets and the slopes were compared to assess differences in weight gain using analysis of variance (ANOVA). In addition, regression was run per treatment over age within each feeding phase and the slopes were compared per physiological phase. In the pre-starter and starter phases a linear function was fitted to the data. In the grower phase, the Mitscherlich function (natural growth) was fitted over age, because of a severe drop in feed intake as the result of sickness in the flock, which was aggravated by clipping (standard operating procedures in a commercial flock) at 240 days old and the onset of winter, which affected their daily gains and therefore their overall bodyweight gains during this period. A linear function was then applied to the data in the finisher phase. ANOVAs were conducted on averages for the production parameters, namely DMI, ADG, FCR, and PER, because no distinct trends were observed in the slopes per treatment. One-way ANOVAs were done on the traits that were measured at slaughter, such as live weight, cold carcass weight, right thigh weight and dressing percentages to identify differences between treatments.

Results

The diets were found to have an effect (P <0.05) on all the production indicators in at least one of the four feeding phases (Table 7). Diet had an effect (P <0.05) on ADG in the pre-starter and starter phases. Diets 4 and 5 had the highest ADG in the pre-starter phase, while diet 1 had the lowest gains across the pre-starter and starter phases. No differences (P >0.05) were found among the diets for ADG in the grower and finisher phases. However, over the whole trial, there were no differences (P <0.05) between treatments 3, 4 and 5, but these treatments were higher in ADG than diets 1 and 2 (P >0.05). Diets 1 and 2 also differed (P <0.05) between themselves.

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Table 7 Least square means ± standard error (LSM ± SE) for the effect of dietary protein concentrations on the production traits of slaughter ostriches

Production Trait	**Phase**	**Diet**				
		1	**2**	**3**	**4**	**5**
Dry Matter Intake (DMI) (kg/bird/day)	All phases	1.43^{a} ± 0.02	1.51^{a} ± 0.06	1.65^{b} ± 0.03	1.64^{b} ± 0.02	1.68^{b} ± 0.03
	Pre-starter	0.40^{a} ± 0.04	0.42^{a} ± 0.02	0.48^{ab} ± 0.02	0.56^{bc} ± 0.001	0.61$_{c}$ ± 0.04
	Starter	1.06^{a} ± 0.09	1.32^{b} ± 0.07	1.46^{b} ± 0.08	1.50^{b} ± 0.01	1.46^{b} ± 0.02
	Grower	1.73^{a} ± 0.06	1.97^{ab} ± 0.21	2.32^{b} ± 0.15	2.26^{b} ± 0.07	2.27^{b} ± 0.01
	Finisher	2.29 ± 0.02	2.38 ± 0.09	2.45 ± 0.07	2.36 ± 0.09	2.40 ± 0.06
Average Daily Gain (ADG) (g/bird/day)	All phases	259.4^{a} ± 7.1	298.9^{b} ± 1.4	340.4^{c} ± 15.1	346.9^{c} ± 9.0	344.9^{c} ± 3.8
	Pre-starter	137.2^{a} ± 12.4	171.7^{ab} ± 14.8	208.1^{bc} ± 12.7	243.4^{cd} ± 11.9	277.3^{d} ± 6.9
	Starter	291.7^{a} ± 17.1	362.6^{b} ± 18.7	427.3^{c} ± 11.3	445.9^{c} ± 13.5	456.0^{c} ± 19.1
	Grower	428.4 ± 21.8	446.4 ± 29.8	456.0 ± 12.6	435.3 ± 17.2	415.6 ± 11.5
	Finisher	250.0 ± 6.8	296.0 ± 27.7	310.4 ± 41.7	309.4 ± 43.3	276.0 ± 13.6
Feed Conversion Ratio (FCR) (kg feed/kg weight gain)	All phases	5.52^{a} ± 0.06	5.07^{b} ± 0.21	4.86^{b} ± 0.12	4.72^{b} ± 0.18	4.88^{b} ± 0.04
	Pre-starter	2.88^{a} ± 0.04	2.48^{b} ± 0.10	2.32^{bc} ± 0.06	2.33^{bc} ± 0.14	2.18^{c} ± 0.08
	Starter	3.63^{a} ± 0.12	3.63^{a} ± 0.06	3.41^{ab} ± 0.11	3.36^{ab} ± 0.08	3.21^{b} ± 0.18
	Grower	4.04^{a} ± 0.12	4.40^{ab} ± 0.30	5.11^{bc} ± 0.36	5.20^{c} ± 0.22	5.46^{c} ± 0.13
	Finisher	9.17 ± 0.22	8.24 ± 1.13	8.14 ± 0.93	7.95 ± 1.21	8.74 ± 0.37
Protein Efficiency Ratio (PER)*	Pre-starter	2.21 ± 0.04	2.30 ± 0.12	2.18 ± 0.09	2.04 ± 0.13	2.01 ± 0.09
	Starter	2.12 ± 0.09	1.93 ± 0.04	1.92 ± 0.08	1.81 ± 0.06	1.78 ± 0.10
	Grower	2.01^{a} ± 0.07	1.73^{b} ± 0.12	1.41^{c} ± 0.10	1.27^{cd} ± 0.05	1.13^{d} ± 0.02
	Finisher	0.92 ± 0.06	1.05 ± 0.13	1.01 ± 0.13	1.08 ± .0.19	0.88 ± 0.02

^{a,b,c,d} Row means with different superscripts differ significantly (P <0.05)
*PER = ADG divided by PI

Differences (*P* <0.05) in DMI were found among the diets over the trial, as well as in the pre-starter, starter and grower phases. No differences (*P* >0.05) were found in the finisher phase, as was the case for ADG. The ostriches on the high protein concentration diets (4 and 5), had the highest DMI in the pre-starter phase. Diet 3 did not differ (*P* >0.05) from diet 4, but diets 1 and 2 had lower intakes (*P* <0.05) than the other diets. For the starter phase, only Diet 1 differed (*P* <0.05) from the other diets, with the lowest intake. Diet 4 had the highest DMI. A similar pattern was evident in the grower phase, where birds from diet 1 had the lowest intake. Although diet 2 did not differ (*P* >0.05) from diet 1, all the other diets had significantly higher (*P* <0.05) intakes, with birds on diet 3 consuming the most feed. No differences (*P* >0.05) were found for DMI in the finisher phase among the treatments. However, ostriches fed diets 3, 4 and 5 had higher intake per day over the whole trial. They were higher (*P* <0.05) than those attained by birds fed diets 1 and 2.

Feed conversion ratio, expressed as kilogram feed required to realize a kilogram bodyweight gain, also differed (*P* <0.05) between diets for the pre-starter, starter and grower phases. No differences (*P* >0.05) were found between the diets in the finisher phase. In the pre-starter phase, there were no differences (*P* >0.05) between diets 3, 4 and 5, with FCRs of 2.32 ± 0.06, 2.33 ± 0.14 and 2.18 ± 0.08, respectively. Diet 2, with an FCR of 2.48 ± 0.10, did not differ (*P* >0.05) from diets 3 and 4, but differed (*P* <0.05) from diet 1. Birds fed diet 1 required the most feed (2.88 ± 0.04 kg) to attain a unit of bodyweight gain of one kilogram. In the starter phase, diets 1 and 2 differed (*P* <0.05) from Diet 5, both with FCRs of 3.63, as opposed to 3.21 ± 0.18 for diet 5. Diets 3 and 4 did not differ from either of the other treatments, with FCRs of 3.41 ± 0.11 and 3.36 ± 0.08, respectively. Interestingly, in the grower phase, diets 1 (4.04 ± 0.12) and 2 (4.40 ± 0.30) attained lower FCR values than the other diets. Diet 1 differed (*P* <0.05) from diets 3 (5.11 ± 0.36), 4 (5.20 ± 0.22) and 5 (5.46 ± 0.13), while no differences (*P* >0.05) were found between diets 2 and 3. These findings contradict the general trends over the trial and in every other feeding phase. Similar to the other production measurements in the finisher phase, no differences (*P* >0.05) were found between the diets. Over the whole trial, however, birds fed diet 1 differed (*P* <0.05) from the rest of the birds with an FCR of 5.52 ± 0.06. Although not statistically different (*P* >0.05) from the remaining four diets, birds fed diet 4 had the lowest FCR of 4.72 ± 0.18.

Differences (*P* <0.05) were found in PER during the grower phase of the trial, but no differences (*P* >0.05) were found across the other feeding phases. Interestingly, in the grower phase, the PER values mirrored those in the same phase for FCR, with diet 1 (2.01 ± 0.07) outperforming diet 2 (1.73 ± 0.12), which had a higher PER value than the other three diets. Although the values for the PER decreased, and those for FCR increased in this example, the effect was the same because of the formula that is used to calculate PER, which is in effect an inverse of the FCR.

Regression models that were fitted over the four phases are presented in Table 8. At the end of the pre-starter phase, differences (*P* <0.05) were evident among the weights of the birds. No differences (*P* >0.05) were found between diets 1 and 2, but collectively they differed (*P* <0.05) from diets 3, 4 and 5. Diet 1 on average had the lightest group of birds at 12.6 ± 1.50 kg each, whereas birds that received diet 5 were the heaviest at 22.8 ± 0.74 kg.

At the end of the starter phase, differences (*P* <0.05) were evident between birds fed diets 1 (35.9 ± 2.39 kg) and 2 (45.7 ± 3.42 kg). Although diets 3 (55.5 ± 1.47 kg), 4 (56.0 ± 2.46 kg), and 5 (58.2 ± 1.23 kg) did not differ (*P* >0.05) from one other, collectively they had significantly higher (*P* <0.05) weights than the other two diets at the end of the phase.

The results from the grower phase mirrored those observed during the pre-starter phase. Diets 1 (58.0 ± 2.05 kg) and 2 (63.3 ± 4.08 kg) did not differ (*P* >0.05) from each other, but together they differed (*P* <0.05) from diets 3, 4 and 5, which had average weights of 73.6 ± 1.85 kg, 76.3 ± 3.26 kg and 74.1 ± 1.51 kg, respectively. Diets 3, 4 and 5 three diets did not differ (*P* >0.05) from one another.

Finally, in the finisher phase, no differences (*P* >0.05) were found between the treatments for the average weight of the birds at the end of this phase (Table 8).

Gompertz growth curves were fitted to the data over the feeding period (Figure 1).The growth measurements of a (maximum weight), b (rate of maturing parameter) and c (age of maximum growth) are presented for all of the treatment diets in Table 9. There were no differences for the a-values. However, differences were found in the b and c estimates. Birds fed diet 1 had the lowest estimates in terms of the value for the rate of maturing (b = 0.009), because they reached their maximum growth at 167 days old. There were no differences among the other treatment diets, but diet 5 had the highest rate of maturing (b = 0.012), which reflected in those birds that reached a (predicted) maximum age of growth in the least number of days (121 days) after the start of the trial (Table 9).

Table 8 Least square means ± standard error (LSM ± SE) for the effect of dietary protein concentrations on phase by phase weight of slaughter ostriches with the fitted functions

Dietary phase	Function fitted	Diets 1	2	3	4	5
Pre-starter (0 to 79 days)	Exponential $BW = a.\exp(b.x)$	12.6[a] ± 1.50	14.4[a] ± 2.34	20.4[b] ± 1.38	20.4[b] ± 1.60	22.8[b] ± 0.74
Starter (80 to 157 days)	Linear $BW = a + (b.x)$	35.9[a] ± 2.39	45.7[b] ± 3.42	55.5[c] ± 1.47	56.0[c] ± 2.46	58.2[c] ± 1.23
Grower (158 to 241 days)	Mitscherlich $BW = a + b(1 - \exp(c.x))$	58.0[a] ± 2.05	63.3[a] ± 4.08	73.6[b] ± 1.85	76.3[b] ± 3.26	74.1[b] ± 1.51
Finisher (242 to 360 days)	Linear $BW = a + (b.x)$	101.9 ± 5.10	97.3 ± 3.12	104.7 ± 3.92	105.7 ± 3.12	102.7 ± 3.32

[a,b] Row means with different superscripts differ significantly (P <0.05)
BW: live weight; a: mature BW in kg; b, c: parameter specific for each function

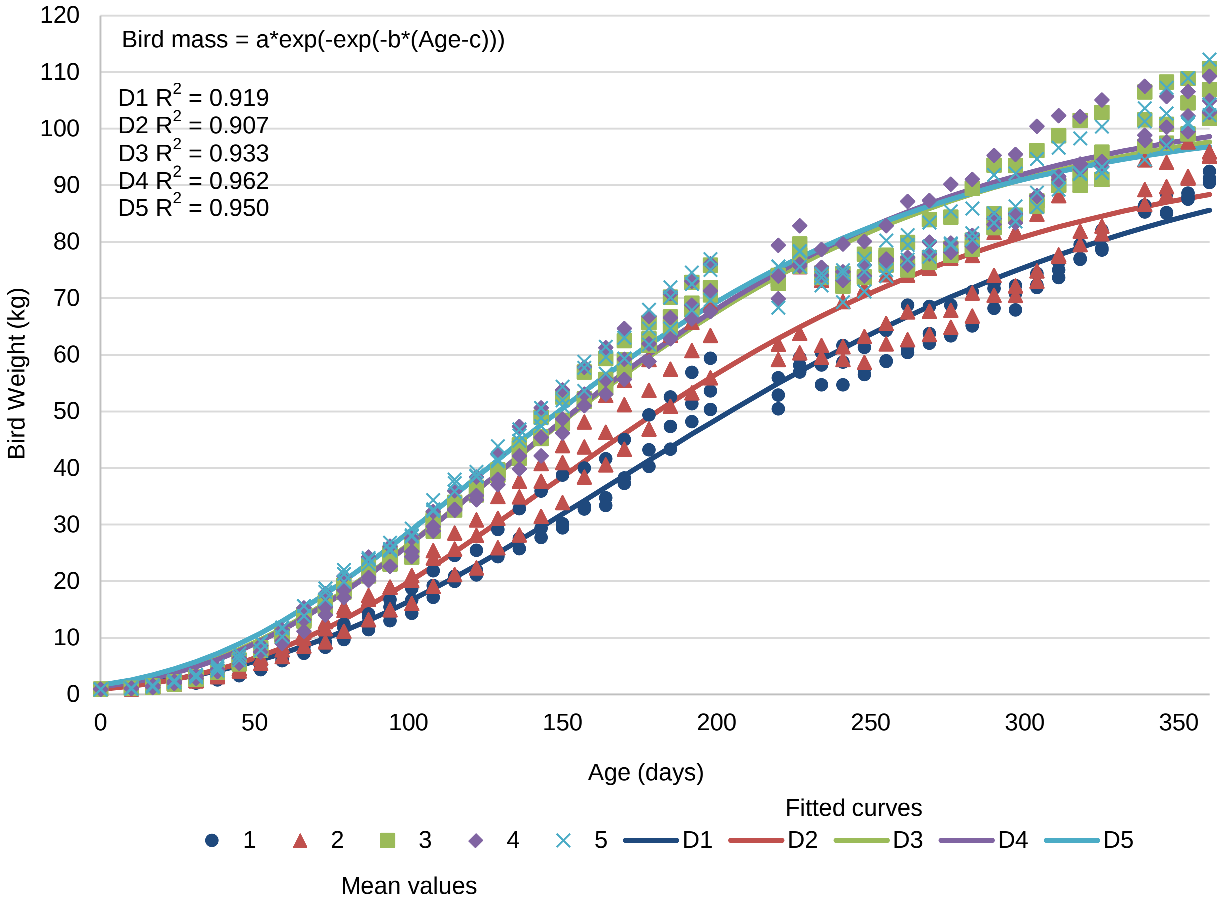

Figure 1 Gompertz growth curves fitted to ostriches body weight increase over time per treatment diet a) maximum weight, kg, b) rate of maturing parameter, and c) age of maximum growth, days

Table 9 Growth parameters ± standard error (S.E) of slaughter ostriches fed diets containing different levels of protein (diets 1, 2, 3, 4 and 5) as predicted by the Gompertz growth curve

Diet	Gompertz model parameters			
	a	**b**	**c**	R^2
1	101.9 ± 5.10	0.009^{a} ± 0.0007	167^{a} ± 12.14	0.919
2	97.3 ± 3.12	0.011^{ab} ± 0.0010	143^{ab} ± 10.77	0.907
3	104.7 ± 3.92	0.011^{b} ± 0.0002	128^{b} ± 2.86	0.933
4	105.7 ± 3.14	0.012^{b} ± 0.0002	128^{b} ± 1.86	0.962
5	102.7 ± 4.05	0.012^{b} ± 0.0008	121^{b} ± 3.32	0.950

^{a,b} Column means with different superscripts differ significantly (*P* <0.05)
a: maximum weight (kg), b: rate of maturing parameter, c: age of maximum growth (days)

Differences (*P* <0.05) were found between the treatments when average live weight at slaughter was considered (Table 10). Diets 1 (91.4 ± 1.37 kg) and 2 (96.8 ± 0.38 kg) had the lightest birds, while diets 3 (106.5 ± 2.23 kg), 4 (102.1 ± 1.46 kg) and 5 (104.4 ± 2.55 kg) did not differ (*P* >0.05. Diets 2 and 4 did not differ (*P* >0.05) from each other. These differences logically filtered down to the cold carcass weights, with diets 3, 4 and 5 having the highest weights of 51.6 ± 0.81 kg, 50.6 ± 0.66 kg and 52.0 ± 0.65 kg, respectively, which did not differ (*P* <0.05). Birds fed diet 2 had lighter carcasses (47.0 ± 0.27 kg), which differed (*P* <0.05) from the three treatments above and diet 1, with the lightest carcasses at 44.5 ± 0.62 kg. The right thigh weight from each bird was weighed, and differences (*P* <0.05) were again evident, which corresponded with the live weights and cold carcass weights of the birds. Diet 1 (16.2 ± 0.11 kg) had the lightest thigh weights, differing (*P* <0.05) from diet 2 (17.2 ± 0.14 kg), which was different (*P* <0.05) from diets 3, 4 and 5. Diets 3, 4 and 5 had right thigh weights that measured 18.8 ± 0.34 kg, 18.6 ± 0.24 kg, and 19.2 ± 0.29 kg, respectively.

No differences (*P* >0.05) were found among treatments in dressing percentages (Table 10). The right thigh weights were multiplied by two to give the weight of the two thighs together, from which the percentage of the thigh weights as a whole of the carcass weight was calculated. No differences (*P* <0.05) were found among the treatments (~73%).

Table 10 Least square means ± standard error (LSM ± SE) for the effect of dietary protein concentrations on slaughter traits for slaughter ostriches

Slaughter traits	Diets				
	1	**2**	**3**	**4**	**5**
Live weight (kg)	91.4^{a} ± 1.37	96.8^{ab} ± 0.38	106.5^{c} ± 2.23	102.1^{bc} ± 1.46	104.4^{c} ± 2.55
Cold carcass (kg)	44.5^{a} ± 0.62	47.0^{b} ± 0.27	51.6^{c} ± 0.81	50.6^{c} ± 0.66	52.0^{c} ± 0.65
Dressing percentage (%)	49.20 ± 0.25	48.74 ± 0.64	48.80 ± 0.37	49.64 ± 0.39	49.90 ± 0.64
Right thigh weight (kg)	16.2^{a} ± 0.11	17.2^{b} ± 0.14	18.8^{c} ± 0.34	18.6^{c} ± 0.24	19.2^{c} ± 0.29
Thigh (both) percentage of carcass (%)	73.02 ± 0.28	73.02 ± 0.15	73.05 ± 0.23	73.27 ± 0.23	73.11 ± 0.13

^{a,b,c} Row means with different superscripts differ significantly (*P* <0.05)

Discussion

During the pre-starter phase, the ADGs by the chicks that received diet 5 (228 g protein/kg feed) were more than double those achieved by the chicks fed diet 1 (152 g protein/kg feed). This supports findings by Gandini *et al.* (1986), who found superior growth in the pre-starter phase, if protein that ranged from 160 g/kg to 180 g/kg feed, was present in the diet. However, more recent work by Carstens (2013) found no differences in ADG for the three treatment groups (168 g protein/kg feed, 202.8 g protein/kg feed and 234.8 g protein/kg feed) that were used in the pre-starter phase. Brand *et al.* (2005) found that given the free choice of diet, slaughter ostriches preferred the one that contained the highest protein concentration.

Therefore, although the aims of the work by Brand *et al.* (2005) differ from this study, the underlying principle of increased intake by birds with access to higher protein levels was the same. An increased intake thus translates into increased ADGs, which was the case in this study.

During the starter phase, only diet 1 differed from the other treatment diets from a DMI point of view. Interestingly, though, diets 3, 4 and 5 had higher ADGs throughout this period, although their intakes did not differ from each other and diet 2. This was a consequence of decreased FCR in birds fed diets 3, 4 and 5, compared with diets 1 and 2. Aganga *et al.* (2003) suggested that protein levels ranging from 170 to 200 g/kg of feed should be used in the starter diet of ostriches. In this study, only diet 5 met those specifications with 178 g/kg feed. Although diet 5 yielded higher gains per day per bird and FCR was below that acquired by diets 1 (131 g protein/kg feed) and 2 (143 g protein/kg feed), there were no differences in these parameters between diets 3 (155 g protein/kg feed), 4 (167 g protein/kg feed) and 5. Therefore, it is possible that those specifications were higher than necessary, and more costly from a financial standpoint to manufacture such diets. This theory seems to be supported by lower levels of protein in starter diets in various studies (Brand *et al.*, 2000; Ahmed *et al.*, 2009; Carstens, 2013).

Glatz *et al.* (2008) found that birds in the grower phase that were fed on a lower protein concentration (126 g/kg feed) outperformed those that were fed a high protein concentration (143 g/kg feed) in DMI and ADG. The results in this study are contradictory, as no differences were found among the treatments for ADG. However, differences were found for DMI, with the higher levels of protein (diets 2, 3, 4 and 5) resulting in birds consuming more feed per day than those subjected to the lowest protein level (diet 1). The FCR results for the grower phase indicate that birds fed diets 1 and 2 were more efficient at converting feed to body mass, which was unexpected and different from the trend across the other phases. On the other hand, it explains how with decreased intake per bird, those in diets 1 and 2 managed to achieve the same daily gains as those birds that consumed more feed in the other three diets. These results were confirmed when the PER values were considered, which displayed a similar trend. The results for this phase may also have been affected by an extended period of decreased intakes and therefore of weight gains across all the camps. The onset of the cold winter weather, and managerial plucking may have contributed, but in all likelihood it was a common disease that affected the whole flock.

In the finisher phase, no differences were found among the treatments for the three production parameters that were measured in this trial. This may be because of the characteristic plateau that is observed in normal growth curves associated with slaughter ostriches at this stage (Cooper & Mahroze, 2004), as indicated by the Gompertz growth curves in Figure 1.

If DMI is broken down into phases, it is interesting to note the increase in feed intake in general throughout. This was expected because of the increased requirements by the birds as growth proceeded and gains in bodyweight were realised. Consequently, the maintenance requirement increased as the birds grew, therefore more nutrients would be needed, in addition to those for bodily functions for production (meat, skin and feathers). With regard to the ADG between phases of the trial, the grower phase yielded the best gains. These results support those produced by Carstens (2013), who found that daily gains increased from pre-starter through the grower phases, then decreased in the finisher phase. Kritzinger (2011) displayed the results in the form of a graph that described the allometry of growth of slaughter ostriches, which was supported by the results in this study.

With regard to FCR values over the course of the trial, a clear trend was seen, which indicated higher feed intake with increase in age and body weight. From a producer's viewpoint, therefore, it is paramount to ensure an optimal slaughter age when the growth rate of the birds decreases beyond a certain point, rendering continued feeding unviable.

With the aid of the Gompertz growth curves and parameter estimates made by the model, an educated reference to this point in the growth of the ostriches can be predicted accurately. Although no differences were predicted in the final weights of the ostriches at slaughter, differences were observed in the growth rates of the birds that were exposed to the diets. Birds that were subjected to higher levels of protein in their diets achieved faster growth rates and reached their maximum growth rate at a younger age than those with protein levels in their diet that were lower than those predicted as optimal by Brand (2006). A possible explanation for the birds that were fed lower protein concentrations yet managed to attain predicted slaughter weights that were not significantly different from those on higher protein feeds may be attributed to the phenomenon of compensatory growth. Strictly speaking, compensatory growth is said to occur when the plane of nutrition is increased beyond the current plane at the time of feeding (Lawrence & Fowler, 2002). This may have taken place when the feeding phase changed from grower to finisher at 242 days old. While no differences were found in predicted final bodyweights that were estimated by regression, differences were found between the treatments for average bodyweight of the birds at slaughter. These differences filtered down, as expected, to the cold carcass weights, which can lose 3% - 5% of their warm carcass weight in the first 24 hours of chilling (Rentfrow, 2010). Interestingly, the dressing percentages did not differ in this trial, which supports the results from other studies by Brand *et al.* (2004), Hoffman *et al.* (2008) and Carstens (2013). Generally, the results produced in this study tend to support the assumption that predicted values in terms of protein in ostrich diets are relatively optimal. With diet 3 in this study being formulated in accordance with the specifications predicted by the model proposed by Gous & Brand (2008), the findings back this assumption.

Conclusion

Levels of protein below the middle concentration, which was used as a control, yielded decreased production performance by the ostriches, because the quantities of proteins and amino acids in their diets were inadequate. On the other hand, an increase in the protein concentrations above the control diet did not generally yield a significant increase in performance. Therefore, it would be recommended that an increase in protein levels in the diets of slaughter ostriches above the middle diet should not be practised.

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Authors' Contributions

Concept and design: TSB; data collection and analysis: SFV; drafting of paper: JvdM; critical revision and final approval of version to be published: LCH. All the authors made substantial contributions to conception and design, acquisition of data, and analysis and interpretation of data. All the authors have seen and approved the manuscript being submitted.

Conflict of Interest Declaration

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

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