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Nutrient utilization in Papua New Guinean mixed-genotype growing pigs fed boiled sweet potato or cassava roots blended with a wheat-based protein concentrate

Michael T. Dom[1], Roy N. Kirkwood[2*], Workneh K. Ayalew[3], Pikah J. Kohun[1], Philip C. Glatz[4], and Paul E. Hughes[4]

ABSTRACT

Sweet potato (SP) and cassava roots are important feeds in Asia-Pacific countries where local mixed genotype (MG) pigs are bred for meat production. However, the impact of dietary fibre on nutrient digestibility and N balance when roots are boiled needs examination. Two consecutive 32 d metabolic trials (Exp1 and Exp2) in 0.7 m raised double-unit crates (1.0 m × 1.0 m × 1.5 m) allowing separate collection of urine and faeces in a 4 × 4 Latin Square design with eight MG growing pigs, four in each trial with mean starting body weights of 24.7 ± 0.74 kg (Exp1) and 30.5 ± 2.15 kg (Exp2), tested the hypothesis that there would be no differences in performance, nutrient digestibility and N balance from feeding a wheat-based pellet feed (STD), 570 g/kg DM boiled SP roots (SBR43), or 550 g/kg DM boiled cassava-roots (CBR45) or milled-roots (CMR45) blended with a complementary protein concentrate at 430 or 450 g/kg DM, respectively. DM intakes on SBR43 and CBR45 were much higher ($p<0.05$) than CMR45 or STD, however, the ADG and FCR shared statistical similarities. Coefficient of apparent total tract digestibility (CATTD) of DM (0.81-0.88), organic matter (OM) (0.88-0.92), and energy utilization (0.97-0.99) were superior ($p<0.05$) in pigs fed the root-based diets than STD. Fibre, protein and fat CTTAD were also improved on the root-based diets, but ash, Ca and total P CTTAD were reduced ($p<0.05$) compared with STD, and from Exp 1 to Exp 2. The N digestibility (NR-Intake %) and utilization (NR-Digested %) were lower for pigs fed the root-based diets due to very high urine N losses ($p<0.05$). However, the N retained (g/d) were comparable and provided MG pigs with 28.2-34.4 (CBR45), 16.4-23.9 (CMR45), 27.2-31.8 (SBR43) and 23.0-27.5 (STD) g N/d respectively. Digestible nutrients were in excess of the requirements of MG pigs, particularly for protein N, and further refinement of the nutrition provided by SP and cassava root-based diets is possible.

Key words: Cassava; sweet potato; digestibility; growing pigs; nitrogen balance

INTRODUCTION

Sweet potato (*Ipomoea batatas*, L. (Lam)) and cassava (*Manihot esculenta*, Crantz) roots and forage provide an increasing contribution to livestock feed in many developing countries across Asia, Africa and the Caribbean (Scott et al. 1992, 2000) and are a major feed resource in Pacific Island countries (PIC's) such as Tonga, Vanuatu and Papua New Guinea (Ochetim, 1993). The two root crops are particularly important for the production of the modern mixed genotype (MG) pigs predominant in Papua New Guinea (PNG) where around two million animals are kept on village farms and a further 12,000 on smallholder and semi-commercial production enterprises providing an important source of income (Quartermain & Kohun, 2002) and animal protein (Gibson, 2001). Sweet potato (SP) and cassava crops serve a dual food-feed purpose, with locally popular cultivars originating from clones supplied by the International Potato Centre. Anti-nutritional factors such as tannins, phytates, and cyanogenic glucosides in cassava, and trypsin inhibitors in SP cultivars grown in PNG are relatively low (Bradbury and Holloway, 1988), and the roots usually boiled in water to improve the digestibility of root starch and other nutrients (Bradbury et al., 1988; Marfo et al., 1990; Barampama & Simard, 1995; Teka et al., 2013). Additionally, protein concentrate feeds such as copra meal, fish meal or agro-products such as corn meal, rice bran and wheat millrun may also be fed to pigs in admixtures or separately. However, the growth of MG pigs, even when maintained under improved conditions, remains lower than their genetic potential and are mostly unpredictable, partly because of inconsistent feed formulations and feeding regimes. Moreover, the modern MG pigs in PNG reflect a geographical and historical spread of many different pig genotypes (Hide, 2003; Spencer et al., 2006; Ayalew et al., 2011). Indigenous crossbred animals are of interest because of their inherent resilience to local environments and ubiquity within local farming communities (e.g. Preston, 2000; Noblet et al., 2013).

Improved nutrition for production animals, particularly growing pigs, was identified as a critical input for research and development in PNG and other PIC's (Ochetim, 1993; Quartermain & Kohun, 2002). Improving the nutrient

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[1]National Agricultural Research Institute, Mainland Research Centre Labu Station, P.O. Box 1639, Lae 411, Morobe Province, Papua New Guinea
[2]The University of Adelaide, School of Animal and Veterinary Sciences, Roseworthy, SA 5371, Australia
[3]International Centre of Insect Physiology and Ecology, PO Box 5689, Addis Ababa, Ethiopia
[4]South Australian Research and Development Institute, Roseworthy Campus, Roseworthy, SA 5371, Australia

*Corresponding author: roy.kirkwood@adelaide.edu.au

utilization and performance of locally farmed livestock species without reliance on grain feeds is a challenge for nutritionists (Hegarty et al., 2010). Commercially available pellet feeds are grain-based and therefore subject to rising commodity prices on global markets, creating an economic burden, which is beyond the small-scale pig farmer's purse. In local contexts, SP and cassava are more economical as these crops grow in abundance, produce adequate yield for minimum input and are harvested all year round (Dominguez et al., 1997; Peters et al., 2001). Therefore, with the objective of maintaining the major portion being of cheaper home-grown feed, a protein concentrate was formulated that would complement the nutrient requirements of pigs when either SP or cassava roots were blended at 55% and 57% DM of the diets with a complementary protein concentrate. The feeding value of three test diets; boiled SP or cassava roots, or milled cassava roots, were tested against a commercially available pig grower feed, used as a proxy standard. The current experiment tested locally bred MG pigs from a highland farm fed diets which were used in previous metabolic experiments using commercial growing pigs of the standard production genotype (Landrace × Large White) × Duroc (Dom et al., 2014, 2017). The experiment tested the hypothesis that there would be no differences in the nutrient digestibility, N balance and growth performance of local MG pigs fed boiled sweet potato or cassava roots, or milled cassava roots, blended with a wheat-based protein concentrate compared to a commercially available wheat-based pellet feed used as a standard.

METHODS AND MATERIALS

Experiment location

Two consecutive metabolic experiments were completed from 15 January to 19 February and 20 February to 24 March at the National Agricultural Research Institute (NARI), Labu Livestock Research Station (Lat. 6° 40' 27" S Long. 146° 54' 33" E), about 15 min by road from Lae Town. Feed, faecal and urine samples were stored on station before delivery to the National Analytical and Testing Services Laboratory, University of Technology, Lae Town.

All pigs were managed according to the animal welfare guidelines (NHMRC, 2013) as prescribed by the University of Adelaide Animal Ethics Committee (Approval Number 0000016426).

Experiment design and animals

Metabolic experiments were conducted in a 4 × 4 Latin Square design with four diets as interchanged treatments fed to four growing pigs over four consecutive 8-d feeding periods. Locally bred mixed genotype pigs were sourced from Robinson Kale Family Piggery at Kindeng, Jiwaka Province (Lat. 5° 52' 9" S, Long. 144° 41' 50" E), approximately 30 min by road from Banz township (1,606 masl). The breeding stock was established over 30 years by multiple crossings of local village pigs (predominantly the boar line) with introduced breeds including Large White, Large Black, Landrace, Duroc, Berkshire and Tamworth. Eight growing pigs were selected from different litters from a single boar line, weaned naturally at 7 weeks age. Sows were treated with Ivomectin® pre-farrowing to minimise parasite transmission to their piglets. No other treatments were administered. All eight pigs were delivered to Labu Station in a single batch and maintained on limited offer (1.0 kg/pig/day) of a wheat-based pellet feed (STD). The pigs were assigned by weight for use in two consecutive experiments and each placed into individual metabolism crates for feeding. The first four pigs (24.71 ± 1.71 kg BW) were selected for Experiment 1 after fasting for 24 h to measure empty body weight. The remaining four pigs (30.46 ± 2.15 kg BW) were maintained on a limited pellet feed offer and used after another 32 d later. All feed was offered ad libitum to pigs in the crates for 24 h before reweighing of the pigs to an accuracy of 0.01 kg and commencement of the trial periods. On days 5 and 8 of sequential feeding periods, each pig was removed from its crate and weighed.

Metabolic crates

Metabolic crates were two double-room, steel units with dimensions 1.0 m × 1.0 m × 1.5 m on stands 0.7 m above floor level. The crates were equipped with sliding trays to collect faeces and angled to allow urine to be rapidly drain from the tray. Any solid contaminants from feed, faeces or hair were trapped by a steel coil that allowed urine to drip through a funnel directly into a 2.5 L sealed brown glass bottle through a fine metal-sieve. Each crate was placed in the centre of a concrete pen in an open-sided shed. Fans were placed at the head of each crate to provide cooling air movement for the pigs for the duration of the experiment. Minimum and maximum shed temperatures were 25°C and 36°C, and 25°C and 31°C during Exp 1 and 2, respectively. Relative humidity ranged from 77% to 90% (NARI weather station).

Treatment diets

A protein concentrate, Conc.1, was formulated and produced in PNG from local and imported products and was designed to complement nutritional imbalances in SP and cassava roots to provide the treatment diets (Table 1). The formulated rations were analysed for proximate nutrient content. Leucine, lysine, methionine, methionine + cysteine (Meth + Cyst), threonine and tryptophan, and dietary fibre as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (Lignin) were estimated from the combined formulation ingredients of Conc.1 and published values for sweet potato roots from Feedipedia.com (Heuzé et al., 2015).

A commercial grower pig pellet feed was used as the standard diet (STD) for comparison with nutritionally balanced diets made from SP and cassava blended with Conc.1. Blended diets consisted of 570 g/kg SP roots with 430 g/kg Conc.1 and 450 g/kg cassava roots blended with 550 g/kg Conc.1 on a DM basis. The SP (Rachel White) and cassava (yellow) roots from identified local cultivars were sourced from Lae Town main market and Dzendzen Village, Boana District, respectively. The SP roots were purchased in bulk as cured mature roots and stored for the duration of feeding. Cassava roots were cured by the clamp method (Booth, 1976) in the pig trial shed immediately on arrival after harvest. To prepare boiled feed the SP (SBR) and cassava roots (CBR) were washed, weighed and placed separately into large steel pots with fresh tap water sufficient to cover the mass. Salt (0.5%

w/w) was added and tubers allowed to cook for about 45 min. To prepare milled cassava roots (MR), cleaned fresh roots were grated using a modified flake mill (Project Support Services Ltd), then sun-dried for about 6 h before being placed into a large-capacity Labec® forced air-draft oven for drying overnight at 105 °C. Dry SP gratings were milled using a roller mill (Project Support Services Ltd) to provide a coarse crumble texture (5-10 mm pieces). Salt (0.5% w/w) was added to MR during mixing with protein concentrate. The wheat-based pellet feed (STD) and Conc.1 meal were stored as received in hessian bags, and opened bags were kept in two large bins fitted with lids.

Table 1. Nutrient composition of boiled sweet potato and cassava roots, milled cassava roots, the protein concentrate, three blended treatment diets and wheat-based pellet feed

Nutrients (g/kg DM)	**Components**				**Treatment diets**			
	SBR*	**CBR***	**CMR***	**Conc.1***	**SBR43**	**CBR45**	**CMR45**	**STD**
Chemical analysis								
DM (as fed)	377	388	888	879	603	609	884	880
OM	368	378	865	791	558	564	832	816
Ash	9	10	23	88	45	45	52	64
Fibre	9	6	14	41	23	22	26	56
Ether Extract	5	3	6	44	23	21	23	38
Protein	10	7	17	329	154	152	157	16.5
Calcium	0.9	5.2	12.0	18.0	8.6	11.0	14.7	9.2
Total P	1.1	1.2	2.7	9.7	5.0	5.0	5.9	9.7
Total N	2.0	1.2	2.7	52.6	24.8	24.3	25.2	26.4
Calculated values								
Leucine**	0.5	0.4	0.4	23.4	10.3	10.7	10.7	10.3
Lysine**	0.4	0.4	0.3	20.3	9.0	9.4	9.3	8.6
Methionine**	0.1	0.0	0.1	8.2	3.6	3.7	3.8	2.4
Meth+Cyst**	0.3	0.0	0.2	12.6	5.6	5.7	5.8	5.3
Threonine**	0.5	0.3	0.2	11.8	5.3	5.5	5.4	5.1
DE (MJ/kg)	16.9	16.8	16.1	15.6	16.3	16.3	15.9	14.8
Lys:DE (kg/MJ)	0.02	0.03	0.02	1.30	0.55	0.58	0.58	0.58
Ca:P	0.82	4.33	4.44	1.86	1.73	2.18	2.51	0.95
NDF***	43	14	71	179	104	88	119	277
ADF***	20	6	48	59	37	30	53	81
Lignin***	4	0.0	15	14	9	6	15	23
Starch***	261	314	714	146	209	238	458	312
Total sugars***	34	0.0	21	41	37	18	30	47

* SBR is Sweet potato boiled roots; CBR and CMR are Cassava boiled or milled roots; Conc.1 is the complementary protein concentrate formulated by Carey Nutrition and blended with SP at 43% DM or with CA at 45% DM, for treatments SBR43, CBR45 and CMR45; wheat-based pellet feed was the standard, STD. ** Calculated amino acid values for Cassava and Sweet Potato roots from Feedipedia.com (Heuze et al., 2015) combined with major source from the formulation of Conc.1 (Carey Nutrition). *** Calculated NDF and ADF, Starch and Total sugar values from Feedipedia.com (Heuze et al., 2015); based on the major ingredient components in cassava, sweet potato and Conc.1, namely, peeled or dehydrated cassava roots, fresh sweet potato roots, wheat grain (low protein), wheat bran (for wheat millrun) and soybean (low protein, non-de-hulled).

Feed offer, refusal collection and pig welfare

The feeding and collection procedure were as for previous experimental work with similar diets fed to commercial breed growing pigs (Dom et al., 2014, 2017). The four 8-d feeding periods included 5-d for adaptation to the test diets and 3-d feeding for total collection of faeces and urine. Feed components were weighed (balance limit 5000 ± 0.5 g) fresh to make blended diet weights equivalent to 2000 g DM diet per offer at the first 10 d period, 3000 g DM for the second and 4000 g DM diet in the third and fourth periods, ensuring that the pigs were fed to appetite. Feed offered was thoroughly hand-mixed and stored daily in individual large plastic dishes. To allow ad libitum feeding, additional feed was provided each day at around 1000 h, 1300 h and 1700 h, as required. Any remaining feed was collected and weighed as refusal. The pigs were washed every morning and metabolic crates cleaned daily. Mist spray was provided by hand as required. Clean piped water was available at all times through steel-nipple drinkers placed next to the feeding trough.

Collection of feed, faeces and urine samples

Samples of each feed component were sent for chemical analysis at the beginning of the experiment. Total collected faeces were weighed fresh, and then dried over 24 h as bulk samples in a large oven at 105 °C (Labec®), then milled to a coarse meal with a hand-grinder. Urine samples were collected in sealed 2.5 L brown glass bottles over 24 h each day. Urine was stored at 4 °C (LG™ refrigerator) immediately after daily sampling. At the end of each 3-d sampling period dried faeces and urine were separately pooled and duplicate samples stored at 0 °C (Westinghouse upright freezer) before delivery to the laboratory for chemical analysis.

Chemical analysis of samples

Proximate analyses of feed, faeces and nitrogen in urine, were conducted at the National Analytical and Testing Services Laboratory Ltd (Lae, PNG) using AOAC (2012) Official Methods. Dry matter (DM) was calculated as DM%=100%–Moisture% after determining moisture (AOAC 930.15) by drying samples for 2 h at 135 °C in a forced-air oven (Thermoline Scientific). Protein was estimated by Total Kjeldahl Nitrogen (AOAC 954.01) after digestion of samples in concentrated sulfuric acid (FOSS Tecator™) and subsequent nitrogen determination on Kjeltec™ 8200 distiller (FOSS), and estimating crude protein as CP%=N%×6.25 (or 5.70 for wheat-based feeds). Total fat content (AOAC 920.39) was determined as the ether extracts (EE) in diethyl ether evaporated by Soxhlet apparatus. Fibre was determined as crude fibre (AOAC 978.10) on a sintered-glass filter as the weighed residue after sulfuric acid digestion and ashing at 500 °C in a muffle furnace (SEM SA Pty Ltd). Ash (AOAC 942.06) was determined by weighing the resulting inorganic residue from a dried, ground sample ignited in a furnace at 600 °C (SEM SA Pty Ltd). Organic matter (OM) was calculated by OM%=DM%–Ash%. Calcium (AOAC 927.02) was determined by Atomic Absorption Spectrophotometry (AAS240FS). Phosphorus was determined as total P (AOAC 964.06) by spectrophotometry (Shimadzu UV1800). 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. Calculation of Digestible Nutrients was completed for 16 pooled samples collected over the four periods of experimentation, and using the proximate nutrient values from feed and collected faeces to employ the general formula Coefficient of Apparent Total Tract Digestibility = [(Nutrients in Feed, g – Nutrients in Faeces, g) / Nutrients in Feed, g]. Nitrogen (N, g/d) Balance included 16 pooled samples of urine collected over the four periods of experimentation, and using the Total N from proximate analysis to estimate Total N Intake, Faecal N, Urine N and calculating Digested N = [(Total N Intake, g/d) – (Faecal N, g/d)] and Retained N = [(Digested N, g/d) – (Urine N, g/d)]. Subsequently, N Retained as a percentage of Intake N was calculated as NR-Intake % = [(Retained N, g/d) / (Total N Intake, g/d) ×100] and N Retained as a percentage of Digested N was calculated as NR-Digested % = [(Retained N, g/d) / (Digested N, g/d) ×100].

Statistical analysis

For suitability of the small sample size, a priori and post hoc power were determined using G*Power Version 3.1.9.2 (Franz Faul, Universitat Kiel, Germany) on preliminary data from published work using similar treatment diets, pig genotype and the same experimental conditions (Dom and Ayalew, 2009a), e.g., at p<0.05 expected powers were 99.95% (n=16), 99.19% (n=8) and 99.99% (n=8) for estimating percent digestibility of DM and CP, and N retained, respectively. Statistical testing was conducted at 95% significance level. Correlation coefficients were calculated on Vassar Stats (http://vassarstats.net/index.html) by linear regression of 32 d shed temperature and DM feed intake. All experiment data were collated on Microsoft® Excel and then GenStat 15th Edition (VSN International Ltd, 2013) was used for the ANOVA by Latin Square design with means separated by Tukey's Honest Significant Difference (HSD).

RESULTS

Composition of experimental treatment diets

Sweet potato (SP) and cassava diets were nutritionally similar but the higher DM content of cassava meal increased the starch and calcium content on an as fed basis (Table 1). The treatment diets were isonitrogenous but not isocaloric due to higher digestible energy calculated for the root based diets, which although 28% lower in DM content were estimated to contain slightly higher gross energy than the wheat-based pellet feed used as the standard comparator. The four diets contained about 9 g lysine/kg and a lysine: DE ratio of about 0.6 kg/MJ, which was within recommendations for growing pigs (NRC, 1998; Moore et al., 2013). Standard feed was much higher in phosphorus, however, the Ca: P ratio of root based diets was slightly in excess of recommended daily requirements for growing pigs. The estimated dietary fibre (NDF, ADF and lignin) content of standard feed, which contained wheat grain (31.2%) and wheat millrun (60.0%), were higher than in the blended SP and cassava diets. The complementary protein concentrate provided more dietary fibre to the blended root diets from three ingredients, namely, soybean (18%), wheat (12%) and millrun (36%).

Experiment 1

Growth performance of MG pigs

Mean BW of 33.4 kg was similar across the trial periods on each test diet for MG pigs starting at 24.7 ± 0.74 kg (BW ± s.e.) and finishing at 45.5 ± 1.61 kg (Table 2). Overall DM intakes were significantly higher for pigs fed on the boiled root diets CBR45 and SBR43 than the milled-cassava (CMR45) and standard feed (STD). The pigs were observed to feed more actively during the cooler hours of the day and at night (no data). However, minimum (r^2=0.05, p=0.05, df=126, one-tailed t-Test) and maximum (r^2=0.11, p<.0001, df=126, one-tailed t-Test) daily shed temperatures determined only 5-11% of the measured DM intake. The mean growth rates (ADG) were similar between the pigs for all four diets, however, a higher feed intake on CBR45 resulted in higher FCR, whereas the FCR of SBR43 and CMR45 were similar. STD provided the most efficient feed conversion to pig growth.

Table 2. Performance of mixed genotype pigs fed blended diets of sweet potato (SBR43) and cassava roots either boiled (CBR45) or as dry meal (CMR45) and wheat-based pellet feed (STD)

Parameter	Grand mean	Treatment diets				SEM	P
		CBR45	CMR45	SBR43	STD		
Experiment 1 (25 kg Start BW)							
Mean BW (kg)	33.4	33.9^{a}	32.9^{a}	33.5^{a}	33.2^{a}	0.433	ns
DMI (g/d)	2,259	2,734^{d}	1,769^{a}	2,449^{c}	2,086^{b}	36.5	***
ADG (g/d)	812	857^{a}	821^{a}	832^{a}	736^{a}	64.9	ns
FCR	2.86	3.81^{c}	2.69^{b}	3.05^{b}	1.90^{a}	0.135	***
Faeces DM (g)	375	342^{a}	378^{b}	358^{ab}	421^{c}	5.71	***
Urine (mL)	1,676	2,314^{c}	1,433^{b}	2,263^{c}	696^{a}	91.0	***
Experiment 2 (30 kg start BW)							
Mean BW (kg)	46.0	46.2^{a}	45.5^{a}	46.2^{a}	46.0^{a}	0.307	ns
DMI (g/d)	2,437	3,073^{b}	1,652^{a}	3,183^{b}	1,839^{a}	92.8	***
ADG (g/d)	808	1032^{b}	671^{a}	825^{ab}	704^{a}	45.8	**
FCR	2.92	2.77^{a}	2.55^{a}	3.79^{b}	2.59^{a}	0.07	***
Faeces DM (g)	396	355^{ab}	320^{a}	443^{b}	467^{b}	24.0	*
Urine (mL)	1,813	2,209^{c}	1,698^{b}	2,385^{c}	960^{a}	65.1	***

Means with the same superscript were significant at $p<0.05$ when separated by Tukey's HSD
In this and subsequent tables, *P*: ns is not significant; * $p<0.05$; ** $p<0.01$, *** $p<0.001$.

Faecal DM output was highest for pigs fed STD but there were statistical similarities for the three root-based diets. Urine output was much lower for pigs fed on the STD diet followed by CMR45, whereas the two boiled-root diets resulted in similar high urine outputs. The moisture content of test diets influenced 28% of the data on the pigs urine output ($r^2=0.28$, $p<.0001$, df=46, one-tailed t-Test).

Nutrient digestibility to 33 kg MG pigs

Coefficient of apparent total tract digestibility (CATTD) of DM and OM was higher for pigs fed the root-based diets (Table 3). Carbohydrate (NFE) CATTD was also superior for pigs fed the root-based diets than STD. Ash CATTD was very low for pigs fed on milled-cassava (CMR45) compared to feeding the boiled-root diets (CBR45 and SBR43) or the STD pellet feed. Fibre CATTD was improved in pigs fed on the three root-based diets compared to STD. Fat CATTD was superior for pigs fed the two boiled-root diets compared to the CMR45 and STD. Protein CATTD was higher in pigs fed the boiled-root diets and STD but on CMR45 the protein digestibility was 7% lower. Ca CATTD were high and similar in pigs fed all the diets. Total P CATTD was much higher for pigs fed on STD and CBR45, but lower for CMR45. Energy utilization was up to 14% higher for pigs fed on the root-based diets.

N balance in 33 kg MG pigs

There were distinct differences in the pigs daily N intake (g/d) on all four diets (Table 4), with CBR45 providing the highest and CMR45 the lowest intake. Faecal losses of N (g/d) in the pigs on all four diets were also distinctly different, with CBR45 again the highest but STD the least. Digested N (g/d) were similar between pigs fed the dry feeds CMR45 and STD but these were lower than for pigs fed boiled-root diets. The daily N balance results were in line with the pigs DM intake and faecal DM output for each of the diets (Table 2). Urine N loses (g/d) were higher in pigs fed the three root-based diets and over 50% lower for pigs fed the STD diet. N retained (g/d) was the lowest for pigs fed CMR45, whereas there were statistical similarities between pigs fed the boiled-root and STD diets. N retention (%) from intake (NR-Intake) and from digested N (NR-digested) were superior for pigs fed the pellet STD. Whereas, for pigs fed the root-based diets, N retention (%) from intake and digested N was much reduced indicating that regardless of higher N intake the N digestibility to pigs fed these diets was less efficient than for pigs fed STD pellet feed.

Table 3. Coefficients of Apparent Total Tract Digestibility of nutrients for mixed genotype pigs fed blended diets of sweet potato (SBR43) and cassava roots either boiled (CBR45) or as dry meal (CMR45) and wheat-based pellet feed (STD)

Nutrient	Grand mean	Treatment diets				SEM	P
		CBR45	CMR45	SBR43	STD		
Experiment 1 (25 kg start BW)							
DM	0.84	0.87^{c}	0.85^{b}	0.87^{c}	0.78^{a}	0.004	***
OM	0.88	0.92^{b}	0.90^{b}	0.91^{b}	0.79^{a}	0.005	***
Ash	0.45	0.59^{c}	0.12^{a}	0.46^{b}	0.62^{c}	0.019	***
Fibre	0.65	0.79^{c}	0.61^{b}	0.78^{c}	0.40^{a}	0.025	***
Fats	0.64	0.74^{b}	0.53^{a}	0.72^{b}	0.56^{a}	0.028	**
Protein	0.90	0.92^{b}	0.85^{a}	0.92^{b}	0.91^{b}	0.010	**
NFE	0.89	0.93^{b}	0.93^{b}	0.94^{c}	0.79^{a}	0.002	***
Ca	0.82	0.86^{a}	0.76^{a}	0.79^{a}	0.87^{a}	0.023	*
Total P	0.66	0.73^{bc}	0.41^{a}	0.67^{b}	0.82^{c}	0.024	***
Energy	0.95	0.99^{b}	0.99^{b}	0.97^{b}	0.85^{a}	0.006	***
Experiment 2 (30 kg start BW)							
DM	0.83	0.88^{b}	0.81^{ab}	0.85^{ab}	0.77^{a}	0.018	*
OM	0.87	0.91^{b}	0.88^{b}	0.90^{b}	0.79^{a}	0.015	**
Ash	0.43	0.47^{b}	0.36^{a}	0.33^{a}	0.56^{c}	0.010	***
Fibre	0.61	0.81^{c}	0.59^{b}	0.54^{ab}	0.50^{a}	0.012	***
Fats	0.52	0.64^{b}	0.47^{a}	0.57^{b}	0.39^{a}	0.017	***
Protein	0.85	0.91^{c}	0.78^{a}	0.86^{b}	0.86^{b}	0.005	***
NFE	0.91	0.94^{b}	0.94^{b}	0.95^{b}	0.82^{a}	0.003	***
Ca	0.70	0.81^{d}	0.57^{a}	0.68^{b}	0.73^{c}	0.006	***
Total P	0.60	0.55^{a}	0.51^{a}	0.49^{a}	0.87^{b}	0.024	***
Energy	0.96	0.98^{b}	0.98^{b}	0.99^{b}	0.87^{a}	0.003	***

Means with the same superscript were significant at $p<0.05$ when separated by Tukey's HSD

Experiment 2

Growth performance of MG pigs

Mean BW of 46.0 kg was similar across the trial periods on each test diet for MG pigs starting at 30.46 ± 2.15 kg and ending at 55.9 ± 1.14 kg (Table 2). DM intake was higher for pigs fed the boiled-root diets CBR45 and SBR43, and lower for pig fed CMR45 or STD. There was no generally observed change in the pigs feed intake during the day or at night. Neither minimum ($r^2=0.0017$, $p=0.323$, df=126, one-tailed t-Test) nor maximum ($r^2=0.0006$ $p<0.389$, df=126, one-tailed t-Test) daily shed temperatures influenced the pigs DM intake. ADG was higher for pigs fed on the boiled-root diets than CMR45 or STD. FCR were similar for CBR45, CMR45 and STD but much lower for SBR43.

Faecal DM output was greater from pigs fed STD and SBR43, while for CBR45 and CMR45 the output were lower. There were higher urine outputs from pigs fed the boiled-root diets CMR45 or STD. The moisture content of the diets (Table 1) influenced 23% of the data on the pigs urine output ($r^2=0.231$, $p=0.00027$, df=46, one-tailed t-Test).

Nutrient digestibility to 46 kg MG pigs

DM, OM and carbohydrate (NFE) CATTD were improved in pigs fed on root-based diets than STD but there were some statistical similarities for DM CATTD (Table 3). Ash CATTD was much lower for pigs fed the root-based diets than STD. Fibre CATTD in the pigs was over 22% higher when fed CBR45, whereas SBR43, CMR45 and STD provided statically similar fibre digestibility to the pigs. There were distinct differences for Ca CATTD on the four diets, in particular for pigs fed CBR45 the calcium digestibility was 27% lower than for pigs fed CMR45. Total phosphorus CTTAD in pigs was over 32% lower for pigs fed the root-based diets than for pigs fed STD pellet. Energy utilization was up to 12% higher to pigs fed on the three root-based diets.

N balance in 46 kg MG pigs

N intake (g/d) in pigs fed the boiled-root diets were almost twice that of pigs fed either CMR45 or STD (Table 4). Faecal N loss (g/d) from pigs was much higher only for SBR43 than the other three diets. The digested N (g/d) were higher for pigs fed the boiled-root diets and similarly lower for pigs fed either CMR45 or STD by about 20 g N/d. There were distinct differences in the pig urine N loses (g/d) from each of the diets, however, the loss was almost twice as high from pigs fed the root-based diets than the STD pellet. N retained (g/d) was almost half the amount for pigs fed CMR45 than for pigs fed CBR45 or SBR43, however, STD pellet diet provided pigs with statistically similar N retained to the milled-cassava diet. The N retention from intake (NR-Intake) and from digested N (NR-Digested) showed some statistical similarities between the pigs fed on each of the four diets.

Table 4. N balance in mixed genotype pigs fed blended diets of sweet potato (SBR43) and cassava roots (CBR45) either boiled or as dry meal (CMR45) and wheat-based pellet feed (STD)

Nitrogen (g/d)	Grand mean	Treatment diets				SEM	P
		CBR45	CMR45	SBR43	STD		
Experiment 1 (25 kg start BW)							
Intake	56.7	66.3^{d}	44.5^{a}	60.7^{c}	55.0^{b}	0.96	***
Faeces	7.9	9.7^{d}	8.7^{c}	7.0^{b}	6.2^{a}	0.03	***
Digested	48.8	56.3^{b}	40.6^{a}	54.1^{b}	44.2^{a}	1.54	***
Urine	21.4	28.1^{c}	21.9^{b}	23.9^{bc}	11.6^{a}	1.08	***
Retained	28.0	28.8^{ab}	23.9^{a}	31.8^{b}	27.5^{ab}	1.40	*
NR-Intake (%)	45.1	48.0^{ab}	35.1^{a}	34.4^{a}	63.0^{b}	3.44	**
NR-Digested (%)	53.2	54.8^{a}	43.6^{a}	42.0^{a}	72.3^{b}	3.10	**
Experiment 2 (30 kg start BW)							
Intake	63.8	80.5^{b}	46.9^{a}	79.1^{b}	48.7^{a}	2.25	***
Faeces	10.4	9.8^{a}	7.8^{a}	14.1^{b}	10.1^{a}	0.74	**
Digested	52.4	65.3^{b}	40.4^{a}	62.2^{b}	41.8^{a}	1.38	***
Urine	27.0	29.8^{c}	28.6^{b}	33.8^{d}	15.8^{a}	0.13	***
Retained	25.2	34.4^{c}	16.4^{a}	27.2b^{c}	23.0^{ab}	1.87	**
NR-Intake (%)	41.1	46.2^{bc}	32.6^{a}	37.4^{ab}	48.0^{c}	1.90	**
NR-Digested (%)	50.5	53.9^{b}	38.9^{a}	49.2^{ab}	59.9^{b}	2.23	**

Means with the same superscript were significant at $p<0.05$ when separated by Tukey's HSD
NR-Intake is N Retained as a percentage of N Intake
NR-Digested is N Retained as a percentage of N Digested

DISCUSSION

Nutrient utilization in MG growing pigs

Two consecutive metabolic experiments on mixed genotype (MG) growing pigs revealed a high digestibility of nutrients from feeding boiled SP or cassava root diets. However N retention was less efficient than for pigs fed the wheat-based pellet diet. Sweet potato and cassava provide highly digestible carbohydrates as soluble starch, whereas the wheat-based standard feed is slightly lower in digestible starch. In addition, the bulky nature of these root and tuber feeds caused the growing pigs to consume comparatively much more feed, which also led to higher levels of protein N intake. Nevertheless, excess N not contributing to growth may be lost in the faeces and as unutilised N in urine. This was the case in the test diets studied.

Voluntary feed intake (VFI) was higher on the boiled-root diets (SBR43 and CBR45) and lower for the dry blended diets (CMR45 and STD). Dom & Ayalew (2009b) and Dom et al. (2010) also reported elevated DM intake for MG pigs kept in open pens and fed boiled SP-roots and the high VFI was on par with nutritionally similar grain diets (wheat, oats, barley, lupins and soybean) fed to growing pigs of improved genotype (e.g. Hansen et al., 2006; Le Gall et al., 2009; Moore et al., 2013). Dietary fibre (NDF, ADF and lignin) in the standard feed and the bulky (high moisture) roots did not reduce VFI to MG pigs although this occurs for feeds such as wheat bran, soybean hulls or sugar beet pulp (Wenk, 2001; Hansen et al., 2006; Bindelle et al., 2008). The feed intake, growth and feed conversion for both experiments were comparable with several different SP and cassava diets fed to grower-finisher pigs of mixed genotype (Ospina et al., 1995; Gonzalez et al., 2002; Giang et al., 2004; Tzudir et al., 2012). These blended diets, therefore, represent an economic alternative to the use of grain feed for growing pigs. However, poor feed conversion on high DM intake reveals that there was either a nutritional or a genetic limitation to the maximum growth achieved by the MG growing pigs.

MG pigs demonstrated over 10% improved DM and OM CTTAD for root-based diets. Boiling roots improved the solubilisation of starch and dietary fibre (Bradbury et al., 1988; Barampama & Simard, 1995). The improved fibre digestibility in the root-based diets may also be related to previous exposure of these animals to high fibre diet and an improved ability to utilize dietary fibre in heavier pigs (Guixin et al., 1991; Noblet et al., 1994; Kyriazakis, 2011). A higher digestibility of starch and dietary fibre provided much greater energy utilization on the blended root diets compared to the wheat-based feed. Energy utilization in pigs fed the root-based diets were superior to a number of complex diets proposed by Noblet et al. (1993) that contained SP (35%), cassava (20-24%) and wheat (25-29%). The higher NDF content in wheat may have contributed to the lower energy utilization of the standard feed, since insoluble fibre increases faecal bulk (Jorgensen et al., 1996) and speeds passage through the gut (Wilfart et al., 2007). Pelleting does not affect the digestibility of dietary fibre (Le Gall et al., 2009) whereas peeling the cassava tubers effectively removes dietary fibre and lignin (Barampama & Simard, 1995; Teka et al., 2013). However, in the present study, the SP roots were not peeled and may be expected to contribute more dietary fibre (Dhingra et al., 2012). Dietary fibre may reduce nutrient digestibility depending on the body weight of the pigs and the retention time of food in the gut (Hansen et al., 2006; Ngoc et al., 2013), which did not appear to be the case in the present experiments although digesta flow rate was not measured. Ngoc et al. (2013) found that mean retention time would decrease at higher DM intakes but that at lower feed intake digestibility would improve and this was irrespective of diet or breed of pig. Restricting the feed offer may be an option worth testing for these nutrient dense diets when fed to MG pigs.

It is likely that these MG pigs retained better digestive capacity for fibre. Fibre CTTAD for root-based diets was improved compared to literature values. Rose & White (1980) reported digestibility coefficients of 0.97, 0.57, 0.75 and 0.95 for OM, protein, ADF and energy in PNG village pigs fed raw chopped SP roots. CTTAD was 0.54-0.78 for boiled SP-roots and 0.79-0.81 for boiled cassava roots. Whereas, fibre digestibility was lower in commercial genotype (CG) pigs fed the same blended diets of milled (0.31) or boiled cassava roots (0.22) or boiled SP-roots (0.33) (Dom et al., 2014, 2017). Crossbreeds of other indigenous genotype pigs, such as Mukota (Ndindana et al., 2002; Chimonyo et al., 2004) and Mong Cai (Giang et al., 2004; Ngoc et al., 2013), demonstrated an improved utilization of diets much higher in dietary fibre but also had lower protein digestibility. Soluble fibre (resistant starch and non-starch polysaccharides) may reduce protein digestibility (Bach Knudsen & Hansen, 1991; Hansen et al., 2006) but this did not appear to be the case for the root-based diets. Protein CTTAD was high for the boiled-roots (0.86-0.92) but reduced on milled cassava-roots (0.78-0.85) where DM intake was also much lower (1,652-1769 g/d). Different ingredient blends, amounts and processing modify the digestibility of nutrients (Noblet & van Milgen 2004) so it is also possible that there was some anti-nutritive factor or the physical form of the dry milled cassava roots affected the palatability and digestibility to pigs. The slightly higher Ash, Ca and Total P CTTAD of 33 kg compared to 45 kg pigs was probably more to do with the greater requirements for skeletal development in young pigs at the lower starting BW.

N balance in MG growing pigs

N digestibility (NR-intake) and utilization (NR-digested) for growth in MG pigs fed the three root-based diets were lower than for the wheat-based diet. In fact, the high urine N excretion indicated that the MG pigs had absorbed above their nutrient requirements for protein and amino acids. This was in agreement with other reports on indigenous Mong Cai pigs and their crossbreeds where N utilization was poorer than for commercially bred pigs regardless of their N intake (Hang, 1998; Ly et al., 2003).

In our work, N intake by pigs on the boiled-root diets was higher than milled-roots or wheat-based pellet diet. High DM intake influences ileal digestibility of protein and amino acids but does not affect total tract energy digestibility (Moter & Stein 2004). DE from the root-starch increased nutrient digestion but also demands greater secretion of digestive juices, which would consequently affect the N balance. This was likely the case for milled-cassava roots for which N balance in the pigs was negative in both trials. It was not likely that soluble fibre in the root-based diets affected the digestion and absorption of amino acids (Bach Knudsen & Hansen 1991; Choct et al., 2010). Furthermore, an increased fermentation of soluble fibre might be expected to cause a shift in N from urine to faeces (Tetens et al., 1991) which was not the case in our study.

Apart from the very low N retained in the 46 kg BW MG pigs fed the milled cassava-roots (16.4 g N/d), the MG pigs produced similar results to CG pigs fed the same diets, notably, boiled SP-roots (27.1 g/d) or cassava-roots (29.9 g/d) or milled cassava-roots (24.6 g/d); and wheat-based diet (27.6 g/d) (Dom et al., 2014, 2017). The similar result demonstrates a significant improvement in the nutrition for the MG growing pigs and thereby a measurable improvement in the local farmed genotypes. By comparison, N retained by Mong Cai and Large White pigs fed wheat bran (68% DM) was 14.63 and 14.5 g/d respectively (Ly et al., 2003). Whereas, N retained by the crossbred (Mong Cai × Yorkshire) fed maize-soybean diet with 12% cassava root meal was 14.9 g/d (Giang et al., 2004).

In contrast, Dom & Ayalew (2009a) used CG pigs from the same commercial piggery and found an improvement in N retained from a sole diet of corn-soybean basal (20.3 g N/d) when 50% was replaced by boiled SP roots (28.6 g N/d). At the much lower protein content in boiled SP-root diet, the pig urine N losses were less than 7 g N/d (Dom & Ayalew 2009a). The lower protein diets fed to CG growing pigs had much improved N utilization. It is clear that SP-roots at 57% DM and cassava-roots at 55% DM in the blended diets was not detrimental to N utilization, but protein and amino acids may need to be reduced for the MG pigs.

Nutrient and energy utilization by MG pigs was better on the root-based blended diets than the wheat-based pellet feed, but N utilization was reduced. Determining the partitioning of digestible energy between lean and fat deposits would provide better identification of the nutritional requirements for producing pork meat using MG pigs. Furthermore, it is proposed that reducing the protein content while maintaining a suitable amino acid profile would improve the efficiency of the blended SP and cassava root diets which provide highly digestible starch and dietary fibre to locally bred MG pigs.

CONCLUSIONS

Sweet potato (SP) and cassava roots blended with a complementary protein concentrate was highly digestible in mixed genotype growing pigs. The SP and cassava root diets provided superior energy utilization and equivalent nitrogen retention to the wheat-based standard feed. However, nutrients were in excess of the requirements of these MG pigs, particularly for protein, and this means that further refinement of the nutrition provided by SP and cassava root-based diets is possible.

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