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Dried cabbage (*Brassica oleracea var. capitata*) waste meal decreases blood cholesterol but does not alter growth performance, and physiological indices of weaned pigs

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ABSTRACT

The study investigated the potentials of dried cabbage waste meal (DCWM) on growth performance, blood biochemical characteristics, physiological indices, and economics of production of weaned pigs. Ninety crossbred (Large white X Landrace; 8.01 ± 0.18 kg body weight) clinically certified weaned pigs of equal sexes were randomly allocated to five dietary treatments containing DCWM. Each treatment consisted of 18 pigs replicated thrice in a completely randomized design. Diet 1 (control diet) contained no DCWM whereas diets 2, 3, 4 and 5 had 50, 100, 150 and 200 g/kg levels of inclusion of DCWM, respectively, replacing parts of the feed. The study lasted for 8-weeks. Feed and water were available *ad-libitum*. Average daily feed intake (715.76–780.03 g/d) increased ($p < 0.05$) while average daily weight (294.17–301.74 g/d) and feed conversion ratio (2.39–2.65) were similar ($p > 0.05$). White blood cell (12.11–14.62 × 10^9/L), lymphocytes (62.93–70.30%), Uric acid (7.74–9.99 mmol/L), HDL (0.89–1.27 mmol/L) and K (130.90–145.72 mmol/L) concentrations increased ($p < 0.05$) whereas cholesterol (2.30–5.06 mmol/L) and triglyceride (0.33–0.87 mmol/L) concentrations decreased ($p < 0.05$) in response to increased DCWM in the diets. Total cost of feeding ($17.96–20.89) reduced ($p < 0.05$) while gross benefits ($48.97–52.30) were significantly better ($p < 0.05$) for pigs fed 100, 150 and 200 g/kg DCWM compared to those fed 0 and 50 g/kg diets. DCWM in pig diets up to 200 g/kg had positive influence on blood cholesterol and economics of production.

1. Introduction

Inadequate nutrition is one of the major challenges confronting pig industry in the developing countries, as a result of limited feed resources (Amole et al., 2022; Rauw et al., 2020). Feed alone constitutes about 60–80 % of the total cost of pig production in the tropics (Bharati et al., 2022). The problem has been aggravated due to the effect of Covid-19 and the on-going Russia – Ukraine war (Makinde et al., 2022). Solving this problem will require exploration of other feed resources that are available locally and cheaper than conventional feedstuffs. The feeding of agro industrial by-products, crops residues and wastes from fruits and vegetables has been advocated, as these are not eaten by human beings and can be converted by pigs into desirable meat (Knorr & Augustin, 2022; Ponnampalam & Holman, 2023).

The potential of vegetable waste has livestock feed has been investigated by several researchers (Wadhwa et al., 2006; Wadhwa & Bakshi, 2013). Laufenberg et al. (2003) observed that vegetable waste could be processed into different value added products, may be fed freshly chopped to livestock or processed, such as when dried, composited or in feed blocks. During dry season, vegetable waste is usually sought after as maintenance feed for livestock especially in arid region. Globally, Cabbage (*Brassica oleracea*) is widely grown, consumed and it is one of the most important vegetable among *Brassicaceae* family. Kibar et al. (2016) reported that the cabbage originated from north European countries,

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around the Baltic Sea coast and the Mediterranean region. The cultivation of the cabbage is less stressful and it adapt easily to any environment. This quality has made it to become widely cultivated throughout the world. Šamec et al. (2011) reported that Cabbage is very rich in nutrients such as minerals, vitamins, and fibers. Phytochemical analysis revealed that white cabbage is also rich in phenolic compounds, carotenoids and glucosinolates (Bhandari & Kwak, 2015; Kusznierewicz et al., 2008).

Mustapha and Baurhoo (2018) reported that dried cabbage leaf residues (DCLR) contained 12.1 % ash, 14.0 % crude protein, 18.9 % NDF, 16.9 %ADF, 2.0 % fat and 4.0 Mcal/kg gross energy. The authors also observed that DCLR was rich in minerals such as Ca, P, Mg, Na, fatty acids and amino acids. Similarly, Nkosi et al. (2016) reported the values of 825, 184, 15, 352, 236, 55, 13 and 3 g/kg DM for dry matter, crude protein, ether extract, NDF, ADF, ADL, Ca and P respectively. Previous studies on the use of cabbage wastes as potential feedstuff for monogastrics especially pigs are limited. In a study conducted at Rowett Research Institute, Bucksburn, Aberdeen (Great Britain), Livingstone et al. (1980) observed similar feed intake among growing pigs fed cabbage waste diet up to 30 % in the diets. In Nigeria, Ilaboya et al. (2021) reported a decrease but not statistically different feed intake among weaner pigs fed diets supplemented with fresh cabbage waste up to 40 %. Also, Nkosi et al. (2016); Pereira et al. (2002)reported that the dry matter intake (DMI) and daily weight gain were reduced as the level of cabbage waste increased in the diet of rainbow trout (*Oncorhynchus mykiss*) and South African Dorper lambs, respectively. We proposed that DCWM might be very useful in pig nutrition but its effect on growth performance, blood profiles, physiological indices, and economics of production of pigs must first be evaluated, hence, the reason for this study.

2. Materials and methods

2.1. Study site

The permission to conduct this study and use of animal and animal protocol was approved by the Animal Ethics Committee of the National Veterinary Research Institute (NVRI), Vom, Plateau State, Nigeria (NIAS/ANS/FCAH&PT (001)). This research was done at the Teaching and Research Farm of the Federal College of Animal Health and Production Technology, Dagwom Farm, NVRI, Vom. Vom is located at the 8° 45` East and 9° 43` North of equator with annual rainfall of 1300–1500 mm and height of about 1.285 metres above sea level. It has a distinct cool climate in December and January, the night may be extremely cold. The wet season extends from late April to October (Climatemp, 2022).

2.2. Sample preparation

Fresh samples of *Brassica oleracea* waste were collected from cabbage farmers in Jos, Plateau State, Nigeria and chopped to pieces of 2.5 mm length using a hammer mill (Mustapha & Baurhoo, 2018). Cabbage is available throughout the year and large quantity of cabbage waste is generated in the area, resulting in the pollution of the environment. The chopped samples were air-dried at 30 °C for 96 h until completely dried, ground into powder using hammer mill with a sieve of 2 mm and labeled as dried cabbage waste meal (DCWM). The sample was then stored in an air-tight container until used for chemical analysis and diet formulation.

2.3. Management of experimental animals, formulation of experimental diets and design

Ninety crossbred (Large white X Landrace; 8.01 ± 0.18 kg body weight [BW]) clinically certified pigs of equal sexes were procured for this study. The pigs were allowed one-week adaptation period, during which ivermectin (0.2 mL/10 kg) and oxytetracycline (1 mL/10 kg) were orally and intravenously administered, respectively. The animals were housed in well ventilated open sided, concrete floor experimental pens, each measuring 4 m x 4 m, to prevent them from the effect of severe weather. Concrete feed troughs and drinkers were constructed in each pen for supplying feed and water, respectively. The weaned pigs were weighed individually and randomly allocated based on sex and weight to five dietary treatments differing in the inclusion level of DCWM. Each treatment consisted of 18 pigs replicated thrice (6 pigs per pen; 3 males and 3 females) in a completely randomized design. Diet 1 (control diet) was formulated without DCWM inclusion whereas diets 2, 3, 4 and 5 consisted of 50, 100, 150 and 200 g/kg levels of inclusion of DCWM, respectively, replacing parts of the yellow maize, soyabean meal and groundnut cake as shown in Table 1. Each pig was fed 0.2 g/kg total mixed ration (TMR), which is similar to 2.5 % of their BW with concurrent adjustment in relation to the increase in BW. The study lasted for 8-weeks. Feed and water were made available *ad-libitum* throughout the study.

2.4. Chemical analysis

Sample of the DCWM and other feed ingredients were taken to Department of Biochemistry laboratory, National Veterinary Research Institute Vom, for chemical analysis using the method described by AOAC (2006). Dry matter was determined after oven-drying the samples at 100 °C for 24 h. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were done using the ANKOM fiber analyzer (Van Soest et al., 1991). The amino acids were quantitatively measured by the procedure of Benitez (1989) using Applied Biosystems PTH automated amino acid analyzer (Technicon Sequential Multisample Analyzer, TSM, (40,405), Model 120A, Version 1.4B, USA). Sample was hydrolyzed for determination of all amino acids in consistent boiling hydrochloric acid for 22 h under a nitrogen flush. Only tryptophan and norleucine were not determined. Procedure earlier described by Wheeler and Ferrel (1971) was used to determine phytate. Each analysis was done in triplicate.

Table 1
Ingredients and chemical composition of experimental diets (g kg^{-1}DM).

Feed components	T_0	T_{50}	T_{100}	T_{150}	T_{200}
Yellow maize (9.8 %)	580	550	520	490	460
Soyabean meal (44 %)	111	96	81	66	51
Groundnut cake	205	200	195	190	185
DCWM[1]	0	50	100	150	200
Wheat bran	68.1	68.1	68.1	68.1	68.1
Bone Meal	25	25	25	25	25
Premix[2]	2.5	2.5	2.5	2.5	2.5
L-Lysine (76 %)	1.7	1.7	1.7	1.7	1.7
DL-Methionine (99 %)	1.7	1.7	1.7	1.7	1.7
Salt	3	3	3	3	3
Palm oil	2	2	2	2	2
Total	1000	1000	1000	1000	1000
Chemical composition					
ME[3] (MJ/kg)	12.65	12.34	11.79	11.48	11.09
Crude Protein	207	206	193	186	181
Calcium	9.6	7.3	7.2	7.2	6.9
Phosphorus	6.0	4.5	4.4	4.4	4.0
Ether extract	9	1.03	0.96	1.03	0.99
Neutral detergent fiber	27.8	29.31	31.73	35	38.18
Acid detergent fiber	16.3	18.89	19.15	23.02	24.55
Lysine	9.9	9.7	9.6	9.4	9.1
Methionine	4.6	4.3	3.9	3.8	3.6

[1] DCWM = dried cabbage waste meal. [3]ME = metabolizable energy.
[2] premix provide per kg of diet: vit. A; 13.340 iu, vit. D3; 2680 iu, vit. E; 10 iu, vit. K; 2.68 mg, Ca pantothenate; 10.68 mg, vit. B12; 0.022 mg, folic acid; 0.668 mg, choline choride; 400 mg, chlorotetrcycline; 26.68 mg, manganese; 13 mg, iron; 66.68 mg, zinc; 53.34 mg, copper; 3.2 mg, iodine; 1.86 mg, cobalt; 0.268 mg, selenium; 0.108 mg.

2.5. Data collection procedures

2.5.1. Growth performance parameters

Average feed intake (*g*) was calculated for pigs in each replicate by subtracting left over from feed given whereas average body weight gain was calculated for pigs in each replicate, as the difference between the weights obtained in preceding week and that of the present week, since data on feed intake and weight gain were recorded weekly. At the termination of the study, feed conversion ratio was calculated as $\frac{feed\ intake}{weight\ gain}$

2.5.2. Blood collection and biochemical analysis

During the last week of the study, blood samples were collected from all the experimental animals through the jugular vein using a hypodermic needle and syringes. Blood collected for haematological analysis were immediately introduced into sterilized glass test tubes (5 mL), containing a speck of Ethylene Diamine Tetra-acetic Acid (EDTA) powder, whereas samples meant for serum determination were collected into a set of test tubes (5 mL) without EDTA. These test tubes were left to stand in the test tube rack in the laboratory in a slanting position for 6 h. The serum separated from each blood sample was then decanted after centrifugation at 2000 rpm for 5 min at 28 °C. The analyses were carried out at the Haematology laboratory section of the Central Diagnostic Division, National Veterinary Research Institute (NVRI), Vom, Plateau State, Nigeria. Haematological parameters such as packed cell volume (PCV), haemoglobin (Hb), white blood cell and differential counts were determined using the procedures earlier described by Dacie and Lewis (2001), while other parameters were calculated using the values obtained for RBC, Hb, and PCV. Serum glucose, uric acid cholesterol, and triglyceride components were analysed spectrophotometrically (Thermo Fisher Scientific Inc., Madison, Wisconsin, USA) using commercial reagent kits (United Diagnostic Industry, Dammam, Saudi Arabia). Serum electrolytes and enzymes were obtained through appropriate commercial kits (Randox Laboratories, United Kingdom) as described by Reitman and Frankel (1957) with modifications.

2.5.3. Measurement of physiological indices

Physiological data were taken twice (8:00 and 16:00 h) daily after the animals were stabilized. Data on rectal temperature of pigs were collected by inserting a digital thermometer through the anus of the pigs to the rectum. The temperature was taken immediately the thermometer beeps. The frequency of heart beat per minute of the experimental pigs was measured using stethoscope and a stop watch. This was recorded for respiratory and pulse rate. Pen temperature was taken using a digital thermometer as earlier described by Njoku et al. (2019).

2.5.4. Economic of production

The cost of the feeds as used in this study included variable cost of feeding the pigs as well as the costs of purchasing and processing the fresh cabbage leaves, hence, all other costs such as capital investment, labor, including housing were similar for all the treatments (Makinde et al., 2022).

2.6. Statistical analysis

The Metabolizable energy (MJ/Kg DM) was calculated by the equation proposed by Robinson et al. (2004): ME = 14.03 – (0.01386 × CF %) – (0.1018 × Ash %). The concentrations of hemicellulose and cellulose were calculated using the formulae of AOAC (1980):

$$\text{Hemicellulose} = NDF - - \text{ADF}$$

$$\text{Cellulose} = ADF - - \text{ADL}$$

Where CF = crude fiber, NDF = Neutral detergent fiber, ADF = acid detergent fiber and ADL = acid detergent lignin.

Data generated on growth performance, blood biochemical characteristics, physiological indices, and economics of production were subjected to one-way analysis of variance (ANOVA) for a complete randomized design using Statistical Analysis Software (Version 9.3, SAS Institute Inc. Cary, NC, USA, (SAS, 2015). The model used for the analysis included the diet as treatment effect. The differences between the treatment means were determined using Tukey *post hoc* test. Significant means were separated at the level of $P \leq 0.05$ using Duncan's multiple range test.

The statistical model used was:

$$\text{Yij} = \mu + \text{DCWMi} + \text{eij}$$

Y_{ij} = Experimental data

μ = general mean

$DCWM_i$ = effect of i^{th} dried cabbage waste meal diets e_{ij} = random error

3. Results

3.1. Chemical composition of dried cabbage waste meal

The results of the chemical composition of dried cabbage waste meal are shown in Table 2. Dried cabbage waste meal contained in g kg^{-1}DM; 940 dry matter, 138 crude protein, 28.3 ether extract, 94.5 crude fiber, 161 ash, 12.80 (MJ/kg) metabolisable energy, 199 NDF, 154 ADF, 52 ADL, and very rich in minerals and essential amino acid composition such as arginine (74.1), leucine (55.4) and valine (42.7). It is also rich in non-essential amino acid composition such as glutamic acids (97.5),

Table 2
Chemical composition of dried cabbage waste meal.

Items	g kg^{-1}DM
Dry matter	940
Crude protein	138
Ether extract	28.3
Ash	161
Crude fiber	94.5
Metabolisable Energy, MJ/kg	12.80
Neutral detergent fiber	199
Acid detergent fiber	154
Acid detergent lignin	5.2
Hemicellulose	45
Cellulose	148.8
Na	1.30
Ca	0.03
Mg	4.48
K	8.56
P	2.87
Ascorbic acid	0.82
Leucine	55.4
Lysine	39.5
Isoleucine	38.3
Phenylalanine	32.8
Trytophan	ND
Valine	42.7
Methionine	9.9
Arginine	74.1
Histidine	21.4
Threonine	36.1
Cystine	12.1
Proline	27.4
Tyrosine	18.9
Alanine	36.2
Glutamic acid	97.5
Glycine	38
Aspartic acid	89.9
Norleucine	ND
Oxalate	1.87
Saponin	8.20
Phytate	0.53

ND = Not determined.

aspartic acids (89.9), and glycine (38). Some of the anti-nutritional factors include oxalate (1.87), saponin (8.20) and phytate (0.53).

3.2. Growth performance of weaner pigs fed cabbage waste meal diets

The results of growth performance of weaner pigs fed diets containing graded levels of cabbage (*Brassica oleracae)* waste meal are presented in Table 3. Average daily feed intake increased ($p < 0.05$) significantly among pigs fed T150 and T200 diets, followed by those fed T50 and T100 diets. Average daily gain and feed conversion ratio were the same ($p > 0.05$) regardless of the DCWM levels in the diets.

3.3. Blood indices of weaner pigs fed cabbage waste meal diets

The results of blood profiles of weaner pigs fed diets containing graded levels DCWM are presented in Table 4. White blood cell counts increased ($p < 0.05$) among pigs fed T150 and T200 diets. Lymphocyte and uric acid concentrations increased ($p < 0.05$) significantly among pigs fed DCWM diets only. Cholesterol and triglyceride concentrations decreased ($p < 0.05$) significantly among pigs fed DCWM diets only. High density lipoprotein was significantly higher ($p < 0.05$) among pigs fed T200 diet only while K concentration was increased ($p < 0.05$) among pigs fed T100, T150 and T200 diets.

3.4. Physiological indices of weaner pigs fed cabbage waste meal diets

The results of physiological indices of weaner pigs fed diets containing graded levels of DCWM are presented in Table 5. All the parameters measured were equal significantly ($p > 0.05$).

3.5. Cost benefit analysis of weaner pigs fed cabbage waste meal diets

The results of cost benefit analysis of weaner pigs fed diets containing graded levels of cabbage (*Brassica oleracae)* waste meal are presented in Table 6. Total cost of feeding decreased ($p < 0.05$) significantly as DCWM levels increased in the diets. Gross benefits were significantly better ($p < 0.05$) among pigs fed T100, T150 and T200 diets compared to those fed T0 and T50 diets.

4. Discussion

4.1. Chemical composition of dried cabbage waste meal

The results of chemical composition of DCWM obtained in this study compared favourably with previous reports (Mustafa & Baurhoo, 2017, 2018; Pereira et al., 2002). The crude protein content of 138 g kg^{-1}DM implied that DCWM is a good source of protein. The value was similar to 141 g kg^{-1}DM (Kazemi et al., 2016) for red cabbage leaves, 144 g kg^{-1}DM (Mekasha et al., 2002) but lower than 204 g kg^{-1}DM (Wadhwa et al., 2006) and 184 g kg^{-1}DM (Nkosi et al., 2016). The protein content is also lower when compared to some edible vegetables such as *Telferia occidentalis* (200 g kg^{-1}DM), and *Amaranthus tricolor* (182 g kg^{-1}DM) as reported by Mohammed et al. (2012). The values (g kg^{-1}DM) obtained for fiber fractions (199 NDF, 154 ADF and 5.2 ADL) agreed with earlier reports of Mustafa and Baurhoo (2017); Negesse et al. (2009). However, higher values of 340 NDF, 230 ADF and 42.2 ADL g kg^{-1}DM were reported by Wadhwa et al. (2006) while Nkosi et al. (2016) reported the values of 352 NDF, 236 ADF and 55 ADL for discarded cabbage waste. Cassida et al. (2007) observed that the high pectin content of brassica plants might be responsible for the relatively high ADF content of cabbage leaf. Van Soest et al. (1991) opined that analysis of ADF was made difficult when pectins formed quaternary detergent precipitate gels in the presence of Ca and acidity.

For minerals and amino acids, K (8.56 g kg^{-1}DM), P (2.87 g kg^{-1}DM), and Mg (4.48 g kg^{-1}DM), were the most abundant minerals while arginine (74.1 g kg^{-1}DM), leucine (55.4 g kg^{-1}DM), valine (42.7 g kg^{-1}DM), lysine (39.5 g kg^{-1}DM), isoleucine (38.3 g kg^{-1}DM) and threonine (36.1 g kg^{-1}DM) were the most abundant essential amino acids. Glutamic acid (97.5 g kg^{-1}DM), aspartic acid (89.9 g kg^{-1}DM), and glycine (38 g kg^{-1}DM) were the most abundant non-essential amino acids. This result may be attributed to the fact that DCWM consisted mostly of cabbage leaves. Rosa and Heaney (1996) reported higher CP concentrations in cabbage leaves than cabbage steams but less than cabbage heads. Glutamic and aspartic amino acids made up (187.4 g kg^{-1}DM) as the most abundant non-essential amino acids in the DCWM sample analysed. This confirms the reports by some workers (Adeyeye, 2004; Aremu et al., 2006; Makinde et al., 2019) that the most abundant amino acids in some plants were glutamic and aspartic acids. The least concentrated essential amino acid is methionine (9.9 g kg^{-1}DM) while cystine (12.1 g kg^{-1}DM) is the least concentrated non-essential amino acid protein in the DCWM sample.

4.2. Growth performance of weaner pigs fed cabbage waste meal diets

The chemical composition of the dried cabbage waste meal (DCWM) used in this study was analyzed, and the results showed that it had a low metabolizable energy (12.80 MJ/kgME) compared to other feed ingredients commonly used in pig diets. Despite this, the inclusion of up to 200 g kg^{-1} DCWM in the diets of weaner pigs did not have any adverse effect on their average daily gain or feed conversion ratio. These results indicate that the diets were able to meet the nutrient requirements for proper growth and development of the pigs. An interesting observation was the increase in feed intake among pigs fed DCWM diets. This could be attributed to the low energy levels in DCWM, which may have caused the pigs to consume more in order to meet their energy requirements. Similar findings were reported by Kwak and Kang (2006), who observed increased feed intake among pigs fed food waste mixture diets with low energy levels. However, in a study conducted by Livingstone et al. (1980) at Rowett Research Institute, Bucksburn, Aberdeen (Great Britain), similar feed intake was observed among growing pigs fed cabbage waste diet up to 300 g kg^{-1} in the diets.

In contrast to our findings, Ilaboya et al. (2021) reported a decrease in feed intake among weaner pigs fed diets supplemented with fresh cabbage waste up to 400 g kg^{-1} in Nigeria. It is worth noting that fresh cabbage waste may differ in their nutrient composition and physical properties, which could explain the differences in feed intake observed

Table 3
Growth performance of weaner pigs fed cabbage waste meal diets.

Items	T_0	T_{50}	T_{100}	T_{150}	T_{200}	SEM	*P*-value
Initial weight, kg	7.96	8.01	8.05	8.02	7.98	0.02	0.6210
Final weight, kg	24.44	24.36	24.95	24.82	24.76	0.10	0.0789
ADG, g/d	294.17	291.84	301.74	299.70	299.70	1.78	0.0596
ADFI, g/d	715.76^{c}	719.87^{b}	727.58^{b}	752.37^{a}	780.03^{a}	6.31	0.0002
FCR	2.65	2.58	2.41	2.40	2.39	0.11	0.1026

SEM = pooled standard error of mean. ^{abc}Different superscripts in the same row are not significantly similar ($P < 0.05$).
ADG = average daily gain.
ADFI = average daily feed intake.
FCR = feed conversion ratio (average daily feed intake/ average daily gain).

Table 4
Blood indices of weaner pigs fed cabbage waste meal diets.

Items	T_0	T_{50}	T_{100}	T_{150}	T_{200}	SEM	*P*-value
white blood cell, x 10^9/l	12.11^b	12.82^b	13.40^b	14.42^{ab}	14.62^a	0.10	0.0424
Haemoglobin, g/dl	15.21	14.65	15.61	15.54	14.88	0.29	0.3993
Lymphocytes, %	62.93^b	65.29^{ab}	66.09^{ab}	69.21^a	70.30^a	1.08	0.0184
Mean corpuscular volume, fl	55.85	56.03	57.85	60.30	56.17	2.01	0.8855
Mean corpuscular heamoglobin, pg	19.06	18.96	20.32	20.10	19.26	0.68	0.8671
Platelets, x 10^9/L	219.68	244.86	293.94	230.23	255.97	18.79	0.7660
Glucose, mmol/L	4.02	4.27	4.90	4.93	4.07	0.49	0.8974
Globulin, g/L	30.19	31.82	23.18	28.30	22.40	3.01	0.5626
Total protein, g/L	60.90	64.72	54.18	60.69	54.57	2.03	0.4717
Uric acid, mmol/L	7.74^b	8.01^{ab}	8.64^{ab}	9.18^a	9.99^a	0.66	0.0494
Cholesterol, mmol/L	5.06^a	3.29^b	3.29^b	2.44^b	2.30^b	0.20	0.0103
Triglyceride, mmol/L	0.87^a	0.46^b	0.41^b	0.40^b	0.33^c	0.02	0.0149
HDL, mmol/L	0.89^b	0.92^b	0.92^b	0.90^b	1.27^a	0.02	0.0250
LDL, mmol/L	0.41	0.39	0.40	0.41	0.40	0.01	0.0912
K, mmol/L	130.90^b	134.11^b	139.67^a	141.67^a	145.72^a	2.78	0.0151
ALP (U/L)	17.32	19.14	19.59	17.24	18.29	0.78	0.1368
AST (U/L)	30.31	31.46	34.67	32.09	34.22	3.06	0.9825
ALT (U/L)	17.31	19.02	21.21	22.31	15.67	1.31	0.3939

SEM = pooled standard error of mean. [abc]Different superscripts in the same row are not significantly similar ($P < 0.05$). Aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphate (ALP), High density lipoprotein (HDL), Low density lipoprotein (LDL).

Table 5
Physiological indices of weaner pigs fed cabbage waste meal diets.

Items	T_0	T_{50}	T_{100}	T_{150}	T_{200}	SEM	*P*-value
Rectal temperature, °C	37.38	37.90	37.40	38.00	38.21	0.23	0.1036
Respiratory rate, b/m	22.82	23.65	23.29	21.56	22.77	0.65	0.1384
Pulse rate, hb/m	78.13	79.52	78.19	80.42	78.55	0.97	0.3503
Pen temperature, °C	25.71	26.39	26.15	25.93	26.88	0.28	0.0598

SEM = pooled standard error of mean. [abc]Different superscripts in the same row are not significantly similar ($P < 0.05$).

in these studies. Similarly, Pereira et al. (2002) and Nkosi et al. (2016) reported reduced dry matter intake and daily weight gain as the level of cabbage waste increased in the diet of rainbow trout (*Oncorhynchus mykiss*) and South African Dorper lambs, respectively. These findings suggest that the effects of cabbage waste on animal performance may vary depending on the species, age, and physiological status of the animals, as well as the level and form of cabbage waste included in the diet.

4.3. Blood indices of weaner pigs fed cabbage waste meal diets

The value obtained for White blood cell (12.11–14.62 × 10^9/L), in this study fall within the range of 12.20–14.25 × 10^9/L reported by Annongu et al. (2009) for pigs fed *Balanites aegyptiaca* fruits in the diets. Also, the value obtained for Lymphocytes (62.93–70.30 %), in this study fall within the normal range of 35.00–75.00 % reported by Mitruka and Rawnsely (1977) but higher than 41.33 50.00 % reported by Adebiyi et al. (2017) for weaner pigs fed diets containing rice waste. A decrease observed in blood cholesterol and triglyceride levels (5.06–2.30 and 0.87–0.33 mmol/L, respectively) among pigs fed DCWM diets is a positive finding as it suggests that DCWM could be used to produce pork with reduced blood cholesterol. It also indicates a general decline in lipid mobilization and lipogenesis. This observation further confirmed the earlier report of Ogbede et al. (2015), that cabbage and other vegetables of the *Brassica* family contained anti-cholesterol properties. The authors observed that dietary fiber is an important component in *Brassica oleracae* var. *capitata L.*, assisting in the reduction of serum cholesterol level, risk of coronary heart disease, and helping to prevent colon, hypertension, and breast cancers (Rodriguez et al., 2006). Nelson and Cox (2005) noted that normal body cholesterol level is important as a constituent of cellular membranes, precursor of steroid hormones and bile acids while excess or abnormal level in the blood is injurious to the body as it causes cardiovascular diseases. Hence, the low serum cholesterol obtained on dietary cabbage might reduce incidence of cardiovascular disease among pigs fed these diets since high blood cholesterol level is known to increase deposition of hard fatty materials in the arteries causing them to clog and interfere with the physiological activity of the heart to supply blood to the body (Helvaci et al., 2021; Ibrahim et al., 2022).

The observed increase in High density lipoprotein (HDL) concentrations (0.89–1.27 mmol/L), among pigs fed T200 diet indicates that DCWM could be a source of good cholesterol (Bumbie, 2017). HDL functions as transporter of cholesterol back to the liver for excretion process. It also transports cholesterol to other tissues that use them to synthesize hormones in a reverse cholesterol transport (Tymoczko et al., 2002). Therefore higher numbers for HDL are linked with better health outcomes as reported by Lewis et al. (2002). Serum K concentration increased significantly among pigs fed DCWM diets. This implied that DCWM is rich in *K* (8.56 g kg^{-1}DM) and its consumption could increase the absorption and availability of this mineral in the blood. The blood serum K concentration (130.90–145.72 mmol/L) obtained in this study fall within the normal range of 135–150 mml./L established by RAR (2009) for healthy pigs. The value obtained for uric acid (7.74–9.99

Table 6
Cost benefit analysis of weaner pigs fed cabbage waste meal diets.

Items	T_0	T_{50}	T_{100}	T_{150}	T_{200}	SEM	*P*-value
Total cost of feeding ($)	20.89^a	20.39^a	19.53^{ab}	19.08^b	17.96^b	0.21	0.0010
Cost/kg of pork ($)	4.19	4.19	4.19	4.19	4.19	–	–
Total weight gain (kg)	16.47	16.34	16.90	16.80	16.78	0.10	0.0596
Value of weight gain ($)	68.97	68.42	70.74	70.34	70.26	0.27	0.0196
Gross benefit ($)	48.97^b	48.03^b	51.21^a	51.66^a	52.30^a	0.35	<0.0001

SEM = pooled standard error of mean. [abc]Different superscripts in the same row are not significantly similar ($P < 0.05$).

mmol/L), was slightly lower than the range of 9.67–13.76 mmol/L reported by Annongu et al. (2009) for pigs fed *Balanites aegyptiaca* fruits in the diets. The non-significant effect of the diets on other blood biochemical indices was an indication that feeding up to 200 g kg^{-1} DCWM in pig diets had no influence on these parameters.

4.4. Physiological indices of weaner pigs fed cabbage waste meal diets

The similarity observed in all the physiological variables is an indication that feeding up to 200 g kg^{-1} DCWM to weanling pigs had no negative effect on respiratory rate, pulse rate, rectal and pen temperature. The values obtained for respiratory rate (21.56–23.65 b/m) were similar to 20.00–26.00 b/m reported by Annongu et al. (2009) for pigs fed *Balanites aegyptiaca* fruits in the diets. Pulse rate of 78.13–80.42 hb/m observed in our study compared favourably with 60–100 hb/m (Edward, 2015) for healthy pigs. Variations in values of pulse rate have been attributed to the effect of environmental temperature on the experimental animals (Njoku et al., 2019). Rectal temperature of 37.38–38.00 °C in this study was similar with 38.84–39.47 °C reported for growing pigs fed diets supplemented with ascorbic acids in the tropics (Njoku et al., 2019). Pen temperature of 25.71 –26.88 °C obtained in this study was lower than 31.70–31.90 °C reported by Annongu et al. (2009). The variations may be attributed to the difference in temperature of the study locations.

4.5. Cost benefit analysis of weaner pigs fed cabbage waste meal diets

The reduction observed in the total cost of feeding among pigs fed DCWM diets may be attributed to the lower cost of DCWM. This indicates that inclusion of up to 200 g kg^{-1} DCWM in pig diets would result in decrease in cost of feed and about $2.93 could be saved kg^{-1} pig feed. Apart from cost saving, gross benefit was also better among pigs fed DCWM diets compared to those fed the control diets. Gross profit of $3.33 per kg pork was made among pigs fed up to 200 g kg^{-1} DCWM compared to those fed the control diets. This shows that DCWM diets were economically superior to the control diet. The results obtained in the present study agreed with the findings of Makinde et al. (2022); Owen et al. (2013) who reported that using alternative or unconventional feedstuffs in livestock diets resulted in decreased cost of production.

5. Conclusion

The results of our study revealed that DCWM is moderately rich in nutrients especially protein, minerals and amino acids, hence, it can be used as feed ingredient for profitable pig production. Also, inclusion of up to 200 g kg^{-1} DCWM in pig diets had positive influence on blood biochemical variables especially white blood cell, lymphocyte, cholesterol, triglyceride, high density lipoprotein and K concentration. Economically, inclusion of 200 g kg^{-1} DCWM in pig diets led to reduction in cost of feed ($2.93 kg^{-1}feed) and gross profit of $3.33 kg^{-1} pork. More studies involving large number of pigs are required to confirm our results.

Animal ethics statement

The experimental procedures were in accordance with the animal care of the Committee of the NIAS/ANS/ FCAH&PT (001).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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