Nutrient utilisation in grower pigs fed boiled, ensiled or milled cassava roots blended with a high protein concentrate

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ABSTRACT

Cassava is a major pig feed ingredient used by smallholder farmers in tropical countries where it is grown abundantly. Due to its high starch content cassava roots may replace maize or wheat as the energy component of rations fed to pigs. A metabolic experiment was conducted using a 4 × 4 Latin Square design to determine the apparent total tract digestibility (ATTD) of nutrients, energy and nitrogen balance of cassava roots prepared by boiling (BR45), ensiling (ER45) or milling into dry meal (MR45). The cassava products (55%DM) were blended with a wheat based protein concentrate (Pig Conc. 1 at 45% DM), and compared with a wheat-based standard feed (STD) offered to (Landrace × Large White) × Duroc grower pigs (28.0 ± 0.8 kg). DM intakes of pigs were higher on the cassava diets ($P < 0.05$) in the order; BR45 > ER45 > STD > MR45. Growth rate (ADG) and feed efficiency (FCR) on MR45 (1138 g/d and 1.81) were better than on STD (847 g/d and 2.41), whereas ER45 (856 g/d and 2.59) was similar to STD ($P > 0.05$). BR45 was similar to STD for ADG (919 g/d) but not for feed efficiency (3.12). The ATTD of DM, organic matter (OM), calcium and energy utilisation (%) in pigs fed the cassava diets were higher ($P < 0.05$) than the control diet. Overall mean protein (78.1% CP), CF (34.3%), fat (64.2% EE) and phosphorus (43.9% Total P) ATTD were similar for all diets ($P > 0.05$). N digestibility (77.9% intake) and N utilisation (64% digested) were also similar ($P > 0.05$). N retained by pigs on MR45 (25.1 g/d) was lower than on STD (27.6 g/d). However, higher N retained ($P < 0.05$) on BR45 (32.0 g/d) and ER45 (31.3 g/d) did not result in improved FCR or ADG, suggesting that high DM intake of soluble dietary fibre may have affected N utilisation, even if energy utilisation was increased by hindgut fermentation. Nevertheless, cassava roots blended with the complementary protein concentrate provided improved nutrition for grower pigs. Ensiling cassava roots allows the option of long term storage of fermented feed with potential benefits to gut health. However, growth performance trials are required to refine the nutrient requirements for local crossbred pigs farmed in tropical climates.

Key words: Apparent total tract digestibility, cassava roots, grower pigs, nitrogen balance.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an alternative energy ingredient for monogastric livestock in tropical and sub-tropical countries where it grows in abundance (Scott *et al.*, 2000). Due to its high starch content cassava roots may replace maize or wheat as the energy component of rations fed to pigs (Pascual-Reas, 1997). Although the perishable root is high in moisture (60 to 65%) cassava roots contain 20 to 31% carbohydrate on a fresh weight basis (Tewe, 2004). Cassava roots are an important supplementary pig feed in Pacific Island countries (PIC's) for both village level and smallholder commercial pig farmers (Ochetim, 1993). Cassava cultivated in PIC's are mainly the 'sweet' varieties which have less hydrogen cyanide (HCN) toxicity (Bradbury and Holloway, 1988; Bokanga, 1994). Suitable processing methods may further eliminate anti-nutritive factors mmincluding

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including tannins, phytates, oxalates and HCN (Marfo *et al*., 1990; Teka *et al*., 2013), which can reduce palatability and digestibility of cassava-based rations. Cassava roots are very palatable as boiled roots, dry meal or as ensiled feed, with likely benefits to intestinal health and at a reduced cost compared to feeds sourced from off-farm (Loc *et al*., 1997). Protein deficiencies in cassava roots can be overcome by including available protein rich ingredients in feed rations, such as soybean meal and fish meal.

Providing an appropriate protein concentrate to blend with cassava is a logical means to overcome the imbalance of essential amino acids in cassava roots. However, poor processing and storage methods for roots and inadequately mixed rations of cassava with protein rich ingredients limit its feeding value to pigs. This makes management of feeding regimes a challenge for smallholder farmers. Boiling roots, peeled or unpeeled, to feed pigs is a common practice that requires added labour, fuel, water and requires an available crop. Also, because cassava roots do not store well, postharvest curing is a useful means of extending the storage life of feed material before further processing. Ensiling and drying are two effective means to reduce HCN and preserve cassava feed. Drying may be the simplest method for detoxifying cassava roots but ensiling is a more cost effective processing technique (Loc *et al*., 1997; Teka *et al*., 2013), particularly in the wet-humid tropics.

This paper reports the findings of feeding cassava roots processed by different methods with a blend of a protein supplement in grower pigs. The experiment tested the hypothesis that there would be no differences between the three blended cassava root diets and a standard commercial wheat-based feed. An initial report on this work has been presented at the 16th Asian Australasian Animal Production Congress in November 2014 (Dom *et al*., 2014).

MATERIALS AND METHODS

Experiment location

This research was approved by the University of Adelaide Research Ethics committee and was conducted at the Papua New Guinea (PNG) National Agricultural Research Institute (NARI) Labu Livestock Research Station, Morobe Province (Lat. 6° 40' 27" S Long. 146° 54' 33" E). The local climate is typically warm and wet with an average daily temperature of 30°C and 84% relative humidity (NARI weather station).

Experimental animals and metabolic cages

Four crossbred pigs (Landrace × Large White) × Duroc, at nine weeks-of-age with similar body weight (28.0 ± 0.8 kg) were placed into individual metabolic crates which were two double-caged, steel units with dimensions 1.0-m × 1.0-m × 1.5-m on stands 0.7-m above floor level. The cages were equipped with sliding trays to collect faeces. The trays were angled to allow urine to be rapidly drained from the tray. Any solid contaminants from feed, faeces or hair were trapped by a steel coil which allowed urine to drip through a funnel directly into a 2.5 L sealed brown glass bottle through a fine metal-sieve. Each cage was placed in the centre of a concrete pig pen in a well-ventilated open-sided shed. Minimum and maximum shed temperatures at pig level were recorded daily. Fans were placed at the head of each cage to provide air-cooling to the pigs, and additional mist spraying by hand-bottles as required on hotter days (~30 °C) for the duration of the experiment. Close observations were made of the pigs in the crates during sample collection days to ensure clean separation of faeces and urine.

Experiment design and treatments diets

The metabolic experiment was conducted using a 4 × 4 Latin Square design with the four treatment diets interchanged to four grower pigs over four consecutive eight-day feeding periods. Pigs were randomly allocated to the four metabolic crates for the 32 d trial with diets interchanged according to the randomized Latin Square schedule. Processing of feed components for each diet is outlined in Table 1. Three different methods were used to prepare the cassava roots, namely, boiling, ensiling and milling into dry meal, to determine the digestibility of nutrients, energy and nitrogen balance of rations when offered to commercially bred grower pigs. Cassava roots of a local 'sweet yellow' cultivar were harvested at maturity (12 months) from a standing crop cultivated at Sauruan Village, Markham District (PNG) located in an alluvial valley where the climate is hot and dry. On the day after harvesting the roots were divided into three parts for field-clamp curing to arrest spoilage of the root starch during storage (Booth, 1976). Cassava roots were boiled daily (BR) as chopped roots,

roots were boiled daily (BR) as chopped roots, or peeled and milled either for ensiling (ER) or dried into a meal (MR). Chemical analysis of the feed components and data from the literature were used to estimate the nutrient content of the treatment diets (Table 2). A commercially available Pig Grower pellet feed (Associated Mills Ltd, PNG) was used as the standard for comparison with the three nutritionally balanced diets made from processed cassava roots at 55% DM, blended with a protein concentrate, Pig Conc.1 at 45% DM. The diets were formulated to provide the essential amino acids and micronutrients to supplement imbalances in cassava, by using nutritional data from NRC (1998) and the database of Carey Animal Nutrition (Australia). In the Pig Grower and Pig Conc.1, soybean, wheat and micronutrients were imported while all other ingredients were available from local producers.

Table 1: Feed components and processing of cassava roots for treatment diet.

Feed	Components	Processing	Label
Pig Conc.1	Mixed in a commercial mill[2] as a dry meal (88% DM)	Blended at 45% DM of daily ration	45%
Pig Grower	Pellets with nutrient content as per formulation[1]	Standard 100% pellet feed, ground[2] from 10mm to <5mm pellet size	STD
Cassava	Boiled roots	55% roots peeled and placed in boiling water for 45 minutes with ~20 g salt, cooled and mashed in feed bowls	BR
Cassava	Ensiled roots (pH 4.0)	55% tubers flake milled then ensiled by standard methods[3], stored in silos for at least 14 days before feeding	ER
Cassava	Milled and dried roots	55% roots flaked[2] and roller milled to crumble, then sundried to at least 90% DM for storage before feeding	MR

[1]Commercial Pig grower pellet feed and Pig Conc.1 formulation provided by Carey Animal Nutrition (Australia). Ingredient composition of Pig Grower: Wheat grain 31.2%, Meat meal 5.25%, Fish meal (PNG) 2.0%, Wheat millrun (PNG) 60%, Limestone fine 0.5%, Salt 0.15%, Choline chloride (75%) 0.05%, Lysine HCl 0.2%, Pig Premix 0.5%, Mycostat 0.05%, Sorbasafe 0.1%. Ingredient composition of Pig Conc.1: Wheat grain, 12%, Meat meal 13%, Blood meal 5%, Fish meal (PNG) 10%, Tallow 4%, Soybean meal 18%, Wheat millrun (PNG) 35.8%, Salt 0.3%, Choline chloride (75%) 0.1%, Rhodimet-88 Liquid (Methionine) 0.4%, Lysine HCl 0.1%, Lae Feeds Pig Premix 1.0%, Mycostat 0.1%, Sorbasafe 0.2%.
Pig Premix: Vitamin A 15.0 miu, Vitamin D 4.0 miu, Vitamin E 45.0 g, Vitamin K 3.0 g, Niacin 25.0 g, Pantothenic Acid 15.0 g, Folic Acid 1.0 g, Riboflavin/B2 6.0 g, Vitamin B12 30.0 mg, Biotin 100.0 mg, Vitamin B6 3.28 g, Vitamin B1 1.80 g, Cobalt 1.0 g, Iodine 1.0 g, Molybdenum 2.0 g, Selenium 0.15 g, Selplex (inorganic Se) 0.15 g, Copper 10.0 g, Iron 100.0 g, Manganese 50.0 g, Zinc 150.0 g, Ethoxyquin 125.0 g, Surmax 200 75.0 g, Mold Inhibitor 500.0 g, Rovabio Excel AP T-Flex 50.0 g.
[2]Associated Mills (Ltd) Lae, Papua New Guinea; Roller Mill (Project Support Services Ltd)
[3]Ensiling methods modified from Peters et al., (2001); Salt (NaCl at 0.05%w/w of feed) used as a preservative in standard ensiling procedure was added at the same proportion to all diets; acidity in ensiled cassava roots was measured at pH 4.0.

Table 2: Nutrient composition of the feed components, cassava roots boiled (BR), ensiled (ER) or milled (MR), blended treatment diets with 45% Pig Conc. 1 (BR45; ER45; MR45) and standard feed (STD).

Nutrients (%)	Components				Treatment diets			
	BR	ER	MR	Pig Conc.1	BR45	ER45	MR45	STD
DM (as fed)	38.8	35.36	88.8	87.9	60.9	59.0	88.4	88.0
OM	37.8	34.4	86.5	79.1	56.4	54.5	83.2	81.6
Ash	1.0	0.92	2.3	8.8	4.5	4.5	5.2	6.4
CF	0.6	0.56	1.4	4.1	2.2	2.2	2.6	5.6
EE	0.3	0.24	0.6	4.4	2.1	2.1	2.3	3.8
CP	0.7	0.7	1.7	32.9	15.2	15.2	15.7	16.5
Calcium	0.52	0.48	1.20	1.80	1.10	1.07	1.47	0.92
Total P	0.12	0.11	0.27	0.97	0.50	0.50	0.59	0.97
Total N	0.12	0.11	0.27	5.26	2.43	2.43	2.52	2.64
Leucine[1]	0.04	0.04	0.09	2.34	1.07	1.07	1.10	1.03
Lysine[1]	0.04	0.04	0.07	2.03	0.94	0.94	0.95	0.86
Methionine[1]	0.00	0.00	0.03	0.82	0.37	0.37	0.38	0.24
Meth+Cyst[1]	0.00	0.00	0.05	1.26	0.57	0.57	0.60	0.53
Threonine[1]	0.03	0.03	0.05	1.18	0.55	0.54	0.56	0.51
Tryptophan[1]	0.004	0.003	0.014	0.35	0.16	0.16	0.16	0.17
DE (MJ/kg)[2]	16.8	16.9	16.1	15.6	16.3	16.3	15.9	14.8
Lys:DE (kg/MJ)[3]	0.03	0.03	0.04	1.30	0.58	0.57	0.60	0.60
Ca:P[3]	4.33	4.36	4.44	1.86	2.18	2.16	2.51	0.94
NDF[4]	1.4	1.3	7.1	17.9	8.8	8.8	11.9	31.5
ADF[4]	0.6	0.6	4.8	5.9	3.0	3.0	5.3	9.2
Lignin[4]	0.0	0.0	1.5	1.4	0.6	0.6	1.5	2.6
Starch[4]	31.4	28.6	71.4	14.6	23.8	22.3	45.8	35.4

[1]Calculated amino acid values for cassava roots from (Heuzé et al., 2015) combined with major source from the formulation of Pig Conc.1 (Carey Animal Nutrition)
[2]Calculated values using proximate data and the formula DE (kCal) = 4,151 – (122 × %Ash) + (23 × % CP) + (38 × %EE) – (64 × %CF), where R^2 = 0.89 (Noblet and Perez, 1993) and 1kCal = 0.004184 MJ.
[3]Ratios calculated using the respective nutrient and energy values in this table.
[4]Calculated NDF and ADF, Starch and Total sugar values from (Heuzé et al., 2015); based on the major ingredient components in cassava and Pig Conc.1, namely, peeled or dehydrated cassava roots, wheat grain (low protein), wheat bran (for wheat millrun) and soybean (low protein, non-de-hulled).

Feed offer, residue collection and pig welfare

The four feeding periods lasted eight days, with five days for adaptation to the test diets and three days of feeding for total collection of faeces and urine. Feed components were weighed (balance limit 5,000 g ± 0.5 g) as fresh weights to make blended diet weights equivalent to 2,000 g DM diet per offer in the first period; 3,000 g DM for the second and 4,000 g DM diet in the third and last periods. Feed offered was thoroughly hand-mixed and stored daily in individual large plastic dishes. The pigs were fed *ad-libitum*. All remaining feed was collected and weighed daily. The pigs were washed and metabolic crates cleaned daily. Cool water was available at all times through steel-nipple drinkers placed next to the feeding trough. The animals and crates were attended by a worker all day and regularly inspected at night and observations recorded on a clinical record sheet. The pigs were removed from the crates for weighing on day five and eight of each consecutive period. Animal welfare was managed as stipulated by the guidelines prescribed by The University of Adelaide Animal Ethics Committee.

Sampling and chemical testing

Samples for each feed component were kept for chemical analysis at the beginning of the experiment. Faeces were weighed fresh, dried at 105 °C in a forced air-draft oven (Labec®) then milled with a hand-grinder to a coarse (0.5 to 1.0-mm) particle size and packed into PTE bags. Urine samples were collected in sealed brown bottles over 24 h on the three sampling days and stored in a fridge (LG®) at 4 °C before pooling at the end of each period. Dried faeces and urine for each period were pooled and duplicate samples stored at 0 °C until needed for chemical analysis at the National Analytical and Testing Services Laboratory Ltd (Lae, PNG). Dry matter (DM) was calculated as the weight difference between fresh and dry samples after removal of moisture by drying 2.0 g samples for 2 h at 135 °C in a forced-air oven (Thermoline Scientific). Total fats as ether extracts (EE) were determined by Soxhlet extraction in diethyl ether. Crude protein (CP) in feed and faeces were determined as Total Kjeldahl Nitrogen (N), by digestion of 0.5 to 1.0 g samples in concentrated sulphuric acid (FOSS Tecator™) and subsequent nitrogen determination (FOSS Kjeltec™ 8200 distiller), with modification for determining urine N. Calcium (Ca) and total phosphorus (P) analyses followed the procedures of AOAC (2012). Fibre (crude) was determined as the weighed residue on a sintered -glass filter after sulphuric acid digestion and ashing at 500 °C in a muffle furnace (SEM SA Pty Ltd.). Ash was the inorganic residue from a dried, ground sample ignited in a muffle furnace (SEM SA Pty Ltd). Calcium and P were determined respectively by flame (AAS240FS) and UV-Vis spectrophotometry (Shimadzu UV1800). Organic Matter (OM) was calculated from tested feed proximate data. Amino acids leucine, lysine, methionine, threonine and tryptophan values were calculated using data from the literature on cassava roots in fresh, peeled and dry form combined with the formulation of Pig Conc.1. Digestible energy (DE) was calculated according to Noblet and Perez (1993), where DE (kCal) = 4,151 – (122 × %Ash) + (23 × %CP) + (38 × %EE) – (64 × %CF), $R^2 = 0.89$ and converted to MJ/kg.

Statistical analysis

Data from a similar experiment (Dom and Ayalew, 2009a) were used to calculate a priori power and required sample size, as well as post-hoc power, using G*Power Version 3.1.9.2 (Franz Faul, Universitat Kiel, Germany). Expected power of testing for coefficient of apparent total tract digestibility (CATTD) of DM and CP, and N retained at $p<0.05$ were 99.95% (n=16), 99.19% (n=8) and 99.99% (n=8) respectively. Statistical testing was conducted at 95% significance level. All experiment data were collated in Microsoft Excel for initial data handling and outlier assessment using sample variances and scatter graph models. Correlation coefficients for DM intake and daily shed temperatures were calculated by linear regression of 32 data sets. ANOVA of the Latin Square design was completed on GenStat 15th Edition (VSN International Ltd, 2013) using Tukey's Honest Significant Difference for the comparison of means.

RESULTS

Grower pig performance

The experiment results are presented in Table 3. The mean starting body weights (BW) for the four periods were similar. Mean Dry Matter Intake (DMI) was significantly higher for pigs fed the BR45 ($P < 0.05$).Growing pig DMI on the ER45 and MR45 diets were both similar to STD (P > 0.05) diet. The average daily weight gain (ADG) and feed conversion (FCR) were superior (P < 0.05) for pigs fed on the MR45 diet. The ADG was not different among pigs fed ER45, STD and BR45 diets (P > 0.05), but pigs fed on the BR45 diet had the least efficient feed conversion (P < 0.05) while pigs fed on the STD diet had better FCR but lower ADG. BR45 and ER45 diets were much lower in DM content compared to the other diets (Table 2). Faecal DM outputs were significantly greater in pigs fed on the STD followed by BR45 diets. DM output from pigs fed ER45 and MR45 diets were much lower than from BR45 and the STD diet (P < 0.05). Differences in the urine output were not significant (P > 0.05) among the diets. There was a significant correlation between fresh weight intake and urine output (r = 0.5201, P = 0.02). Minimum and maximum temperatures ranged between 24 and 35 °C. DM intake had a significant correlation with minimum temperature (r = -0.2099, P < 0.05) but was not correlated with maximum daily shed temperatures (r = 0.1645, P > 0.05).

Nutrient digestibility in grower pig

Apparent total tract digestibility (ATTD) of DM, OM, and calcium and energy utilisation (%) on the cassava root diets were significantly higher than on STD (P < 0.05) (Table 3). The ATTD for fibre, EE, total P and CP was not affected by the diet (P > 0.05).

N-balance in grower pig

There were no significant dietary differences (P > 0.05) in N intake, output in faeces and urine, or digested. There were significant differences in N retained (g/d) with retention in pigs fed BR45 greater than for pigs fed the MR45 diet (P < 0.05), while pigs fed the ER45 and STD diets were similar (Table 3). There was no significant dietary effect on N digestibility (P > 0.05) but N utilisation (%) was reduced by 11, 15 and 18% from N digestibility on BR45 and ER45, MR45 and STD, respectively, but the differences were not significant (P > 0.05).

Table 3: Performance, Apparent, Total Tract Digestibility and N balance in grower pigs fed blended cassava diets either boiled (BR45), ensiled (ER45) or milled (MR45) or a standard commercial feed (STD).

Parameters	Treatment diets				S.E.D.	Significance
	BR45	ER45	MR45	STD		
			Performance			
Start BW (kg)	42.9	42.1	44.7	42.0	2.47	ns
DMI (g/d)	2787^{c}	2194^{b}	1989^{a}	2030^{ab}	52.2	***
ADG (g/d)	919^{ab}	856^{a}	1138^{b}	847^{a}	65.3	*
FCR	3.12^{c}	2.59^{bc}	1.81^{a}	2.41^{ab}	0.18	**
Faeces DM (g)	444^{b}	311^{a}	356^{a}	685^{c}	23.3	***
Urine (mL)	3236	2848	2214	2171	516.2	ns
			N balance (g/d)			
Intake	65.6	59.9	52.9	60.5	4.95	ns
Faeces	15.4	12.1	12.2	13.4	1.54	ns
Digested	50.2	47.8	40.7	47.1	4.15	ns
Urine	18.2	16.5	15.6	19.5	3.40	ns
Retained	32.0^{b}	31.3^{ab}	25.1^{a}	27.6^{ab}	1.91	*
Digestibility (%)[1]	77.2	79.7	76.8	78.1	1.75	ns
Utilisation (%)[2]	66.4	69.2	61.3	59.3	4.80	ns

Table 3: Performance, Apparent, Total Tract Digestibility and N balance in grower pigs fed blended cassava diets either boiled (BR45), ensiled (ER45) or milled (MR45) or a standard commercial feed (STD) *cont'd.*

Parameters	Treatment diets				S.E.D.	Significance
	BR45	ER45	MR45	STD		
	Apparent Total Tract Digestibility (%)					
DM	84.3^{b}	87.0^{b}	83.9^{b}	69.4^{a}	2.21	***
OM	80.2^{b}	82.6^{b}	85.9^{b}	71.5^{a}	2.39	**
Ash	46.1	58.2	53.6	31.8	8.20	ns
CF	27.1	33.5	37.9	38.7	4.96	ns
EE	64.9	67.4	69.3	55.1	5.21	ns
CP	77.3	80.3	76.8	78.1	1.91	ns
Ca	51.6^{b}	57.4^{b}	64.1^{b}	13.7^{a}	4.09	***
Total P	37.7	53.1	48.4	36.4	46.8	ns
Energy Retained	90.8^{b}	91.4^{b}	90.1^{b}	81.1^{a}	0.91	***

Means on the same row with superscripts a, b and c are Tukey's HSD for values significantly different at $p<0.05$.
S.E.D. is the standard error of differences between any two means.
Significance levels: ns is not significant, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.
[1]N Digestibility (%) = N Retained / N Intake × 100%
[2]N Utilisation (%) = N Retained / N Digested × 100%

DISCUSSION

Feed intake, growth and efficiency

Bulky feeds such as boiled or ensiled cassava roots may be expected to reduce voluntary feed intake compared to the milled cassava root or the wheat based standard diet by inducing early and prolonged satiety (Bindelle *et al.*, 2008). However, in the present study this was not the case where DMI on the two bulky diets ER45 and BR45 were almost 2.2 kg and 2.7 kg DM/d respectively. In addition, the high daytime shed temperatures (~35 °C) did not reduce daily feed intake since given sufficient cool periods (24 °C) in the evenings the pigs increased their feed intake. Growing pigs feed intake is reduced at ambient temperatures above their thermal comfort zone but even for short periods (4 hrs) at cooler temperatures feed intake is compensated and this may affect growth rates as either lean or fat gain (Trezona *et al.*, 2002).In the present work, growth rates were driven by high DM intakes and energy utilisation of over 90% on the blended diets. However, feed conversion ratios indicated differences in the efficiency of nutrient utilisation for growth. Increased metabolic heat energy from digestion of dietary fibre affects growing pigs more than pigs with greater body weight (Noblet and Le Goff, 2001). The dietary fibre content in STD diet was a disadvantage to the growing pigs when fed to satisfaction under the current experiment conditions.

Digestibility of nutrients

There were similarities with the reported nutrient digestibility and utilisation of cassava root diets in this work and in the literature. ATTD of DM, OM, CF, CP, EE and Ash were comparable to other reports for cassava root diets (e.g. Ospina *et al.*, 1995; Hang, 1998; Phuc *et al.*, 2000). Ospina *et al.* (1995) fed cassava root meal in a series of diets with graded protein levels provided by mineral fortified soybean meal. Two of their diets supplied 250 and 300 g CP/d and provided similar nutrition to our test diets. Phuc *et al.* (2000) estimated digestibility coefficients (by regression) for cassava root meal blended with soybean meal, and further substituted with either ensiled cassava leaves or dry leaves meal. By comparison to their estimates, we found lower CF and similar CP ATTD and N digestibility and utilisation (%), but improved N retained (g/d) for the blended test diets and standard feed. It appears that the soybean meal and its level of inclusion with cassava roots had different effects on digestibility in growing pigs regardless of the similar nutrition provided. One likely factor is that soybean meal is higher in soluble dietary fibre and protein than wheat. In fact, nutrient utilisation and pig performance in this work were comparable to diets based on wheat, barley, maize, oats and sweet potato (Bellego *et al*., 2001; Hansen *et al*., 2006; Le Gall *et al*., 2009; Dom and Ayalew, 2009a, b) in diets where dietary fibre did not reduce nutrient digestibility in growing pigs. The crude and dietary fibre (ADF, NDF and lignin) in the cassava -root diets was much lower than the wheat-based STD diet. Furthermore the cassava starch provided a highly digestible source of energy for pig growth. Cassava roots blended at 45% DM provided effective nutrition to match pig performance on the grain based diets.

Effects of dietary fibre from wheat

Wheat bran was the main component in the standard pellet feed (60%) and in the protein concentrate (35.8%). In the blended diets, wheat millrun (35.8%), wheat grain (12%) and soybean meal (18%) increased the level of dietary fibre (NDF, ADF and lignin). Wheat and cassava starch are highly digestible in pigs, but cassava roots (peeled) are lower in dietary fibre. The lower crude fibre digestibility on the blended diets was probably due to insoluble cellulose and lignin. Reduced digestibility on high dietary fibre is related to body weight and a shorter retention time of digesta in the gut (Hansen *et al*., 2006; Ngoc *et al*., 2013). Insoluble fibre in wheat bran may not affect ileal digestion, nor undergo microbial degradation, however, transit time is decreased and faecal bulking in the large intestine results (Bach Knudsen and Hansen, 1991ab). The latter two effects were observed in pigs fed the standard diet (STD) where faecal output was much greater. In contrast, faecal output from pigs fed the cassava root diets was much lower, demonstrating less faecal bulking on the low fibre diets. Peeled cassava roots did not provide additional dietary fibre and the starch and non-starch polysaccharides (NSPs) in cassava roots are readily solubilized by the three processing techniques used (Barampama and Simard, 1995; Teka *et al*., 2013). Increased solubility resulted in the elevated digestibility of carbohydrates in blended diets compared to the standard feed. Digestibility of DM, OM and energy for cassava meal is higher than for maize, sorghum and barley in pigs (Pascual-Reas, 1997). The improved digestibility of starch and NSPs provided more energy for growth on the blended cassava root diets. It is presumed that energy absorbed from hind gut fermentation on cassava diets also contributed to the improved grower pig performance. However, dietary fibre was a disadvantage to nutrient and energy utilisation on pigs fed the standard feed, which despite high N retained (g/d) for lean growth resulted in lower body weight gain.

Nutrient utilisation in grower pig

Nutrient digestibility rather than the small differences in macronutrient content (< 1.5 MJ DE/kg and < 1.3% CP, and < 0.03 kg lysine/MJ DE) in the four test diets affected pig growth and feed efficiency. Higher nutrient digestibility was reported for the same genotype pigs fed cassava root diets, but with lower growth and feed efficiencies (Ospina *et al*., 1995; Phuc *et al*., 2000). Those lower performances were attributed to different environments (cages versus penned) and protein levels but not the digestibility of cassava roots (Pascual-Reas, 1997). High starch levels in milled cassava roots and low dietary fibre in the boiled, ensiled or milled roots, resulted in improved energy retention. Moreover, the improved N retained (g/d) on cassava root diets suggested that the amino acids provided by the complementary protein concentrate might have been of great benefit for nutrient utilisation despite the lower dietary protein.. N utilisation was not affected at low protein levels with sufficient amino acid supplementation (Bellego *et al*., 2001; Kerr *et al*., 2003). The cassava root diets were slightly higher in leucine, lysine, methionine, and methionine+cystine but the higher dietary fibre, particularly NDF, in the wheat-based standard was a disadvantage. Increased ileal N is influenced by the level and type of dietary fibre (Schulze *et al*., 1995; Ngoc *et al*., 2013) but amino acid digestibility is not affected (Sauer *et al*., 1991). It is likely that ileal N absorption improved on cassava root diets. Total tract N retained on the diets was superior to cassava roots blended with fish meal, at 14.2 g/d (Hang, 1998), or soybean meal, at 14.8 g/d (Phuc *et al*., 2000), and this was related to higher N intake (g/d) not lower N excretion (g/d).

Reduced urine N and increased faecal N excretion is expected for diets with soluble dietary fibre but not insoluble fibre (Tetens *et* *al*., 1996). However, this was not indicated for the test diets in this work. The blended cassava root formulations improved N utilisation (%) and retention (g/d) on par with the standard diet. However, pig growth was poorer when fed BR45 diets than the MR45 diet despite a much higher DM intake on the boiled roots diet. This may be explained by greater endogenous secretions in the gut caused by higher nutrient levels, fibre and protein, which increased the energy required for digestion at the expense of growth (Nyachoti *et al*., 1997; Hodgkinson *et al*., 2000). A non-significant improvement in N digestibility to N utilisation in pigs fed the boiled root and the ensiled cassava root diets supports the observation of Hang (1998) that higher levels of cassava root improved N retention and are an indication of improved amino acid absorption. It is likely that part of this retained N was from undigested protein used by microbes feeding on the fermentable NSPs (Van Der Meulen and Jansmen, 1997). There appeared to be no net advantage to pigs fed the ensiled root diet (ER45) although improved growth rates and feed efficiency and gut health were reported in pigs fed fermented liquid feeds (FLF's). In particular, DMI is not reduced despite the slurry feeding of FLF's and there is an improvement in gut pH and leading to beneficial changes in the gut microbial population (Canibe and Jensen, 2003; Missotten *et al*., 2010). These factors may also apply to fermented cassava roots fed as blended diets.

CONCLUSION

Boiled, ensiled or dry milled cassava roots, blended to 55%DM with a supplementary protein concentrate can provide more than adequate nutrition for grower pigs compared with a standard commercial feed in terms of nutrient digestibility, ADG and FCR. Cassava roots are readily available to smallholder pig farmers in PIC's where the ensiled feed provides a further means for improved pig productivity at the farm level by use of stored fermented feed. However, digestibility and growth performance trials are required to further refine the nutrient requirements for local mixed genotype crossbred pigs farmed under tropical climate.

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CONFLICT OF INTEREST

All authors report no conflict of interest in regard to this study.

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