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Research Article

Nutritional Value of the Nile Crocodile (*Crocodylus niloticus*) Meal for Aquaculture Feeds in South Africa

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Abstract: The Nile crocodile (*Crocodylus niloticus*) aquaculture industry, primarily for the production of skins, is amongst the largest aquaculture industry in sub-Saharan Africa and produces a range of meat waste products. The aim of this study was to evaluate the nutritional value of raw and cooked meal derived from different parts of *Crocodylus niloticus* carcasses as a potential source of protein in animal feed production, especially fish. Proximate composition of major nutrients such as moisture, crude protein, crude fat, crude fibre, ash and selected minerals were analysed in October-November 2018 for comparison with other meal sources. Results indicated that *Crocodylus niloticus* derived meal is of a comparable quality for use in aquaculture feeds, compared to by-product meal quality reported for meal derived from bovine bones and meat, feathers, blood and other poultry by-products. Crocodile meal is hypothesised to be a suitable fishmeal replacement in the production of aquaculture feeds.

Keywords: Aquaculture; Fish nutrition; Fish production; proximate composition

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Introduction

The Nile crocodile (*Crocodylus niloticus*) of the family Crocodylidae is a widely distributed carnivorous reptile occurring throughout sub-Saharan Africa (Fergusson, 2010). It is the largest and most widely farmed species in Africa and is the only crocodilian species found in South Africa (Botha, 2005). The reptile uses a wide array of freshwater habitat types, including rivers, lakes, swamps, estuaries and other such as wetlands (Leslie and Spotila, 2001). Populations in South Africa are threatened by disturbance to wildlife stressors associated with cattle and human activity near nesting areas (Combrink et al., 2016), alien plants (primarily *Chromolaena odorata*) (Leslie and Spotila, 2001) and water pollution resulting in disease (Ashton, 2010; Woodborne et al., 2012). Other threats include habitat loss, indirect anthropogenic effects including water resource development, prey reduction and hunting for the artisanal trade in leather goods (Fergusson, 2010).

The aquaculture of *C. niloticus* has been established more than 25 years ago in southern Africa (Tosun, 2013). Commercial production of *C. niloticus* in the region is of noticeable economic and ecological importance. According to Flint et al., (2000); Nogueira and Nogueira-Filho, (2011), culturing of crocodiles can be used for enhancement of wild populations in selected areas, creation of jobs, environmental education programmes and collection of biological data on captive species and tourists attraction.

The *C. niloticus* production industry traditionally focuses on producing skins used in the production of high-quality fashion accessories (Ashton, 2010). The increase in production costs in this industry has forced the farmers to look at alternative means of increasing profitability in this industry (Hoffman et al., 2000). Tourism and meat production were identified as the major components of skin production. However, the demand for crocodile meat, especially in South Africa is very low and strict regulations are imposed onto the industry pertaining to the use and disposal of crocodile carcasses. Although (Hoffman et al., 2000), reported that crocodile meat produced can either exported or sold to the restaurant trade or used as unprocessed crocodile feed for other crocodiles on the farm, processing of crocodilian meat for human consumption always involves the farmer in strictly regulated abattoir management and additional responsibilities relating to packaging, labelling shipping and record keeping (Luxmoore, 1992). Furthermore, abattoirs facilities are costly to build, maintain and operate. The difficulty and expense involved in meeting the requirements of hygienic meat production has prompted farmers to dispose tons of whole crocodile carcasses (Luxmoore, 1992).

According to FAO et al. (2013), the world demand for proteins of animal origin is expected to double by 2050. New initiatives are required to produce the necessary quantities of high quality protein (Boland et al., 2013). There is a lack of published information on chemical composition of and associated nutritional value of crocodile carcass derived meal for aquaculture feeds. The aim of this study was to evaluate the chemical composition of and associated nutritional value of meal derived from different parts of *C. niloticus* carcass and compare with other meal used in aquaculture feeds. This research is part of an effort to diversify the use of crocodile meat by enhancing the knowledge of the chemical composition of *C. niloticus* meal and using meat as processed product while closing the gap in proteins of animal origin.

Materials and Methods

Sample preparation and analysis

Ten carcasses from 4 years old crocodiles were obtained from an abattoir at Albert falls Crocodile farm in Pietermaritzburg, KwaZulu-Natal province, South Africa. Crocodile carcass has no value after the skin has been removed. Each carcass was divided into legs, torsos and necks and then meat, fat and bones separated. Meats were then transported to University of KwaZulu-Natal, Pietermaritzburg campus for analysis. Some of meat samples were taken from the legs, neck, and torso and placed in polyethylene bags, vacuum sealed and placed in a water bath at 75ºC for 50 minutes to have a cooked samples for all parts. Thereafter the samples, still in bags were cooled under running water at 25ºC for 40 minutes (Hoffman et al., 2000). Then samples of raw meat and cooked meat were taken and dried (for easy grinding and increasing shelf life before further processing) in the oven at 100ºC for 3 hours and then grinded using a coffee blender. Sieved through 1.0 µ mesh sieve. Samples of raw meal and cooked meal of legs, torsos, necks, raw mixture and cooked mixture were analyzed in October-November 2018 at Soil Science and Animal Science departments at University of KwaZulu-Natal, Pietermaritzburg Campus for proximate analysis. All samples were replicated four times. Nitrogen (N) content was determined on a Leco TruMacR Carbon Nitrogen Sulfur elemental analyser using Dumas combustion. Crude protein was calculated as N x 6.25. Crude fat content was determined using Soxhlet method as described in AOAC Official method 920.39 (Horwitz, 1975). Crude fibre was determined as loss of ignition of dried lipid-free residues with 1.25% H_2SO_4 and 1.25% NaOH solutions using the filter bag technique with ANKOM Fibre analyser 200. Moisture content was determined using an air-circulated oven at 95ºC for 72 hours. Ash content was determined by burning pre-weighed samples in muffle furnace at 550ºC overnight as described in AOAC Official method 942.05. Minerals were determined using the Fast Sequential Atomic Absorption Spectrometer (AA280FS) (Paul et al., 2014), after ashing samples.

Statistical analysis

Statistical analyses were performed using SPSS software Version 25. The Shapiro–Wilk test was used to check if the data was normally distributed. One-way Analysis of Variance (ANOVA) was used to test for significant differences at a significant level of α=0.05 between the means of the treatment. The results were considered significantly different at a probability of $p<0.05$. Where there was a significant difference in means, Tukey’s multiple comparison test was used to compare the variance among the means.

Results

There was a significant difference in crude protein content of the meal from different parts of *C. niloticus* **(Table 1).** The differences among the means are shown in **Table 2**. High protein content that ranged between 81% to 85% for raw meal and 78% to 84.5% for cooked meal were obtained **(Table 2).**

Table 1: Proximate analysis of major nutrients of Nile crocodile (*Crocodylus niloticus*) meal from different parts.

Major nutrients	F	p
Crude protein	33.620	<0.001
Crude fat	17.068	<0.001
Crude fiber	12.218	<0.001
Ash	2.830	0.027
Moisture	1.857	0.122

DF: Degree of Freedom between groups=7, within=24; F: F Statistic; p: probability

There was a significant difference in crude fat, crude fibre, and ash content of meal from different parts of *C. niloticus* **(Table 1).** The differences among the means are shown in **Table 1.** Crude fat content ranged between 3.63% to 8.46% for raw meal and 6.22% to 8.75% for cooked meal **(Table 2).** Crude fibre ranged between -0.03% to 0.04% for raw meal and -0.02% to 0.26% for cooked meal **(Table 2).** Ash content ranged between 2.41 and 3.2 for raw meal and 2.66% to 3.83% for cooked meal **(Table 2).**

There was no significant difference in moisture content of the meal from all different parts of *C. niloticus* **(Table 1).** Mean values ranged between 8.73% to 12.40% for raw meal and 11.0450% to 12.39% for cooked meal **(Table 2).**

Table 2: Mean crude protein, moisture, crude fat, crude fibre, ash and overall average for raw and cooked meal from leg, neck, torso and mixture of three parts (leg, neck, and torso) of the Nile crocodile, (*Crocodylus niloticus*). Values are means (± Standard Deviation) of four replicates for each part.

Components[1]	Raw leg	Raw Neck	Raw Torso	Raw Mixture	Cooked Leg	Cooked Neck	Cooked Torso	Cooked Mixture
Crude protein	85.06 ± 0.25^{a}	82.11 ± 0.17^{b}	81.05± 1.30^{bc}	83.04 ± 0.14^{bd}	84.55 ± 1.69^{ad}	80.02 ± 0.39^{c}	82.03 ± 0.23^{bce}	78.16 ± 0.30^{e}
Moisture	12.40 ± 0.88	9.75 ± 1.18	8.73 ± 2.72	9.78 ± 0.35	12.39 ± 0.81	12.03 ± 2.18	11.04 ± 1.17	12.19 ± 0.47
Crude fat	3.63 ± 0.26^{a}	8.45 ± 0.35^{b}	4.12 ± 0.07^{ac}	4.48 ± 2.86^{ad}	6.22 ± 0.12^{bcd}	8.22 ± 0.10^{bc}	8.13 ± 0.42^{bcde}	8.75 ± 0.34^{e}
Ash	3.24 ± 0.41^{a}	3.32 ± 0.46^{ab}	2.74 ± 0.41^{ab}	2.41 ± 0.42^{b}	3.23 ± 0.16^{ab}	3.08 ± 0.32^{ab}	2.83 ± 0.58^{ab}	2.66 ± 0.01^{ab}
Crude fibre	0.01 ± 0.07^{a}	0.04 ± 0.06^{ac}	-0.03 ± 0.06^{ab}	0.04± 0.04^{ab}	-0.02 ± 0.07^{ab}	0.26 ± 0.02^{b}	0.11 ± 0.02^{ac}	0.04 ± 0.04^{a}

[1]Mean values ± standard deviation within same row with different superscripts are significantly different (p<0.05).

Table 3: ANOVA results for selected minerals composition of the Nile crocodile, (*Crocodylus niloticus*) meal from different parts.

Minerals	F	p
Calcium	25.813	<0.001
Sodium	7.313	<0.001
Zinc	6.849	<0.001
Potassium	5.377	0.001
Magnesium	4.043	0.005
Aluminium	2.473	0.046
Iron	2.172	0.074
Copper	0. 915	0.512

DF=Degree of Freedom between groups=7, within=24; F: F statistic; p: probability

Table 4: Mean (±Standard Deviation) of selected minerals for raw and cooked meal from leg, neck torso and mixture of three parts (leg, neck, and torso) of the Nile crocodile, (*Crocodylus niloticus*). Values are means (± SD) of four replicates for each part.

Minerals[1]	Raw Leg	Raw Neck	Raw Torso	Raw Mixture	Cooked Leg	Cooked Neck	Cooked Torso	CookedMixture
Potassium	39.67 ± 0.30^{a}	38.20 ± 1.77^{a}	37.23 ± 1.69^{a}	32.90 ± 6.15^{ab}	32.11 ± 5.72^{ab}	34.60 ± 2.60^{ab}	34.71 ± 1.67^{ab}	27.66 ± 1.07^{b}
Sodium	11.24 ± 0.16^{a}	8.72 ± 0.61^{b}	10.98 ± 0.42^{a}	11.17 ± 1.28^{ac}	9.27 ± 1.34^{ab}	11.44 ± 0.18^{ac}	9.67 ± 0.69^{ab}	10.66 ± 0.32^{ac}
Calcium	1.42 ± 0.06^{a}	2.30 ± 0.02^{b}	2.11 ± 0.03^{b}	1.93 ± 0.07^{b}	1.86 ± 0.33^{abc}	1.40 ± 0.05^{ad}	1.73 ± 0.33^{abc}	2.80± 0.18^{bc}
Magnesium	1.54 ± 0.08^{a}	1.69 ± 0.12^{a}	1.62 ± 0.08^{ab}	1.49 ± 0.08^{a}	1.41 ± 0.20^{ab}	1.50 ± 0.05^{abc}	1.78 ± 0.14^{abc}	1.59 ± 0.08^{abc}
Zinc	0.35 ± 0.05^{a}	0.15 ± 0.09^{b}	0.20 ± 0.02^{bc}	0.22 ± 0.01^{bc}	0.21 ± 0.02^{bc}	0.27 ± 0.02^{c}	0.20 ± 0.03^{bc}	0.23 ± 0.02^{bc}
Iron	0.22 ± 0.02	0.12 ± 0.02	0.21 ± 0.05	0.21 ± 0.02	0.16 ± 0.01	0.21 ± 0.01	0.24 ± 0.11	0.18 ± 0.05
Aluminium	0.13 ± 0.03^{ab}	0.10 ± 0.02^{ab}	0.15 ± 0.02^{ab}	0.16 ± 0.01^{ab}	0.16 ± 0.02^{ab}	0.17 ± 0.03^{a}	0.15 ± 0.02^{ab}	0.16 ± 0.03^{ab}
Copper	0.09 ± 0.03	0.07 ± 0.02	0.06 ± 0.04	0.04 ± 0.01	0.01 ± 0.03	0.01 ± 0.02	0.01 ± 0.03	0.27 ± 0.05

[1]Mean values ± Standard Deviation in the same row with different superscripts are significantly different (p<0.05)

There was no significant difference in Iron and Copper content of meal among different parts of *C. niloticus* **(Table 3)**. Mean values ranged between 0.12% to 0.22% for raw meal and 0.16% to 0.24% cooked meal for Iron **(Table 4).** Mean values for Copper ranged between 0.04% to 0.09% for raw meal, and 0.01% to 0.27% for cooked meal **(Table 4).**

There was a significant difference in Potassium, Sodium, Calcium, Magnesium, Zinc, and Aluminium contents of *C. niloticus* meal from different parts **(Table 3).** The differences among means are shown in **Table 4**.

Discussion

The chemical composition of meal derived from *C. niloticus* carcasses including nutritional value were evaluated for consideration to use as fishmeal replacement in aquaculture feeds. According to Gatlin et al. (2007), the candidate ingredient to be considered as suitable to replace fish meal must be a widely available, have a competitive price, be ease to produce, handle, ship and store for use in feed production. Furthermore, it must possess certain critical nutritional characteristics, such as low levels of fibre, starch, especially non□soluble carbohydrates and anti-nutrients, and have a relatively high protein content, favourable amino acid profile, high nutrient digestibility and reasonable palatability (Gatlin et al., 2007).

According to (Ahn, 2014), moisture content in feedstuff is an important factor for sale, purchase, transportation and storage. Furthermore, high moisture content can result in moulding and shorten the shelf life of the meal. Recommended maximum moisture content for different grades of fishmeal (Tacon et al., 2009) and for quality specification for purchasing by-products meal such as meat bone meal, meat meal, feather meal, blood meal and poultry by-product meal is 10% (Davis, 2015). *Crocodylus niloticus* derived meal tested in this study has averages of 10% for raw and 12% cooked moisture content which is within maximum recommended range reported by Tacon et al., (2009) and Davis, (2015), as there were no significant differences in raw and cooked meal from different parts of *C. niloticus* carcasses.

Results from the present study include significant differences in crude protein from *C. niloticus* meal derived from different parts. The content was higher than 60% in all parts (which is the highest minimum recommended level for grade 1 fishmeal reported by Tacon et al., 2009). Proteins are regarded as the major growth-promoting factor in feed, excess protein not utilized efficiently for growth are used for deamination and excretion of excess amino acids absorbed (Jauncey, 1982). Animal proteins source are considered good-quality proteins since they contain a good balance of essential amino acids.

According to Craig and Helfrich, (2009), fats are high-energy nutrients that can be utilized to partially spare protein in aquaculture feeds. Furthermore, fats supply about twice the energy as proteins and carbohydrates (Craig and Helfrich, 2009). A recent trend in fish feeds is to use higher levels of lipids/fats in the diet. Although increasing dietary lipids, may help reduce the high costs of diets by partially sparing protein in the feed, problems such as excessive fat deposition in the liver can decrease the health and market quality of fish (Craig and Helfrich, 2009). Crocodile meal analysed in this study had less than 10% crude fat, which is within maximum recommended for different grades of fishmeal (Tacon et al., 2009).

Fibre is known to provide physical bulk to the feed (De Silva and Anderson, 1994). Furthermore, a certain amount of fibre in feed permits better binding and moderates the passage of feed through the alimentary canal. According to De Silva and Anderson, (1994), it is not desirable to have a fibre content above 8-12% range in diets for fish because excessive fibre content results in lower digestibility of nutrients. The analysed crude fibre content of meal from different parts of crocodile under study were within the safe dietary limit for fish.

Minerals are inorganic elements necessary in the diet for normal body functions (Craig and Helfrich, 2009). According to Watanabe et al., (1997), fish may derive these minerals from the diet and also from ambient water. Even though they are required in small quantities, minerals are important for skeletal formation, maintenance of colloidal system, regulation of acid-base equilibrium and biologically important compounds such as hormones and enzymes (Watanabe et al., 1997). If excess amounts of the elements are ingested or assimilated, toxicity may develop and resulting in crocodile meal being unsuitable as animal feeds.

Considering recommended proximate composition of fish meal of different grades (Tacon et al., 2009) and quality specification for purchasing by-product meal such as meat bone meal, meat meal, feather meal, blood meal and poultry by-product meal (Davis, 2015), the results of currents study indicate that *C. niloticus* meal

Table 5: Comparison of proximate composition (%) of different nutrients from raw and cooked *Crocodylus niloticus* meal and the recommended values for fishmeal of different grades adapted from Tacon et al., 2009.

Nutrients	Tacon et al., 2009 values			Values from this study	
	Grade 1	Grade 2	Grade 3	Raw	Cooked
Moisture (%) maximum	10	10	10	10	12
Crude protein (%) minimum	60	50	40	83	81
Crude lipid (%) maximum	8	10	11	5	8
Ash (%) maximum	2	3	4	3	3
Hard and sharp solid materials	Not permitted				

Table 6: Quality specification for purchasing by-products meal from selected by products as recommended by Davis, 2015 and that of crocodile (*Crocodylus niloticus*) meal from the study.

	% values as recommended by Davis, 2015					Crocodile meal from this study	
Parameters	**Meat bone meal**	**Meat meal**	**Poultry by-product meal**	**Feather meal**	**Blood meal**	**Raw**	**Cooked**
Moisture (%) maximum	10	10	10	10	10	10	12
Protein (%) Minimum	50 or as specified	55 or as specified	58	80	85	83	81
Fat (%)	10	10	11	5	0.5- 2.0	5	8
Crude fibre (%) Maximum	3	3	3	4	2	0.02	0.09
Ash (%) Maximum	-	-	18	4	5	3	3

meet quality specifications and that means *C. niloticus* meal can be used as fishmeal replacer in aquaculture feeds **(Tables 5 and 6).**

Conclusion

Considering quality specification of by-product meal such as meat bone meal, meat meal, feather meal, blood meal and poultry by-product meal, our study showed that *C. niloticus* meal meet quality specifications for aquaculture feeds. Future studies should be aimed at determining the quality of crocodile meal in controlled animal feeding, by measuring growth performance, feed conversion ratio, health, physiology and digestibility of feeds containing crocodile meal.

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