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ORIGINAL RESEARCH ARTICLE

Evaluation of Metabolizable Energy Values in Extruded Sweet potato-cereal Bran blends as energy concentrates for chickens

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ABSTRACT

Knowledge of the metabolizable energy of any feedstuff is key to efficiently using them in feed formulations for any livestock species. This experiment was conducted to determine the metabolizable energy of novel sweetpotato-bran energy concentrates in roosters by the regression method as a first step towards optimizing the use of these concentrates in poultry feeding. Three sweet potato-bran blends; sweet potato and corn bran, SP-CB (3:2), sweet potato and rice bran, SP-RB (3:2), and sweet potato and wheat bran, SP-WB (7:3) were extruded at 100ºC in a single screw extruder. Nine experimental diets were then created by incorporating extrudates in a reference diet (21.2%CP, 2845 kcal/kg ME, 0.95% calcium, 0.35% available phosphorus, 0.43% methionine, and 1.01% lysine) at 0, 5, 10, and 15% in replacement for glucose monohydrate ($C_6H_{12}O_6 \cdot H_2O$), and titanium dioxide was incorporated in the complete diets at 0.5% as indigestible marker.Forty 30-week-old ISA brown roosters were placed in metabolic cages (2 roosters per cage)and fed one of the 10 diets (reference diet + nine experimental diets) for a 7-day adaptation period and 3-day excreta collection. Diets and excreta were analyzed for dry matter, Kjeldahl nitrogen, titanium, and gross energy. The metabolizable energy value of energy concentrates; SP-CB, SP-RB, and SP-WB were estimated as the slope of the linear relationship between the inclusion rate of extruded sweet potato-bran blends and the glucose-corrected AMEn value of the experimental diets and revealed metabolizable energy values of 3.01 kcal/g, 3.11 kcal/g, and 3.16 kcal/g, respectively, being 68.6%, 72.7%, and 74.2% of their analyzed gross energy values.

Keywords: Metabolizable energy assay, *Ipomea batatas*, Extrusion cooking

INTRODUCTION

Energy concentrates are energy-dense yet characteristically low protein feeds, with examples ascereals; corn, wheat, millet, rye, barley, roots and tubers; cassava and sweetpotato, and agricultural by products such as brans and molasses.Maize remains the most used energy feedstuff in the diets of poultry (Khan, 2017) being 60-70% of a typical corn-soybean meal diet, despite competitive demand for maize as food, feed for other livestock and biofuel production. In recent years, the poultry feed industry has seen an increase in high protein concentrates of vegetable and/or animal origin that promise improved bird performance and require little skill in feed formulation while encouraging dilution with conventional energy ingredients like corn, wheat and wheat bran to the detriment of non-conventional energy-rich ingredients like cassava and sweet potato.The potential benefits of non-conventional energy-rich ingredients such as sweet potato can be exploited to create energy concentrate feeds that can be combined with commercially available protein concentrate products to obtain balanced complete feeds for poultry.

Sweet potato (*Ipomea batatas*) is a seasonal crop grown in tropical and subtropical regionsfor its storage roots, and is the 6th most important food crop after rice, wheat, potatoes, maize and cassava (CIP, 2022). An estimated 3.87 million metric tonnes of sweet potato (4.32% of global production) is grown in Nigeria, making her the 4th largest grower of sweet potato in 2020 behind China (54.98%), Malawi (7.73%), and Tanzania (4.9%) (FAOSTAT, 2022). Sweet potato and maize compare favourably as high starch feedstuffs, with comparable metabolizable energy of 14.8 MJ/kg (3535 kcal/kg) and 14.5MJ/kg (3463 kcal/kg), respectively (Woolfe, 1992). The starch in sweet potato roots is considered to be highly resistant to hydrolysis by amylase as its amylose forms a tightly packed structure, reducing its surface area and limiting substrate-enzyme interaction (Waramboi *et al*., 2012), making it a desired source of slowly digestible starch in foods (Kostrakiewicz-Gierałt, 2021). Challenges stacked against the use of sweetpotato roots for poultry feeding include the high moisture and short shelf life of fresh sweet potato roots, dustiness and bulkiness in finished feed with the potential to induce crop impaction and inflammation of respiratory surfaces (Ukachukwu, 2005),its high reducing sugar and soluble fibre content, and its major soluble protein, ipomoein (Varon *et al*., 1989)which may elicit a laxative effect (Duke, 1983)and responsible for observed wet dropping and pasting vent in chickens(Agwunobi, 1999; Maphosa *et al*., 2003). Furthermore, the trypsin inhibitor content of raw sweet potato roots which ranges from 153-628 TIU/g protein (Senanayake *et al*., 2014) further impairs its digestibility, lowering its metabolizable energy value.

With about 55% of Nigeria's sweet potato harvest lostto postharvest spoilage arising from skinning, wounding, desiccation and infection by microorganisms and storage pests, brought upon by poor storage conditions, environmental conditions and marketing constraints,reduction of postharvest losses is key to increasing the efficiency of production systems (Willett *et al*., 2019; Bechoff *et al*., 2022), and can be addressed by developing sweet potato roots-based energy concentrates for poultry species using high-temperature short-time extrusion technology.Extrusion cooking technology - a high-temperature short-time process in which ingredients are subjected to a combination of moisture, high pressure, high temperature and mechanical shear - has the potential to deactivate heat labile antinutrients, improve nutrient digestibility, as well as improve the shelf life/stability and textural properties of the finished product. This article reports the determination of metabolizable energy of extruded sweet potato-bran energy concentrates developed for feeding poultryusing a semi purified reference diet adapted to the regression technique.

MATERIALS AND METHODS

The methods and protocols adopted in this research work were reviewed by the Department of Animal Science, University of Ibadan, and the authors conformed to the ethical standards for the conduct and reporting of animal research (Jarvis *et al*., 2005; Kilkenny *et al*., 2010).

Preparation of extruded sweet potato-bran blends

The sweet potato (*Ipomea batatas*)roots and brans; corn, rice and wheat, used in this work were obtained from reputable feed stockists. Sweet potato flour was produced from white-fleshed sweetpotato roots which were washed to eliminate sand and debris, then chipped and dried in a forcedair oven at 60ºC until constant weight was attained. The sweet potato and brans were dry-milled finely, and three sweetpotato-cereal bran blends (Table 1) were created from sweetpotato and corn bran (3:2), sweetpotato and rice bran (3:2), and sweetpotato and wheat bran (7:3).

Table 1. Calculated analysis of conventional corn-wheat bran energy concentrate, raw sweetpotato-bran blends and analyzed composition of extruded sweet potato-bran blends

	Conventional energy concentrate	SP-CB 3:2	SP-RB 3:2	SP-WB 7:3
Calculated nutrients				
Crude protein, %	11.29	6.17	8.44	7.30
Sugars, %	-	4.78	5.00	6.05
Starch + sugars, %	-	54.47	53.98	55.13
Crude fibre, %	3.86	5.56	5.70	4.89
Calcium, %	0.04	0.11	0.16	0.16
Phosphorus, %		0.27	0.78	0.43
Non-phytate phosphorus, %	0.09	0.08	0.31	0.19
Lysine, %	0.25	-	-	-
Digestible lysine, %	-	0.11	0.20	0.16
Methionine, %	0.20	-	-	-
Digestible methionine, %	-	0.08	0.11	0.07
Digestible methionine + cysteine, %	-	0.13	0.18	0.13
Digestible threonine, %	-	0.12	0.16	0.13
Analyzed composition				
Gross energy, kcal/g DM		4.39±0.00	4.28±0.00	4.26±0.00
Dry matter, %		89.85±0.78	90.60±0.99	89.25±1.77
Crude protein, %		5.50±0.85	5.38±1.17	6.18±0.32
Ether extract, %		3.75±0.21	3.70±0.28	5.09±0.58
Crude fibre, %		10.80±0.99	9.45±1.06	4.50±0.14
Carbohydrates (calculated as nitrogen free extract, %)		53.13 ±3.08	64.28±2.65	70.09±.87
Ash, %		16.66±5.83	7.80±0.28	3.40±0.1.56

The sweet potato-bran blends were adjusted to 30% moisture content with water, hand mixed, and fed manually through a feeding unit into single screw industrial extruder. The extruder characteristics were screw length-to-diameter (L/D) ratio,6:1, barrel length, 317.5mm, screw speed: 305rpm, die diameter:8mm, feed rate: 33.6kg/h, and extrusion temperature:100ºC. The extruded sweet potato-bran blends were again dried in a forced air oven at 50ºC until constant weight was attained, and subsequently stored at room temperature.

Birds Management and Diets

This trial was conducted at the Teaching and Research Farm of the University of Ibadan, Nigeria. Forty 30-week old ISA brown roosters (1.5-2.2kg body weight)were selected from a research flock pre-weighed, identified individually by a pre-numbered plastic leg ring, then transferred into metabolic cages (120cm × 69cm × 85cm, 2 roosters per cage) equipped with feeding troughs, nipple drinkers and excreta collection trays, in an open-sided building with natural lighting (14L:10D)and ventilation.The roosters were placedon a restricted regime of 100g/dayof a grower (mash) diet (20.9%CP, 3059 kcal/kg ME, 48.7% starch, 3.7% crude fibre, 1.0% calcium,0.66% phosphorus, 0.56% methionine, and 1.26% lysine) for 2 weeks, and encouraged to consume their rations within one hour of serving while water was offered *ad libitum*.

Nine experimental diets were formulated from a semi-purified reference diet containing 15% glucose monohydrate ($C_6H_{12}O_6 \cdot H_2O$)(Table 2), with glucose monohydrate in the basal diet substituted with the sweet-potato bran blends; SP-CB, SP-RB, or SP-WB, on an equal-weight basis (Lammers et al., 2008, Table 3). Titanium dioxide was incorporated in the complete diets at 0.5% as indigestible marker. Each cage was randomly allotted to one of the ten diets (standard reference diet + nine experimental diets)for a 7-day adaptation period and 3-day collection period. During the collection period, excreta was collected daily for 3 days, weighed, and stored at -20ºC. The roosters were randomized at the end of the collection period and the study repeated to augment the small sample size.

Table 2. Ingredients and nutritional composition of standard reference diet

Ingredients	g/kg complete diet
Maize	307.0
Soya bean meal	350.0
Glucose monohydrate ($C_6H_{12}O_6.H_2O$)	150.0
Palm kernel cake	150.0
Dicalcium phosphate	14.0
Limestone	15.0
Salt (NaCl)	2.0
DL-methionine	2.0
Lysine-HCl	2.0
Vitamin-mineral premix	3.0
Titanium dioxide	5.0
Total	100.0
Calculated nutrients	
Metabolizable energy (kcal/kg)	2845.0
Crude protein, %	21.2
Calcium, %	0.95
Available phosphorus, %	0.35
Digestible lysine, %	1.01
Digestible methionine, %	0.43
Digestible methionine + cystine, %	0.63

Mineral and vitamin premix for roosters (composition/kg product): vitamin A, 10,000 IU; vitamin D3, 2,000 IU; vitamin E, 32 mg; vitamin K3, 1.6 mg; vitamin B1, 2.5 mg; vitamin B2, 4.4 mg; niacin, 44 mg; calcium pantothenate, 9.2 mg; vitamin B6, 4 mg; vitamin B12, 0.02mg; choline chloride, 400 mg; folic acid, 0.8 mg; biotin, 0.064 mg; manganese, 96 mg; iron, 80 mg; zinc, 64 mg; copper, 6.8 mg; iodine, 1.2 mg; cobalt, 0.24 mg; selenium, 0.096 mg; antioxidant, 96 mg.

Table 3. Layout of ingredient substitution in experimental diets used in this study

Ingredients	**Diets** **Reference (Standard) diet**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Glucose monohydrate	+++	++	+	-	++	+	-	++	+	-
SP-CB (3:2)		+	++	+++						
SP-RB (3:2)					+	++	+++			
SP-WB (7:3)								+	++	+++

SP-CB; Sweet potato-corn bran blend, SP-RB; Sweet potato-rice bran blend, SP-WB; Sweet potato-wheat bran blend, +++; 15% inclusion in the diet, ++; 10% inclusion in the diet, +; 5% inclusion in the diet, -; 0% inclusion in the diet

Chemical analyses

Total excreta collected per cage was dried at 55ºC in a forced air oven to constant weight, and milled, thereafter aliquots were stored for analyses. Sweet potato-bran blends, experimental diets and excreta were subjected to chemical analyses: dry matter (AOAC, 2005; ISO 967.08), crude protein (AOAC, 2005; ISO 988.05), ether extract (AOAC, 2005; ISO 2003.06), gross energy (ISO 9831:1998), while experimental diets and excreta were further assayed for titanium content (Short *et al*., 1996). All results were reported as means of triplicate measurements.

Calculations and Statistical Analysis

The nitrogen-corrected metabolizable energy (MEn) of the extruded sweet potato-bran blends was estimated by regressing the AMEn values to the proportion of the extruded sweet potato-bran blends in each experimental diet (Lammers *et al*., 2008, Adeleye *et al*., 2021). The AMEn of the experimental diets were calculated by pre-determined equations of (Lesson and Summers, 2001) stated below.

$$AME_n = GE_{diet} - \frac{GE_{excreta} \times Ti_{diet}}{Ti_{excreta}} - 8.22 \times N_{retained}$$

Where AME_n(kcal/kg) = nitrogen-corrected apparent metabolizable energy content of the diet; GE_{diet} and $GE_{excreta}$ (kcal/kg) = gross energy of the diet and excreta, respectively; Ti_{diet} and $Ti_{excreta}$ (%) = titanium in the diet and excreta, respectively; 8.22 (kcal/kg) = energy value of uric acid; and $N_{retained}$ (g/kg) = the nitrogen retained by the roosters per kilogram of diet consumed.

Retained nitrogen was estimated as:

$$N_{retained} = N_{diet} - \frac{N_{excreta} \times Ti_{diet}}{Ti_{excreta}}$$

Where N_{diet} and $N_{excreta}$(%) = the nitrogen content of the diets and excreta, respectively. The studentized t-test was used to investigate possible significant statistical differences between batches, in the absence of which, replicates from both batches were pooled.

The metabolizable energy, ME of the sweet potato-bran blends were estimated by linearly regressing the dietary AME of the sweetpotato-bran blends diets less energy associated with glucose contribution against the inclusion level of the sweetpotato-bran blends in the diets of roosters (Sell *et al*., 2001; Lammers *et al*., 2008). The ME values for the extruded sweet potato-bran blends were also calculated as a percentage of their GE values. All analyses, descriptive statistics and studentized t-test, were conducted in JASP (version 0.17.1).

RESULTS AND DISCUSSION

The novelty of sweet potato-bran blends as energy concentrates for chicken feeding is responsible for the scarcity of literature addressing their nutritional properties prompting this study. Results of the analyzed composition of the sweet potato-bran blends; SP-CB, SP-RB, and SP-WB (see Table 1), showed similar gross energy composition (4.39 *vs* 4.28 *vs* 4.26 kcal/g) on dry matter basis which were similar to values reported for dehydrated sweet potato roots (Heuzé *et al*., 2020), however higher crude protein and ether extract were recorded for the SP-WB blend (6.18% and 5.09%, respectively), compared to the SP-CB (5.5% and 3.75%, respectively)and SP-RB (5.38% and 3.7%, respectively)blends. The term "metabolizable energy," or ME, refers to the portion of "potential feed energy" (i.e., gross energy) which may be used to carry out metabolic functions such as biosynthesis, maintenance, growth, and productivity in poultry species, and knowledge of any feedstuff's metabolizable energy value is germaine for its efficient incorporation in feed formulas. A marginal gap is often observed between the gross energy and metabolizable energy values for any feedstuff and are considered energy losses due to heat increment, and inadvertently undigested or unabsorbed feed components. Activities of antinutritional bioactives such as soluble and insoluble starch fractions, non-starch polysaccharides, and inhibitors of digestive enzymes may also restrict the metabolizability of feedstuffs(Nalle *et al*., 2011). In comparison to table values for metabolizable energy obtained from prediction equations and *in vitro* analyses, the measurement of metabolizable energy by in vivo bioassays is regarded as the gold standard.

Figure 1 depicts the regression of dietary apparent metabolizable energy of the sweetpotato-bran blends diets less energy associated with glucose contribution (Y, kcal/g) against the inclusion level of the sweetpotato-bran blends in the diets (X, g) of roosters in the current study. Regression equations were; for SP-CB,y = 3.01x + 2861.40, r^2 = 0.88,for SP-RB, y = 3.11x + 2797.17, r^2 = 0.92, and for SP-WB, y = 3.16x + 2902.37, r^2 = 0.84, hence estimated metabolizable energy corrected for nitrogen (MEn)values for the sweet potato-bran blends; SP-CB, SP-RB, and SP-WB, were 3.01 kcal/g, 3.11 kcal/g, and 3.16 kcal/g, respectively, representing 68.6%, 72.7%, and 74.2% of their analyzed gross energy values.

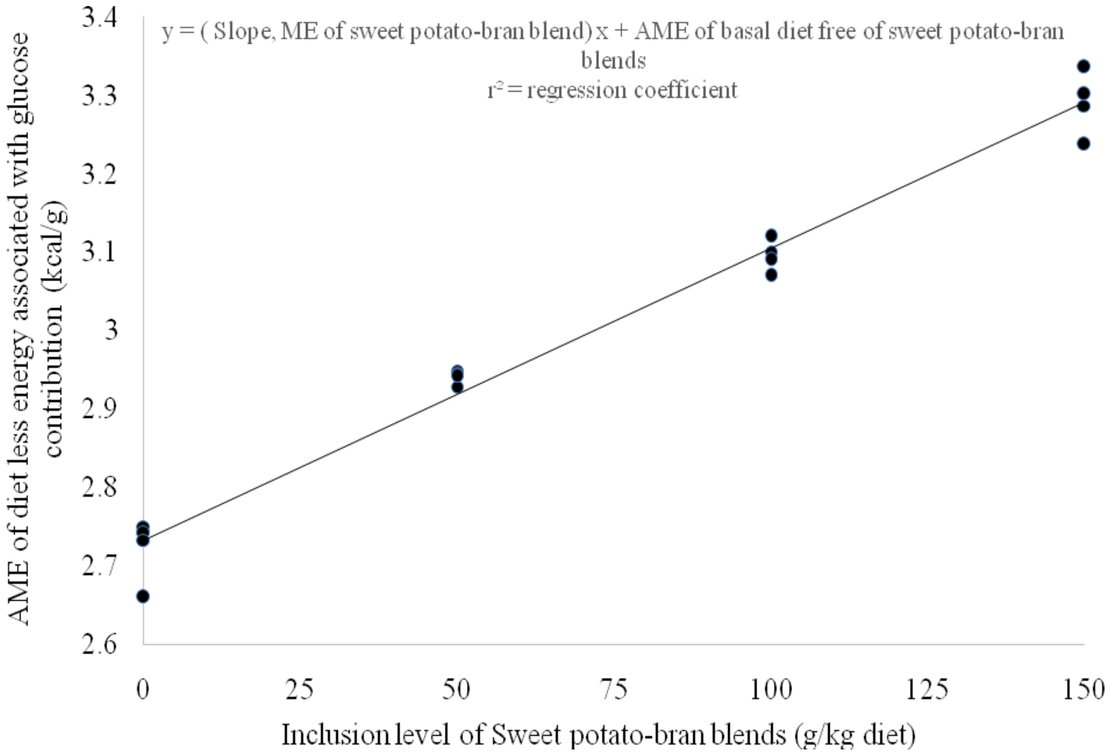

Figure 1: A depiction of the regression of dietary AME of diet less energy associated with glucose contribution (Y, kcal/g) against the inclusion level of the sweet potato-bran blends in the diets (X, g/kg diet) of roosters. (each dot represents data from 1 cage containing 2 roosters).

As expected, the MEn values observed here are lower than 3.26-3.46 kcal/g reported for AMEn of dehydrated sweet potato roots in cockerels (Bryan and Anderson, 2017; Heuzé *et al*., 2020). Also, AMEn values obtained in the current study were also marginally lower than AMEn/TME of other energy cereals; maize (3.72kcal/g), wheat (3.48kcal/g), and barley (2.24kcal ME/g) in laying hens (Mathlouthi *et al*., 2002; Barzegar *et al*., 2019). Earlier studies from our laboratory reported similar plasma glucose responses for maize, wheat, and sweet potato starch in broiler chickens (Adeleye *et al*., 2016) supporting the use of sweet potato-based concentrates in poultry feeds.

CONCLUSION

Novel extruded sweet potato-bran energy concentrates made from sweet potato-corn bran (3:2), sweet potato-rice bran (3:2), and sweet potato-wheat bran (7:3) had metabolizable energies of 3.01 kcal/g, 3.11 kcal/g, and 3.16 kcal/g, respectively, with moderately high energy metabolizability of 68.6%, 72.7%, and 74.2%. As a result, they could be excellent energy concentrates for use in poultry feed formulations.

CONFLICT OF INTEREST STATEMENT

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

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