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Carcass traits and primal pork cuts of growing Windsnyer pigs fed diets containing Amarula oil cake

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Abstract

Carcass characteristics and primal pork cuts of local pig breeds are rarely documented, therefore, the current study was conducted to establish the relation between incremental levels of Amarula oil cake (AOC), carcass traits, primal pork cuts, and relative internal organ weight of Windsnyer pigs. Twenty-five clinically healthy, growing, male Windsnyer pigs with an initial body weight of 19.92 ± 8.74 kg (mean ± standard deviation) were used. Pigs were used in their growing period when they were about 67 days old. The study lasted six weeks excluding one week of adaptation period. Pigs were allotted to pens in a completely randomized design and assigned to each of the five experimental diets, which contained 0, 50, 100, 150 and 200 g/kg DM of Amarula oil cake, respectively. Feed and water were offered *ad libitum*. Post slaughter, data for carcass characteristics, primal pork cuts, and relative organ weights of Windsnyer pigs were analysed using polynomial regression. There was a negative linear relationship between increasing levels of Amarula oil cake, carcass length, warm carcass weight and cold carcass weight. Stomach weight, backfat thickness, drip loss, and the hepatosomatic index increased linearly with increasing levels of Amarula oil cake. The kidneys, small intestines, and large intestine weight had a quadratic response to Amarula oil cake inclusion level. The heart, lungs, and spleen were not related to increasing levels of Amarula oil cake inclusion. Incremental levels of Amarula oil cake diets impaired carcass characteristics and the selected visceral organs, therefore Windsnyer pigs can be fed Amarula oil cake up to100 grams per kilograms dry matter.

Keywords: backfat thickness, carcass length, drip loss, hepatosomatic index, slow-growing pigs, warm carcass
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Introduction

Indigenous pigs are the main source of livelihood for most people globally, more especially for resource-limited farmers found in many developing countries (Halimani *et al*., 2010). Their production can therefore alleviate poverty and improve food security. Globally, the production of pork from indigenous pigs is very low, suggesting that most indigenous pig breeds found in rural communities are kept for home consumption and as cash investments (Madzimure *et al*., 2012). Indigenous pigs have a low feed conversion ratio. They, however, produce pork of good organoleptic properties and can be

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raised under low-cost conditions (Leterme *et al*., 2005; Halimani *et al*., 2012). The exploitation of indigenous pig breeds and providing knowledge about them is crucial and it contributes markedly to preserving their existence because of their distinct roles and functions in sustainable agricultural development (Chimonyo *et al.,* 2006).

Pig breeds in Africa are closely related to international pig breeds (Ramírez *et al*., 2009). The indigenous pig breeds of South Africa, such as the African-type pig, the Kolbroek and the Windsnyer pig are all classified as *Sus scrofa*. They exhibit similar characteristics to the strongly-introgressed Chinese and British pig breeds (Ramírez *et al*., 2009), suggesting that these pig breeds can thrive in other countries due to their genetic similarities. A commonly-found type of indigenous pig breed in South Africa is the Windsnyer pig. Its resilience to diseases and superior ability to utilise fibrous agricultural by-products has long been established (Kanengoni *et al*., 2014; Ncobela *et al*., 2018).

Amarula tree (*Sclerocarya birrea* subspecies caffra) is an African indigenous tree that is mostly found in the northern parts of Eswatini, Limpopo, Mpumalanga, and KwaZulu-Natal. The kernels are used for making traditional beverages, farmers use it to make protein supplement for poultry, and as a source of food by rural households (Mlambo *et al*., 2011; Mthiyane and Mhlanga, 2017). Amarula oil cake is a by-product of oil extraction from Amarula kernels. The nutritional characteristics of Amarula oil cake, such as high crude protein and fibre content, may influence carcass quality of pigs positively when used intensively. Kerr *et al*. (1995), reported poor carcass yield grades of pigs fed on reduced protein diets compared to carcass yield of pigs which were fed high crude protein diets. Therefore, the high crude protein content of Amarula might positively affect carcass grades of Windsnyer pigs. The ability of Windsnyer pigs to tolerate fibrous feeds might improve carcass characteristics of pigs. Fibrous diets negatively affected warm carcass weights of pigs due to increasing gut contents in the Mong Cai pig breed (Len *et al*., 2008). Jha *et al*. (2013) reported that incremental fibre levels in pig diets reduced carcass weight of pigs. Most fibrous feeds do not meet nutrient requirements of pigs, therefore, balanced diets such as Amarula oil cake, which provides both fibre and protein to Windsnyer pigs, might increase slaughter weight of Windsnyer pigs, hence improving carcass quality. Visceral organ weight accounts for about 15 % or less of the entire weight of animals (Yen, 1992) and they respond to inclusion of fibrous or tanniferous diets (Agyekum *et al*., 2012). Heavier relative weight of heart, liver, and kidneys was reported in pigs on high fibre diets compared to low fibre diets (Len *et al*., 2009). Dietary interventions that improve carcass traits of indigenous pigs are therefore, required.

Carcass length is a trait of economic importance that affects the weight of many pork cuts (Poto *et al*., 2007). Carcass dressed weights, carcass length, and carcass conformation are direct determinants of carcass grades and thereby revenue (Chimonyo *et al*., 2010). Understanding these carcass characteristics of Windsnyer pigs could provide knowledge to enhance the choices for health-conscious consumers. The relationships between carcass characteristics, primal pork cuts, and relative internal organs of Windsnyer pigs fed on Amarula oil cake (AOC) diets are poorly understood. Such knowledge might change the current negative perspective that policymakers and pork scientists have about indigenous pig breeds. The objective of the study was, therefore, to determine the relationship between incremental levels of AOC, carcass characteristics, primal pork cuts, and visceral organ weights of South African Windsnyer pigs. It was hypothesized that incremental levels of AOC would linearly increase carcass characteristics, primal pork cuts, and visceral organ weights of South African Windsnyer pigs.

Materials and methods

The experiment was conducted at Agricultural Research Council (ARC), Animal Production Institute (Irene, Pretoria, South Africa). The study site is located at 25°55′ S, 28°12′ E, and at an altitude of 1525 m above sea level. The average annual temperature is 19°C.

Amarula oil cake was sourced from African Exotic oils, Limpopo Province, South Africa. Prior to oil extraction of Amarula kernels, Amarula nuts were dried according to Malebana *et al*. (2021) and transported to the Agricultural Research Council for the formulation of experimental diets. Two experimental diets which included a total mixed ration and bulky ration were formulated. The total mixed ration was formulated to meet or exceed the nutritional requirements of growing Windsnyer pigs according to Carter *et al.* (2016) and was used as the summit diet. The bulky diet was formulated to contain 200 g/kg of AOC and was used as a dilution diet (Hlongwane *et al*., 2021). The other five experimental diets were formulated by mixing the summit diet with a dilution diet according to Gous & Morris (1985). The blending ratios of the experimental diets were as follows, 100:0, 75:25, 50:50, 25:75, and 0:100, respectively. The ingredient composition of the summit and dilution diets are shown in table 1.

Table 1 Ingredient composition of the summit and dilution diets (g/kg DM**)**

Ingredient	Summit diet	Dilution diet
Maize	545.1	609.8
Sunflower oil cake	150	-
Wheat bran	150	147.9
Sunflower oil	26.4	-
Monocalcium phosphate	8.9	8.3
Feed lime	12.4	19.7
Lysine	17.0	12.3
Amarula oil cake	-	200
Soybean oil cake	88.2	-
[#]Mineral and vitamin premix	2	2

[#] Provides (/kg DM of diet): vitamin A Acetate, 2 000 000 IU; vitamin D3, 400 000 IU; vitamin E, 1 000 mg; vitamin B1, 200 mg; vitamin B12, 0.5 mg; vitamin C, 1 000 mg; vitamin B2, 250 mg; vitamin B6, 200 mg; vitamin K3, 200 mg; calcium pantothenate, 500 mg; nicotinic acid, 1 000 mg; folic acid, 50 mg; di-methionine, 2 000 mg; cystine, 300 mg; lysine, 3 000 mg; arginine, 2 000 mg; tryptophan, 1 000 mg; DM, dry matter

The use of animals was approved by the Agricultural Research Council (ARC) Animal Production Institute Ethics Committee (reference number APAEC2019/17). A total of 25 healthy, South African Windsnyer, male pigs with an initial body weight of 19.92 ± 8.74 kg (mean ± standard deviation (SD) were used for the study. The pigs were 67 d old and were randomly selected at ARC–Irene pig breeding unit. The pigs were used for the growing period which lasted for six weeks, excluding a one-week adaptation period. Cleaning and disinfection of the trial facility was done before the arrival of pigs. After cleaning, the trial facility was retested for a week. The pigs were penned individually in a 1.5 x 0.9 m pens in environmentally-controlled housing. Pigs were allocated in a completely randomized block design and were also blocked by body weight with five replicates of pigs assigned to each experimental diet. The house temperature and humidity were 22.5 ± 2.10 °C and 47.5.2 ± 7.25 % (mean ± SD), respectively. Pigs were given a period of one week to adapt to the new environment and treatments. Feeders were monitored at least twice a day to ensure constant access to the experimental diets and lower any possible spillages during feed consumption. Feed and water were offered *ad libitum* to all pigs.

Samples of the experimental diets were collected and analysed in triplicate (n = 3) at the University of KwaZulu-Natal, Pietermaritzburg (South Africa), Animal Science Laboratory. Procedures from the Association of Official Analytical Chemists (AOAC, 2005 & 1990) were followed. The dry matter (DM) content was determined according to method 2001.12 (AOC, 2005), ash method 990.05 (AOC, 1990), crude protein method 1990.3 (AOC, 1990), and ether extract method 920.39 (AOC, 1990). The gross energy (GE) was determined with a bomb calorimetry (MS-1000 modular calorimeter, Energy Instrumentation, Centurion, South Africa). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to method by Van Soest *et al*. (1991). The bulk density, swelling, and water holding capacity of the diets was determined according to water displacement method described by Kyriazakis and Emmans (1995), Canibe & Bach Knudsen (2002), and Whittemore *et al*. (2003), respectively. Minerals were determined with the Varian 720 Inductively Coupled Plasma Emission Spectrometer (ICP–OES, Frankfurt, Germany) with an atomic absorption. Amino acids were determined with acid hydrolysis according to method 982.30 (AOAC, 1990). The nutrient composition of Amarula nut cake and experimental diets is shown in Table 2.

Table 2 Nutrient composition of Amarula nut cake and experimental diets of growing Windsnyer pigs

Components	Amarula	Amarula inclusion level (g/kg DM)				
		0	50	100	150	200
Dry matter (g/kg)	963.5	956.8	958.9	954.4	953.8	956.3
Ash (g/kg)	49.8	51.2	50.6	46.9	47.2	47.0
Crude protein (g/kg)	362.2	194.9	176.8	162.6	157.0	140.3
Ether extract (g/kg)	343.9	44.4	56.0	72.4	78.1	96.8
GE (MJ/kg DM)	25.3	17.7	17.7	17.8	18.1	18.5
NDF (g/kg)	357.3	305.9	312.3	327.5	341.3	353.0
ADF (g/kg)	245.6	85.8	93.4	99.5	111.2	121.1
ADL (g/kg)	114.3	19.4	25.8	34.7	42.9	48.6
Bulk density (g/ml)	1.7	1.5	1.5	1.6	1.6	1.7
SC (ml/g)	3.8	2.9	3.0	3.2	3.4	3.6
WHC (g_{water}/g_{feed} DM)	4.9	3.4	3.6	3.8	4.2	4.4
Minerals						
Calcium (g/kg)	1.8	7.1	7.9	8.3	8.3	8.2
Magnesium (g/kg)	5.7	2.4	2.2	2.1	2.1	2.0
Phosphorus (g/kg)	9.4	6.3	5.5	5.5	5.5	5.1
Potassium (g/kg)	8.3	7.9	6.6	6.2	5.8	5.1
Sodium (mg/kg)	345.7	243.2	255.4	239.8	233.8	227.3
Iron (mg/kg)	95.5	161.5	169.8	149.5	143.3	135.5
Copper (mg/kg)	27.9	73.3	58.4	58.2	60.2	59.8
Manganese (mg/kg)	10.2	84.9	73.8	70.2	84.6	63.0
Zinc (mg/kg)	60.2	48.5	44.8	45.0	42.2	38.7
Cobalt (mg/kg)	0.1	0.3	0.3	0.3	0.3	0.2
Molybdenum (mg/kg)	0.3	0.5	0.4	0.3	0.3	0.2
Calculated nutrients						
Dry matter (g/kg)	-	860.4	-	-	-	896.6
Crude protein (g/kg)	-	180.0	-	-	-	180.0
Ether extracts (g/kg)	-	63.2	-	-	-	87.6
Crude fibre (g/kg)	-	36.8	-	-	-	62.5
DE (MJ/kg DM)	-	13.8	-	-	-	13.8
Calcium (g/kg)	-	8.8	-	-	-	10.0
Phosphorus (g/kg)	-	6.0	-	-	-	6.0
M+C (%)	-	0.6	-	-	-	0.6
Methionine (%)	-	0.3	-	-	-	0.3
Lysine (%)	-	2.0	-	-	-	1.4

ADF – acid detergent fibre (g/kg DM), ADL – acid detergent lignin (g/kg DM); NDF – neutral detergent fibre (g/kg DM); WHC – water holding capacity (g_{water}/g_{feed} DM); M+C – methionine + cysteine, GE- gross energy, SC-swelling capacity, - denotes not detected

After the experimental feeding period, pigs were fasted for 24 h and weighed to determine the slaughter weight. Pigs were transported to the ARC abattoir located about 1.5 km from the trial facility for slaughter. All pigs were handled based on routine abattoir procedures of ARC, Irene, before slaughter and included the ante-mortem inspection by the ARC veterinarian. The pigs were then stunned with an electrical stunner set at 220 V and 1.8 A with a current flow for 6 s and exsanguinated within 10 s of stunning. Exsanguination, de-hairing, evisceration, and cutting were done according to Kanengoni *et al*. (2014). Carcass length (CL) was measured using a measuring tape from the first rib to the pubic bone and warm carcass weight was measured with a scale after dressing. The ham length was measured from the cranial edge of the pubic symphysis to the medio-distal point where the hind trotter was removed. Thereafter, carcasses were stored at the abattoir cold room and kept at 0 °C for 24 h. The dressing percentage was determined by considering warm carcass weight as a percentage of slaughter weight (SW). The cooler shrink (CS) was calculated from the carcasses under chill storage in a cold room (0 °C for 24 h) using the following formula:

$$\text{Cooler Shrink (\%)} = (1 – (\text{cold carcass weight} / \text{warm carcass weight}) \times 100 \quad (1)$$

The initial pH and temperature reading were taken immediately after slaughter from the *longissimus thoracis* muscle (eye muscle) using a pH meter. Prior the recording of pH, the pH meter electrode was calibrated at pH_4 and pH_7 buffers. Distilled water was used to rinse the electrodes after each measurement to avoid contamination amongst treatments. Carcasses were kept in a cold room and stored at ~0 °C for 24 h. Thereafter, measurements for cold carcass weights (CCW) were then taken. The final pH and temperature were recorded 24 h post slaughter.

Backfat measurements were taken at first rib (dorsal fat thickness at first rib, DFT1), last rib (dorsal fat thickness at last rib, DFT2), and last lumbar vertebra (dorsal fat thickness at last lumbar vertebra, DFT3) off the median plane cut surface (Kanengoni *et al*., 2014). All other carcass measurements were taken from the left side. The backfat depth was measured at P2 position of each carcass with a vernier calliper over the eye muscle, 60 mm from the carcass midline. From the same cut where P2 measurements were taken, a sample joint measuring 2.5 cm thick and 16 cm long measured along the surface of the back of the eye muscle was cut out and weighed (chop mass). This sample joint was placed in a nylon mesh and sealed in plastic bags, which was then tied in such a way as to prevent the sample joint from touching the bottom of the plastic bag or air coming into the bag. The sample was then stored in a refrigerator between 0 and 5 °C for 24 h, after which the mass of the water lost was calculated from the weight of the water in the bag and used to calculate the drip loss; this was done in all pigs (Kanengoni *et al*., 2014).

Upon slaughter, the heart, liver, lungs, spleen, kidney, stomach, and small and large intestines of each pig were removed and weighed separately with a digital scale. The contents of stomach, small intestines, and large intestines were emptied before recording their weight. The weight of visceral organs was scaled by dividing the weights of the heart, lungs, spleen, kidney, stomach, small, and large intestines with slaughter weight. The hepatosomatic index (HSI) was calculated by dividing the liver weight by slaughter weight and expressed as a percentage (Liu *et al*., 2009).

The normality of the data was determined using the PROC UNIVARIATE procedure of SAS, (2009). The LS means statement in SAS, (2009) was used to compare the least square means using the probability difference (PDIFF) option. Relationships between inclusion levels of Amarula oil cake and carcass characteristics, primal pork cuts, and relative organ weights were determined with the polynomial regression procedure of (SAS, 2009).

Results

Table 3 shows the relationship between incremental levels of Amarula oil cake diets, carcass traits, and primal pork cuts of South African Windsnyer pigs. Increasing inclusion levels of Amarula oil cake linearly reduced the slaughter weight, carcass length, warm carcass weight, and cold carcass weight of pigs (P < 0.05). Increasing inclusion levels of AOC led to a linear increase in backfat thickness and drip loss (P <0.05). Other carcass traits such as pHh_{45}, pH_{24}, $temperature_{45}$ and $temperature_{24}$, cooler shrink, dressing percentage, and shoulder fat showed no relationship with increasing inclusion level of AOC diets (P >0.05). The dorsal fat thickness (DFT3) decreased linearly with increasing inclusion levels of AOC (P <0.05). Other primal pork cut traits such as ham length, ham diameter, backfat depth at P2 position, dorsal fat thickness 1, dorsal fat thickness 2, hind quarter weight proportion, shoulder weight proportion, and rib weight proportion were not affected by increasing inclusion levels of Amarula oil cake (P >0.05). The relationship between AOC inclusion level with slaughter weight, carcass length, warm carcass weight, cold carcass weight, back fat thickness, drip loss and dorsal fat thickness of pigs is shown in Figure 1 (A–G).

Table 4 shows the relationship between incremental levels of Amarula oil cake and visceral organ weights of pigs. Increasing inclusion levels of Amarula oil cake diets increased the (hepatosomatic index) HIS and stomach weight of pigs linearly (P < 0.05). The kidneys, small intestines, and large intestine weights of Windsnyer pigs decreased quadratically with increasing inclusion levels of Amarula oil cake diets (P <0.05). The heart, lungs, and spleen showed no relationship with increasing inclusion levels of Amarula oil cake (P >0.05). The relationship between AOC inclusion level with hepatosomatic index, stomach weight, kidney weight, small intestine (SIW), and large intestine (LIW) weight of Windsnyer pigs is shown in Figure 2 (A–C).

Table 3 Relationship between increasing levels of Amarula oil cake, carcass traits and primal pork cuts of Windsnyer pigs

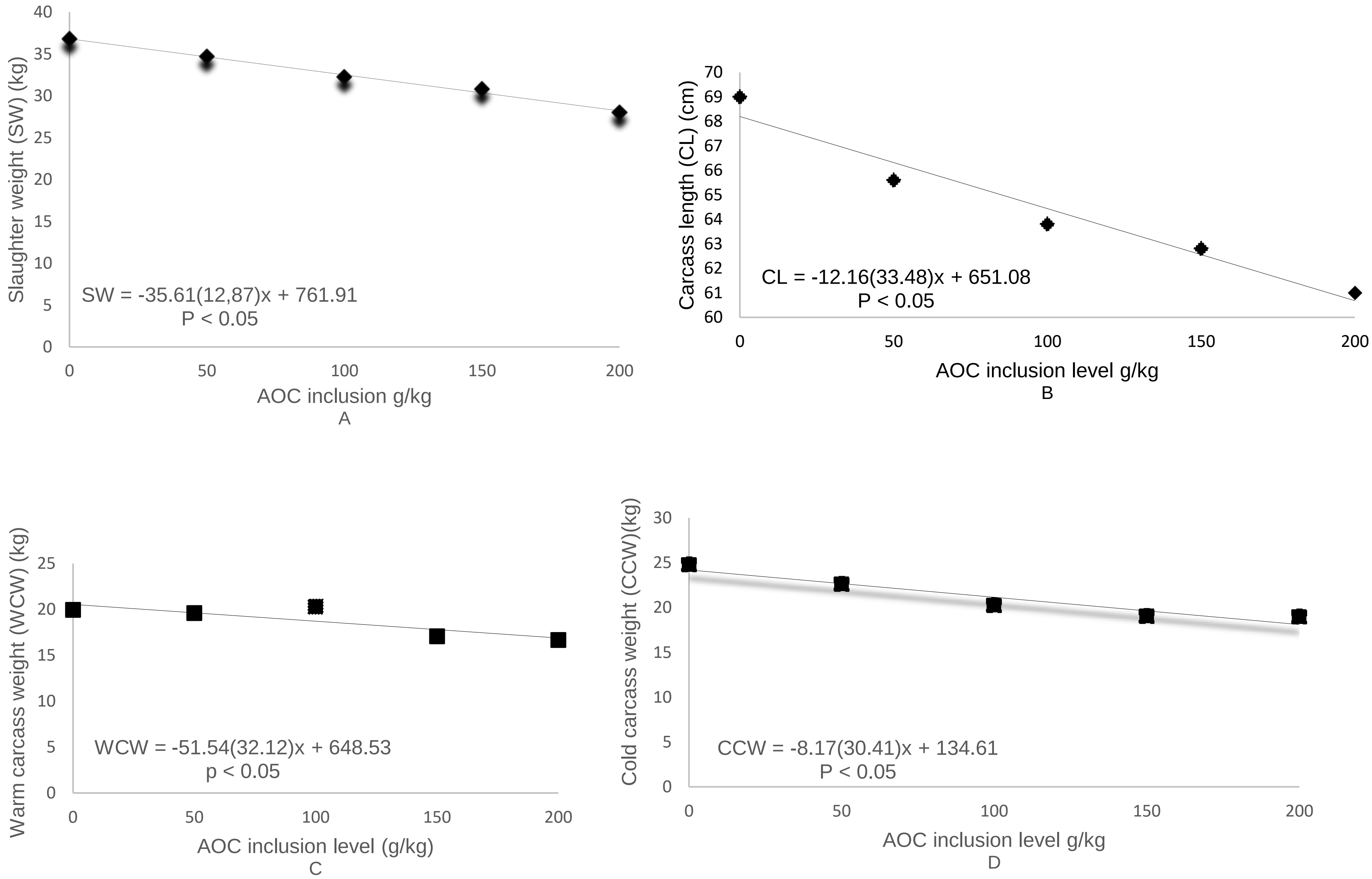
Measurements	Inclusion level of Amarula oil cake (g/kg DM)					SEM	Significance		
	0	50	100	150	200		Linear	Quadratic	R^2
Dressing percentage (%)	65.50	65.56	72.18	61.82	72.53	6.73	NS	NS	0.03
Slaughter weight (kg)	36.80	34.70	32.24	30.80	28.00	3.86	*	*	0.33
Carcass length (cm)	69.00	65.60	63.80	62.80	61.00	2.76	*	NS	0.19
WCW (kg)	19.96	19.50	20.30	17.06	15.66	1.57	*	NS	0.23
Cold carcass weight (kg)	24.82	22.62	20.26	19.04	19.00	1.49	***	NS	0.34
pH_{45}	6.50	6.57	6.36	6.58	6.60	0.09	NS	NS	0.03
pH_{24}	5.37	5.70	5.31	5.79	5.24	0.13	NS	NS	0.01
$Temperature_{45}$	36.57	33.18	37.04	35.24	36.64	0.73	NS	NS	0.03
$Temperature_{24}$	5.32	2.56	4.42	6.92	5.88	1.19	NS	NS	0.01
Cooler shrink (%)	4.19	3.07	3.66	3.72	3.13	0.74	NS	NS	0.03
Backfat thickness (mm)	19.00	19.40	19.45	19.79	20.00	0.60	**	NS	0.26
Shoulder fat (mm)	27.00	25.00	29.80	31.00	26.20	3.25	NS	NS	0.11
Chop (kg)	0.14	0.13	0.12	0.10	0.10	0.02	NS	NS	0.11
Drip loss (%)	0.22	0.14	0.27	0.38	0.62	0.16	*	NS	0.06
Primal pork cuts									
Ham length (cm)	26.80	28.00	27.60	25.20	27.60	1.40	NS	NS	0.11
Ham diameter (mm)	28.60	27.40	30.60	29.40	31.00	2.60	NS	NS	0.09
Backfat depth at P2	90.00	76.40	93.00	70.00	68.80	9.04	NS	NS	0.13
DFT1 (mm)	26.40	30.80	26.40	30.80	26.40	4.03	NS	NS	0.00
DFT2 (mm)	15.80	21.20	17.60	18.60	17.60	1.76	NS	NS	0.07
DFT3 (mm)	23.00	22.20	19.80	18.80	17.20	1.62	**	NS	0.31
HQWP %	22.55	24.63	22.86	26.62	21.62	4.40	NS	NS	0.04
SHDWP %	26.18	14.06	14.12	15.17	12.31	5.96	NS	NS	0.09
RWP %	13.13	13.59	12.22	13.12	11.68	2.60	NS	NS	0.01

Dorsal fat thickness (DFT), Warm carcass weight (WCW), Hind quatre weight proportion (HQWP), Shoulder weight proportion, Rib weight proportion (RWP), Coefficient of determination (R^2), Standard error of the mean (SEM). *P< 0.05; **P< 0.01; ***P< 0.001; NS: not significant (P >0.05)

Table 4 Relationship between inclusion levels of Amarula oil cake and visceral organ weights of Windsnyer pigs

Visceral organs (g/bw)	Inclusion level of Amarula oil cake (g/kg DM)					SEM	Significance		R^2
	0	50	100	150	200		Linear	Quadratic	
Heart	2.93	3.16	3.85	4.14	3.82	0.72	NS	NS	0.07
Hepatosomatic index (%)	1.37	1.61	1.74	1.82	1.93	0.23	*	NS	0.25
Lungs	9.81	7.81	9.35	11.50	12.87	1.67	NS	NS	0.14
Spleen	1.40	1.58	1.97	2.47	2.25	0.48	NS	NS	0.11
Empty stomach	11.81	15.48	18.30	22.11	23.08	3.38	**	NS	0.33
Kidney	3.14	3.60	4.22	4.20	3.91	0.55	*	*	0.36
Small intestine	23.19	23.76	24.15	24.96	23.59	2.98	NS	*	0.19
Large intestine	33.88	34.70	34.98	35.00	33.00	6.20	NS	*	0.23

Standard error of the mean (SEM), Coefficient of determination (R^2), **P* <0.05; ***P* <0.01; NS: not significant (*P* >0.05), g/kg DM (grams/kilogram dry matter)


Slaughter weight (SW) (kg)
SW = -35.61(12,87)x + 761.91
P < 0.05
AOC inclusion g/kg
A
Carcass length (CL) (cm)
CL = -12.16(33.48)x + 651.08
P < 0.05
AOC inclusion level g/kg
B
Warm carcass weight (WCW) (kg)
WCW = -51.54(32.12)x + 648.53
p < 0.05
AOC inclusion level (g/kg)
C
Cold carcass weight (CCW)(kg)
CCW = -8.17(30.41)x + 134.61
P < 0.05
AOC inclusion level g/kg
D

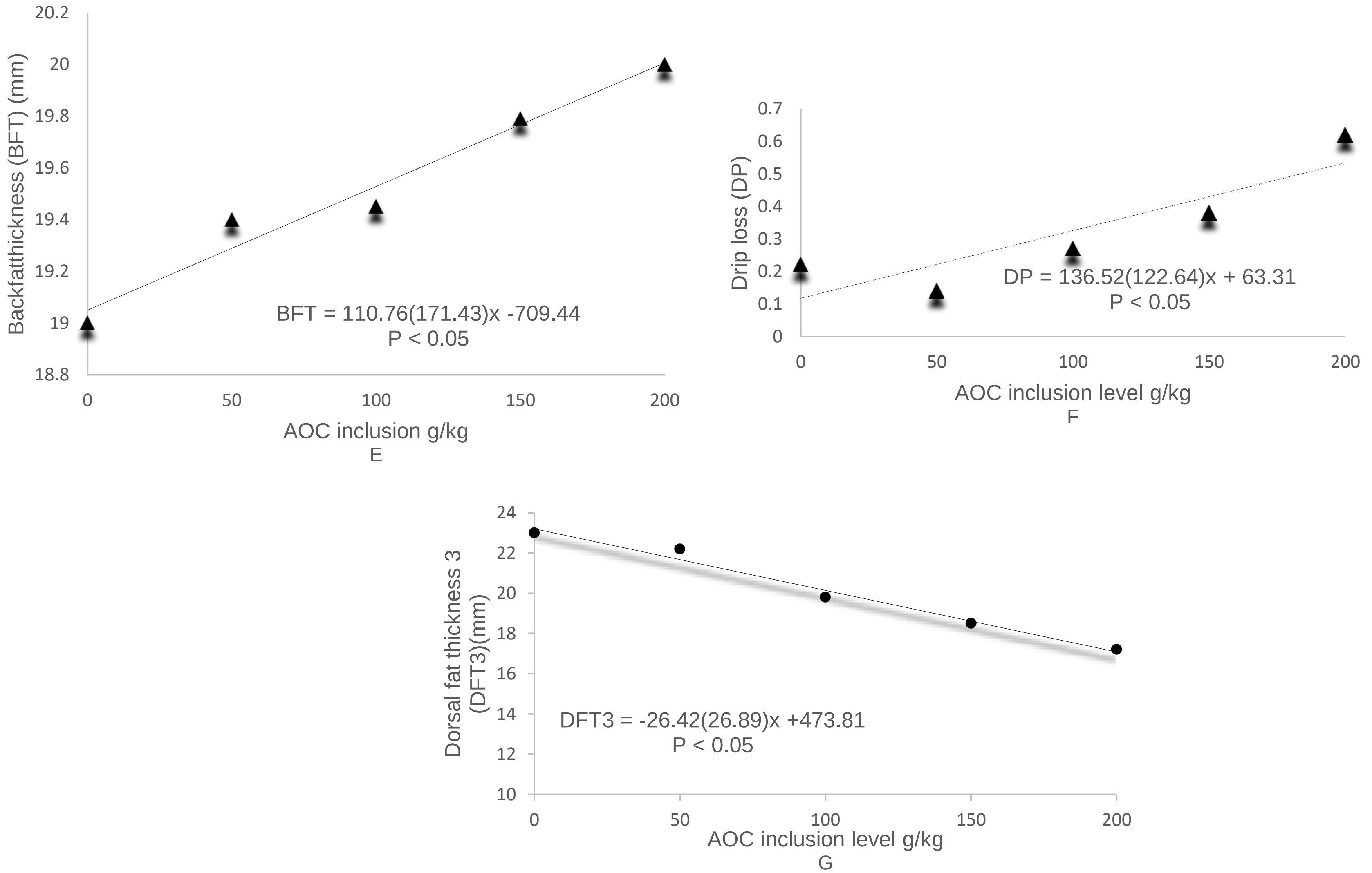
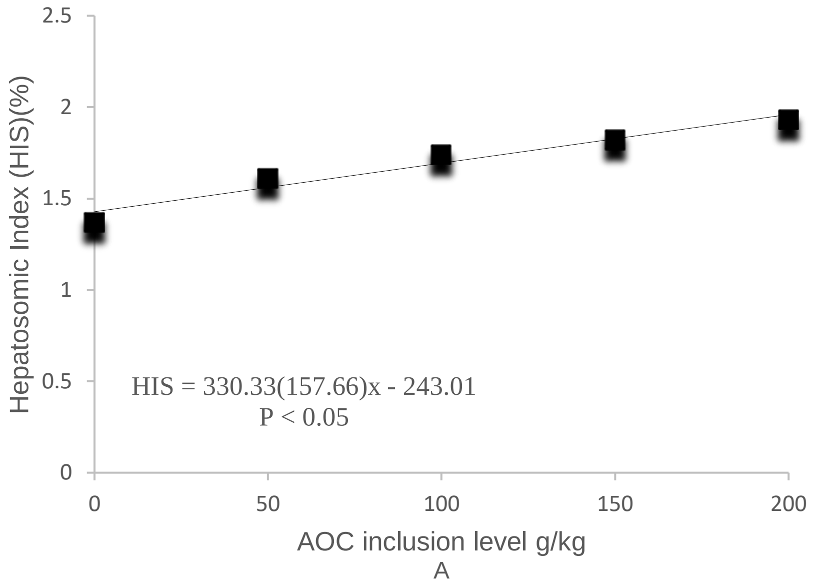
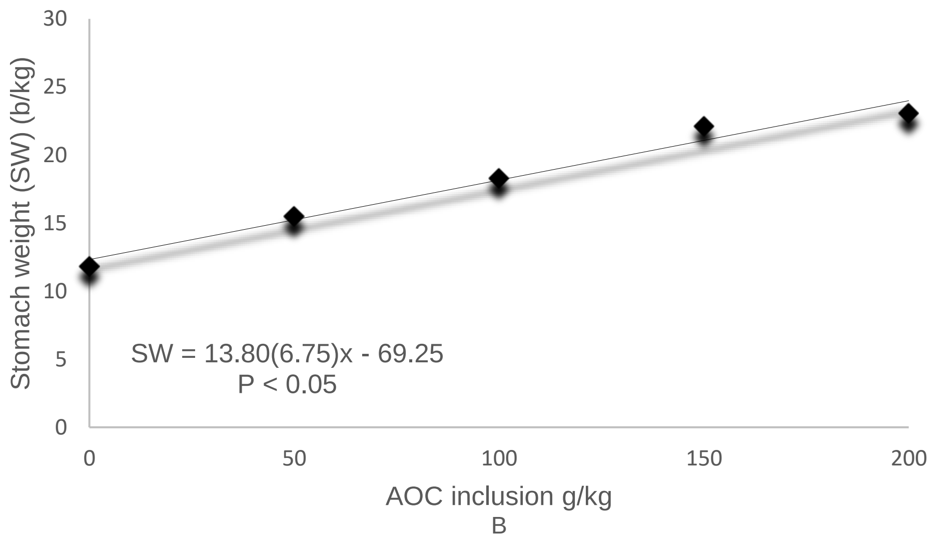


Figure 1 (A–G) Relationship between Amarula oil cake (AOC) inclusion level (g/kg) with slaughter weight, carcass length, warm carcass weight, cold carcass weight, back fat thickness, drip loss, and dorsal fat thickness of Windsnyer pigs


2.5
2
1.5
1
0.5
0
Hepatosomic Index (HIS)(%)
HIS = 330.33(157.66)x - 243.01
P < 0.05
0
50
100
150
200
AOC inclusion level g/kg
A


30
25
20
15
10
5
0
Stomach weight (SW) (b/kg)
SW = 13.80(6.75)x - 69.25
P < 0.05
0
50
100
150
200
AOC inclusion g/kg
B

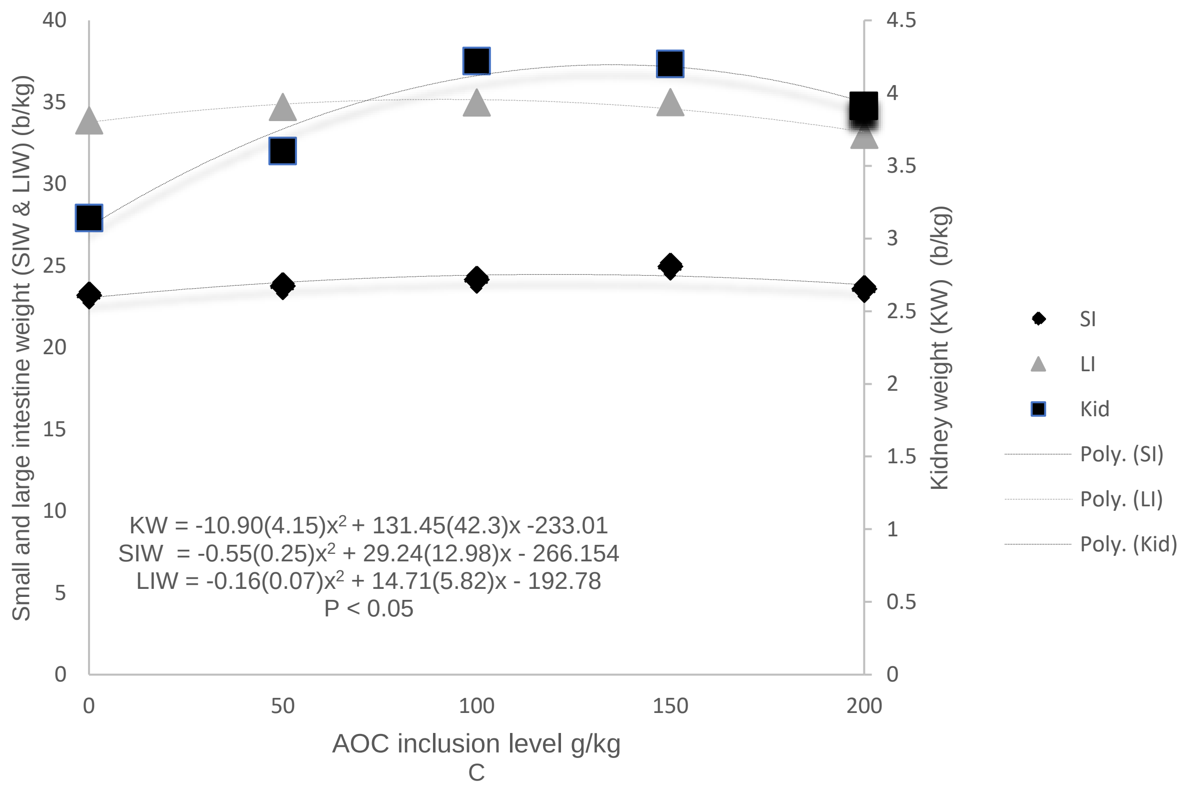


Figure 2 (A–C) Relationship between Amarula oil cake (AOC) inclusion level with hepatosomatic index, stomach weight, kidney wight, small intestine (SIW) and large intestine (LIW) weight of Windsnyer pigs

Discussion

Indigenous pigs such as the Windsnyer pig are rejected by the carcass classification systems used in abattoirs. Strategies that improve the production of indigenous pig genotypes, selection standards that include Windsnyer pigs in breeding programs, and the conservation of indigenous pigs are of the utmost importance in tropical countries. There is limited research about the relationship between increasing levels of Amarula oil cake diets and carcass characteristics of Windsnyer pigs.

The observation that the slaughter weight of Windsnyer pigs decreased with increasing levels of Amarula oil cake suggests that including higher amount of the oil cake in the diet compromises pig performance. Miya *et al*. (2019), reported a similar linear reduction in slaughter weight of broilers that were fed on increasing levels of *Vachellia tortilis* leaf meal diets. Khanyile *et al*. (2016), however, reported a quadratic decrease in slaughter weight of pigs fed on increasing levels of *Vachellia tortilis* leaf meal. Nevertheless, such a quadratic decrease concurs with the fact that high inclusion levels of *Vachellia* diets overall reduced the slaughter weight of pigs.

The linear decrease in carcass length with increasing inclusion levels of Amarula oil cake concurs with Ncobela *et al*. (2018). The decreasing carcass length of South African Windsnyer pigs can be related to the linear reduction in average daily gain. Windsnyer pigs grow up to a point, after which they essentially deposit fat, hence affecting its weight. Several African indigenous pig genotypes are reported to have high fat deposition when attaining puberty (Chimonyo *et al*., 2010).

As expected, increasing levels Amarula oil cake linearly decreased both the warm and cold carcass weights of pigs. Len *et al*. (2008) reported a similar reduction in warm carcass weight of Mong Cai pigs fed on high fibrous diet. The reduction in warm carcass was related to increased weight of gastrointestinal tract of pigs which was a result of the high fibre content of the diet. Fibrous feeds increase the size of internal organs in pigs (Qin *et al*., 2002). Increasing AOC level increased the fibre level in the diet. Similarly, Ćirić *et al.* (2017) showed strong correlations between the slaughter weight, warm carcass weight, and cold carcass weight of pigs.

Carcass quality of pigs can also be assessed by measuring backfat thickness, which estimates the thickness of the subcutaneous fat. Both the backfat and intramuscular fat alter pork quality and should be considered (Chimonyo *et al*., 2001). As expected, increasing levels of AOC linearly increased backfat thickness of Windsnyer pigs (Liu *et al*., 2015; Khanyile *et al*., 2016). Our results were, however, in contradiction with those of Ncobela *et al*. (2018), who reported a linear reduction in backfat thickness of Windsnyer pigs fed on increasing levels of potato hash silage. The discrepancies between the two studies can be explained by differences in ether extract concentration of the diets which, in turn, alters the energy content of the diets. Fats are used as energy sources in monogastric animals. The consumption of energy-rich diets triggers lipogenesis and, consequently, visceral fat deposition. The ether extract and gross energy were directly proportional to the inclusion level of AOC.

Drip loss is an important characteristic that affects palatability and acceptability of meat (Forrest *et al*., 2000). Increasing the inclusion level of AOC linearly increased drip loss in Windsnyer pigs. Our results were consistent with those of Mushandu *et al*. (2005), who reported a linear increase in drip loss of Mukota pigs fed on increasing levels of sorghum-based diets. On the contrary, diets with the incorporation of avocado, had no effect on drip loss of Large White × Landrace pigs (Seshoka *et al*., 2020). Apart from the diet, drip loss is also affected by pig genotype and pH of meat (Mushandu *et al*., 2005; Kanengoni *et al.,* 2014). Both the initial and final pH in the current study showed no response to inclusion levels of AOC.

Increasing AOC inclusion level in Windsnyer pig diets was expected to increase the backfat measurement (DFT1, DFT2, and DFT3) of Windsnyer pigs due the high fat content of AOC. However, that was not the case in the current study. Increasing levels of AOC diets linearly reduced the dorsal fat thickness (DFT3), as also reported by Ncobela *et al*. (2018). The reduction in DFT3 might be assumed to have also been caused by the linear reduction of carcass length, which affects most pork cuts (Poto *et al*., 2007).

The hepatosomatic index is the scaled liver weight expressed as a percentage. A linear increase in the hepatosomatic index (HSI) with increasing levels of AOC suggest that higher levels of the oil cake increase liver weight. On the contrary, Ma *et al*. (2002) & Bakare *et al*. (2017) showed a reduction in liver weights of pigs fed on maize cob and straw-based diets, respectively. The present results were nevertheless consistent with those of Khanyile *et al*. (2016), who reported a linear increase in liver weight of pigs fed on *Vachellia* diets. The increasing HSI might be related to increasing weight of the stomach of pigs, which might have resulted in an increase in the secretion of liver enzymes that detoxify toxic substances in the diets. A linear increase in stomach weight of Windsnyer pigs was indeed observed. The results are consistent with Kaensombath *et al*. (2013) and Bakare *et al*. (2017), who reported an increase in stomach weight of Moo Lath pigs fed Stylo silage and Landrace pigs fed on maize cob-based diets. The fibre content of the diet influences the weight of visceral organs (Nyachoti *et al*., 2000). Similar observations were also confirmed by Zhao *et al*. (1995).

A quadratic decrease in kidney, small, and large intestine weight of pigs with increasing levels of Amarula oil cake diets was observed in the study. Miya *et al*. (2019), reported a linear increase in relative liver weights of broilers fed on increasing levels of *Vachellia* diets. It is possible that high inclusion levels of AOC and the time of exposure of the pigs to the diets affected the relative kidney weight of pigs in our study. As such, the duration of feeding also needs to be considered when AOC based diets are used. Kidneys are the main sites for clearance of nitrogen and detoxify toxic compounds in the body. Increasing dietary protein level increase the weight of liver and kidneys of pigs (Chen *et al*., 1996). The presence of mycotoxins in Amarula diets was detected by Mthiyane & Mhlanga. (2017). Mycotoxins reduce pig performance by reducing protein digestibility and absorption. Increasing AOC levels in the diet might also increase the amount of mycotoxins that result in mould development in the diet.

A linear increase in both small and large intestines of Windsnyer to dietary inclusion level of AOC pigs was expected. Indeed, this would be due to the increased bulk properties and the cell wall constituent contents of AOC diets. In addition, the hind gut of Windsnyer pigs can ferment fibrous feeds effectively, as demonstrated earlier (Kanengoni *et al*., 2014). The observed quadratic reduction in both the small and large intestines could have been related to the quadratic reduction in ADFI, suggesting that Windsnyer pigs can tolerate AOC-based diets up to 150 g/kg DM. The small and large intestines of pigs are sites for nutrient and water absorption. Dietary factors that affect the normal functioning of these organs may, therefore, interfere with nutrient absorption, hence reducing growth and health of pigs. Incorporating Amarula oil cake increased feed bulk. An increase in water holding capacity and bulk density reduces energy availability and consequently reduces pig growth (Linares & Huang, 2010). The absorption of nutrients is largely influenced by feed intake, which is, in turn, affected by dietary properties of the feeds (Nyachoti *et al*., 2004). The decrease in both small and large intestine weights at higher levels of AOC diets could be a clear indication that the intestinal epithelium was compromised, suggesting that gut health and morphology of Windsnyer pigs to AOC-based diets need to be investigated.

Conclusions

There was a negative linear relationship between slaughter weight, carcass length, warm carcass weight, cold carcass weight, and dorsal fat thickness with increasing levels of AOC. Backfat thickness and drip loss showed a positive linear relationship with increasing levels of AOC. Other selected carcass characteristics and primal pork cuts had no clear relationship. The HSI and stomach weight showed a negative linear relationship with increasing levels of Amarula oil cake. The kidneys, small and large intestine weight showed a negative quadratic relationship with increasing levels of AOC, suggesting that high levels of Amarula also constrained some of the selected gastro-intestinal tract content of Windsnyer pigs. However, some gastrointestinal tract content such as the heart, lungs and spleen were not affected by the inclusion level of Amarula. Incremental levels of AOC diets impaired carcass characteristics and selected visceral organs of pigs, therefore Windsnyer pigs can be fed AOC up to100 g/kg DM. When carcass traits and visceral organs of Windsnyer pigs are selected, low levels of Amarula oil cake needs to be considered. The gut health of Windsnyer pigs also need to be considered when feeding pigs with Amarula-based diets.

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Author contributions

FT designed the study, did data collection, statistical analyses, writing of the first draft of the manuscript and writing the final draft of the manuscript. **VAH** edited the first draft of the manuscript, the final draft of the manuscript. **MC** designed the study, he is the main leader of the project, he also contributed with funding of the project, supervised the project, and revised the manuscript. **AMA** designed the study, he is the co-supervisor of the project, he also contributed with funding, and he edited the final manuscript. Manuscript was approved by all authors.

Conflict of interest declaration

None of the authors of this paper has a financial or personal relationship with other or organizations that could inappropriately influence or bias the content of the article.

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