Feeding Value of Sweet Potato and Cassava to Growing Pigs

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BSc (Chemistry)

A Thesis submitted for the fulfilment of the requirements of the Doctor of Philosophy

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Table of Contents

Thesis Summary

Sweet potato (SP) roots and cassava tubers provide an important feed resource for smallholder farming of pigs in many countries where grain-based feeds are less available. Root and tuber provide digestible starch energy and lower protein however dietary fibre may reduce the digestibility of nutrients and N retention in growing pigs when fed together with protein containing ingredients. Inclusion of SP vine and foliage in daily diets fed to pigs provides an additional source of N, amino acids and dietary fibre. Furthermore, where smallholder producers exploit either commercial (CG) or mixed genotype (MG) pigs their specific nutrient requirements should be determined in order to provide cost-efficient feeding strategies. A series of seven metabolic trials and two growth trials tested the nutrient utilization and growth performance of CG (Landrace × Large White × Duroc) and Papua New Guinean MG pigs fed blended SP or cassava diets. Seven metabolic trials were all conducted in 4×4 Latin Square design using SP or cassava prepared as boiled, ensiled or milled feed, blended with complementary protein concentrates (wheat-based) into nine test diets, with each set of three diets compared against a wheat-based standard feed, using four CG or MG growing pigs (25-30 kg BW) fed to satisfaction over four 8-d periods. One station-based growth trial was conducted in a replicated 4×4 Latin Square design using 16 MG entire-male (8) and female (8) growing pigs (25 kg BW) on restricted feeding of one of two blended SP diets or one of two wheat-based pellet diets over four 10-d periods. One farm-based growth trial was conducted in a 2×6×8 Randomized Complete Block design using 96 MG castrate-male (47) and female (49) growing pigs (21 kg BW) on restricted feeding of either a blended SP root diet or wheat-based pellet diet over 90-d's. CG pigs were obtained from a large scale commercial piggery and MG pigs were obtained from a local smallholder piggery in PNG. Nutrient utilization was high but N balance and growth performance of pigs varied when fed the prepared forms of root-based and wheat-based diets; between marginally different body weights, and apparently influenced by dietary exposure and genotype. Fibre digestibility in

MG pigs was improved compared to CG pigs, N retained from different diets was influenced by the root sources and prepadiets, and it is likely that the protein and amino acid requirements are substantially lower for MG growing pigs. Evaluation of nutrition for sows, weaners and finishers and study of the effect of fermentable carbohydrates on gut physiology and health in MG pigs were recommended.

Thesis Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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List of Publications

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Dom, M T., Ayalew, W. K., Kohun, P. J., Glatz, P. C., Kirkwood, R. N.& Hughes, P. E. (2017). Nutrient utilization in local mixed genotype growing pigs fed wheat-based protein concentrates blended with sweet potato roots ensiled with or without vines. *Animal* (Submitted)

Dom, M. T., Ayalew, W. K., Kohun, P. J., Glatz, P. C., Kirkwood, R. N.& Hughes, P. E. (2017). Effect of restricted feeding of blended sweet potato root silage or cereal-based pellet feeds on the growth performance of Papua New Guinean mixed genotype growing pigs. *Tropical Animal Health and Production* (Submitted)

Conference Oral Presentations

Dom, M., Ayalew, W., Glatz, P., Kirkwood, R. &Hughes, P. (2014). Effect on Nutrient Digestibility and Nitrogen Balance in Grower Pigs Fed Three Forms of Blended Cassava Roots. Proceedings of the 16th AAAP Animal Science Congress, 10-14 November 2014, Gadjah Mada University, Yogyakarta, Indonesia,Vol. II pp. 676-679.

Dom, M., Pandi, J., Ramita, I., Besari, F., Sine, M., Dowa, E., Ayalew, W., Kohun, P. &Glatz, P. (2014). Farming Poultry, Pigs and Fish Using Local Feeds is Technically, Practically and Economically Achievable. 6th Research, Science & Technology Conference, 17th - 21st November 2014, University of Papua New Guinea, Waigani Campus.

Dom, M., Kohun, P., Ayalew, A. & Glatz, P. (2014). Responding to farmer's needs: efficient conservation of feed and improved production of pigs, Regional Symposium, The Territory of Wallis & Futuna, "Sustainable Agriculture: Serving the community, 24th - 28th November 2014, Mata Utu, Uvea Island.

Chapter 1: Rationale to research - Current and future research to support smallholder pig production in Papua New Guinea

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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

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Current and future research to support smallholder pig production in Papua New Guinea

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Abstract

The village pig in Papua New Guinea (PNG) has been crossbred with commercial breeds resulting in mixed-genotype pigs that are ubiquitous in today’s small-scale production systems. There has not been a thorough assessment of the nutritional requirements of mixed-genotype pigs, although growth has improved, despite wide variation in housing, environment and health. In addition, there has been little focus on integrating nutritionally balanced diets into the pig production system to improve overall productivity for small-scale farmers growing their own feed. Research collabodiet between PNG National Agriculture Research Institute (NARI), the Australian Centre for International Agricultural Research (ACIAR), the South Australian Research and Development Institute (SARDI) and the University of Adelaide is now focused on providing nutritionally balanced diets of sweet potato or cassava blended with a formulated concentrate using local protein ingredients with synthetic amino acids and minerals. The research will assess the effects of different root starch sources and processing methods and compare commercial breeds (e.g. Large White-Landrace × Duroc) with mixed-genotype pigs. This paper provides a summary of the research outputs to date and an outline of the next steps to improve pig productivity and sustainable farming in PNG.

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Introduction

The pig (*Sus scrofa papuensis*) has played an indispensable role in village subsistence living and cultural interaction in Papua New Guinea (PNG) since its arrival 6,000 years ago and subsequent domestication (Hide 2003). Through the years, widespread crossbreeding with introduced genotypes, and transfers from one area to another for trade, has resulted in a mixed-genotype animal which is well suited to low-input farming systems (Hide 2003).

In past decades, pigs provided very little animal protein at the household level. However, this has changed dramatically in recent years, and household pork consumption is 11 kg per person per annum (Gibson and Rozelle 1998). Papua New Guinea is now a net importer of meat (Bourke and Harwood 2009), while pig production in the country has remained stagnant.

There is great potential to boost pig productivity in PNG, and a growing interest by smallholder farmers in commercial pig production. Local production needs to be economically and environmentally sustainable, and locally produced feeds have a major part to play. Sweet potato and cassava are widely produced starch sources, and opportunities exist for sourcing protein from an increasing number of fish-canning factories. These are the major ingredients required for nutritionally balanced animal feed. There is an inherent logic to maximising the use of such local feed resources. Converting food–feed crops and industrial by-products into high-value feeds, recycling waste from piggeries into crop production and using integrated farming systems are all resource efficient and will contribute to local production which is economically and environmentally sustainable. To achieve this will require focused research, and scientific and technological innovations. This paper summarises past research and development (R&D) efforts, discusses the most recent outputs and sets the future agenda to improve the productivity of small-scale pig production.

An overview of pig research in PNG

Government policy and strategic plans (MoAL 2007; NSPTF 2009) recognise the importance of subsistence and smallholder farming in PNG, but agricultural development programs lack consistency and measurable achievements do not accumulate. Productivity of this subsector remains low relative to the yield potential of food crops and production potential of livestock species. There remains much room for improvement in rural farming, particularly with regard to commercialisation.

Indiscriminate and uncontrolled crossbreeding of village pigs has continued for almost two centuries, since the arrival of European settlers and missionaries who brought livestock species with them (Hide 2003). Early government policy supported crossbreeding of native pigs with exotic genotypes with the aim of improving production at the village level (Hide 2003). In the absence of interventions to maintain and promote desirable genotypes of pig, various grades of crossbred pigs are now raised in the villages. It appears that the native genotype is becoming increasingly rare, at least as a domesticated animal. Spencer et al. (2006) found that PNG genotypes were very diverse and Ayalew et al. (2011) noted that village pigs are well adapted to the current village farming practices. These mixed crossbred animals are maintained under variable conditions of housing, feed quality and disease and parasite challenges. Despite this, they appear to perform much better than the parent genotypes. Today, mixed-genotype pigs are the preferred production animals but their nutritional requirements, health status and environmental performances have not been assessed.

Village pigs thrive under low-input subsistence farming. Village pigs kept under grazing systems grew at 190 g/day on a very simple diet of raw sweet potato and earthworms (Rose and White 1983). Rose and White (1980) also reported high digestive capacity of native pigs for raw sweet potato diets. The sweet potato pig feeding system enabled relatively high production, but in the past pig meat provided little nutritional benefit as consumption was confined to festive occasions.

Gibson (2001) reported at the turn of the century that pork meat was the most consumed meat in PNG, at 11 kg per person per annum, a vast increase from the 0.3 to 90 g per person estimated 30 years earlier (Malynicz , 1973). However, Gibson (2001) stated that his analysis was based on outdated and debatable figures from the 1996 Household Food Survey and that this work needs to be repeated.

The source of household pig meat is often difficult to identify, i.e. whether it is produced in the village, bought from rural/urban markets, or from a commercial fresh meat supply. Moreover, the production and marketing chain of pig meat is undefined. Data on imported meats provide only an aggregate value of animal products. In a mini-survey of Mount Hagen and Lae frozen meat outlets, Dom et al. (2010) found imported cheap pork meat cuts competing with higher quality cuts from local commercial producers.

Of the five key factors for managing and improving pig production, i.e. genetics, nutrition, reproduction, health and environment, the research focus to date has been on nutrition and health. Hide (2003) and Quartermain (2004) provided a bibliography of research on aspects of pig farming in PNG over the preceeding 60 years. Surveillance on health status of pig herds is severely lacking, but a technical document by Watt et al. (1977) and bibliographic summary by Hide (2003) provided a comprehensive list of microbial, parasitic and nutrition-related diseases which can be used as a starting point for further survey. The work was recently updated by Brioudes and Gummow (2013) and Brioudes et al (2014). External factors such as climate, temperature and humidity are expected to affect levels of pig production, given the variable conditions and skills with which pigs are managed across lowland and highland areas. Evidence is lacking on the effects of such stressors under PNG farming conditions but it is generally observed that better management at the most basic level of village pig farming allows improvement in sow reproductive performance, piglet survival and growth.

Dom and Ayalew (2009a, b) demonstrated that a diet based on locally ensiled sweet potato starch supplementing 50% DM of maize-soybean diet led to comparable digestibility and growth performance as sole maize-soybean diet fed to commercial pigs as well as local mixed-genotype pigs. Additionally, Dom and Ayalew (2010) and Dom et al. (2010) observed pigs of two separate mixed-genotype breeding stocks and found adequate growth rates under improved feeding with commercial pellets when housing and health were well managed at either warm and wet lowland (average daily gain 720 g/day) or cool highland (average daily gain 592 g/day) locations. The same authors also used copra meal and fishmeal with mixed results, where the diets appeared to be lacking in some nutrients. The sweet potato ensiling technology marks another major advance in pig feeding systems following the introduction of the crop 400 years ago, and the modified Lehman feeding system of protein concentrate supplement with *ad libitum* staple feed 40 years ago. Feeding fresh or dried forage and silage of crops such as sweet potato, cassava and taro roots, and foliage such as kangkong (*Ipomoea aquatica*) and legume plants (e.g. leucaena and mulberry) is supported by a great deal of evidence in the literature and their use has also been trialled in PNG (Quartermain 2004).

While growth performance on pig feeding trials may be improved, and anecdotally successful in a number of small-scale ventures, this result has not progressed to overall improvements in productivity or profitability. Nutritional imbalance of livestock diets, poor availability of raw feed materials, and high cost of essential ingredients remain major challenges to farm-level productivity for all monogastric animals. Bourke and Harwood (2009) estimated that PNG imports 63,000 tonnes of grain-based feed per annum, while up to 91,000 tonnes of by-product concentrates was produced annually. Despite this apparent abundance of feed resources, unmanageable feed costs continue to limit the development of local pig, poultry and inland fish production.

Through collaborative research projects between the PNG National Agriculture Research Institute (NARI), the National Fisheries Authority (NFA) and ACIAR aimed at introducing feed mills at community level, pig feed production is now linked with poultry and aquaculture feed production to capitalise on the combined demand from all three non-ruminant animals. It is anticipated that the increase in marine fish canneries in Lae and Madang will lead to greater availability, and hopefully reduced costs, of fishmeal protein. But this is also dependent on sufficiently high and consistent local demand, allowing prices to be more reasonable. The same may be said for local supply of wheat millruns, rice bran, copra meal and palm kernel meal.

Additionally, it is argued that sweet potato and cassava root crops provide the most readily available local feed resources for small-scale producers, and efforts to improve their nutritional value are the current best option. Improved production performance of pigs, poultry and fish on test diets at NARI Livestock Research Station indicate that the use of root starch from sweet potato and cassava combined with animal proteins, grains, minerals and synthetic feed micro-ingredients may provide economically attractive options for commercial monogastric animal production in PNG.

Current research projects

There are currently two ACIAR-funded collaborative livestock projects in PNG: one to improve surveillance of animal diseases (AH/2006/157) and another to develop feeding systems to support pig, poultry and fish enterprises (ASEM/2010/53). The first project is led by the PNG National Agriculture Quarantine Inspection Agency (NAQIA) and James Cook University. The second is a collaborative project between NARI, NFA, local NGOs (Christian Leaders Training College, Lutheran Development Services, Ok Tedi Mining Limited), SARDI and ACIAR. It includes postgraduate research through the School of Animal Veterinary Science of the University of Adelaide.

The animal health surveillance project (AH/2006/157) facilitated the collection and reporting of signs of disease in the country's livestock by introducing simple checklists and providing training to livestock owners and animal health auxiliary staff in provincial departments, commercial livestock companies and NGOs. This will expand the reach of government animal health staff, assist with documentation and assessment of PNG's animal health status for endemic animal diseases, and facilitate more rapid reporting of exotic diseases and outbreaks of newly emerging diseases (which may be zoonoses, affecting both animals and humans). Improved information on disease distribution, prevalence and incidence will also greatly assist in disease control programs.

The feeding system project (ASEM/2010/53) is identifying local resources that could be utilised more effectively for feeding fish, pigs and poultry. The aim is to encourage the establishment of small-scale feed mills and develop cheap, balanced diets based mainly on local feed resources rather than imported ingredients. In particular, the project extends the feeding value of sweet potato and cassava in blended concentrates for poultry, pigs and inland fish production. For improving pig feeding systems, current research is looking into providing nutritionally balanced diets of sweet potato or cassava blended with a formulated concentrate using local protein ingredients with synthetic amino acids and minerals. The research assessed the effect of different root starch sources and processing methods and compared the performance of commercial breeds (e.g. Large White-Landrace x Duroc) with mixed-genotype pigs. Similar research has been completed for broiler feeding systems and is being advanced for layer birds (J. Pandi, unpublished data); and similar work is also planned for fish feeding systems, particularly for tilapia (*Oreochromis niloticus*).

Pig productivity and on-farm profitability using various available feed resources (e.g. sweet potato, cassava, banana, copra meal and by-products) will be evaluated. Diets based on least-cost feed formulation will be tested at institutions and on-farm to identify those which result in the most profitable pig production.

Trends in pig production and consumption in PNG

FAOSTAT (2013) data indicate that, after a rise in 2005–06, meat production in PNG has remained stable over the last five years (Table 1). Demand for poultry is obvious from increased importation when trade tariffs ended. Similarly, increasing demand is predicted for pig meat, although there was a decline in 2009 (data not shown). Game meat, from fishing and hunting, is a major source of protein for rural households, particularly in remote areas and where fishing is convenient; but this may change with rural development.

There has not been an official livestock census in PNG since the early 1970s. According to the PNG census in 2000 (NSO 2002), of the 600,000 livestock farmers 60% are engaged in pig production. Table 2 provides a break-down of the different types of pig production, including figures from Bourke and Harwood (2009) who updated the estimates based on number of sows. The smallholder sector has two broad categories: 360,000 traditional farmers (i.e. individual herd owners) engaged in non-commercial farming, and another 2,000 household farms providing irregular supply to local markets, in addition to 100 commercial farms.

Table 1. Meat production in PNG from 2005 to 2011 (tonnes).

Year	**Game meat**	**Pig meat**	**Cattle meat**	**Sheep meat**	**Goat meat**	**Chicken meat**	**Duck meat**	**Cow milk, whole, fresh**
2011	355,000	76,000	3,210	27	11.4	5,760	14	180
2010	355,000	74,000	3,210	27	11.4	5,850	14	180
2009	380,000	72,000	3,210	27	12.0	5,940	14	185
2008	375,000	70,000	3,210	27	11.25	5,940	13	180
2007	365,000	70,000	3,210	27	11.25	5,850	13	175
2006	355,000	68,000	3,165	27	11.25	5,850	13	170
2005	330,000	68,000	3,135	30	11.25	5,670	13	165

Source: Available at http://faostat3.fao.org/browse/area/168/E

Table 2. PNG pig industry structure and characteristics.

Holding type	Herd size	No. of herds	No. of pigs	Trends	Breeds
Smallholder, traditional	1–20	360,000	1,800,000	Static. May be increasing with human population	Native
Smallholder, penned, household	1–3	1,000 (2,000*)	2,000 (4,000*)	Growing slowly	Native, crossbred**
Smallholder commercial	10–100	50 (100*) (including prisons and high schools)	2,000 (6,000*)	Growing slowly	Modern commercial
Medium-scale commercial	100–500	4 (3 institutional)	1,500 (2,000*)	Static	Modern commercial
Large-scale commercial	>500	7	20,000 (2,500 sows*)	Static	Modern commercial

Source: Quartermain and Kohun (2002).
* Updated figures from Bourke and Harwood (2009).

** Authors' observations.

Value chain assessment of pig production is recommended based on the classification provided by Quartermain and Kohun (2002) (T. Simos, pers. comm. 2012), and an example value chain map is presented in Figure 1. While conducting value chain assessment requires extensive surveys and market research, there are some available data from which estimates can be made.

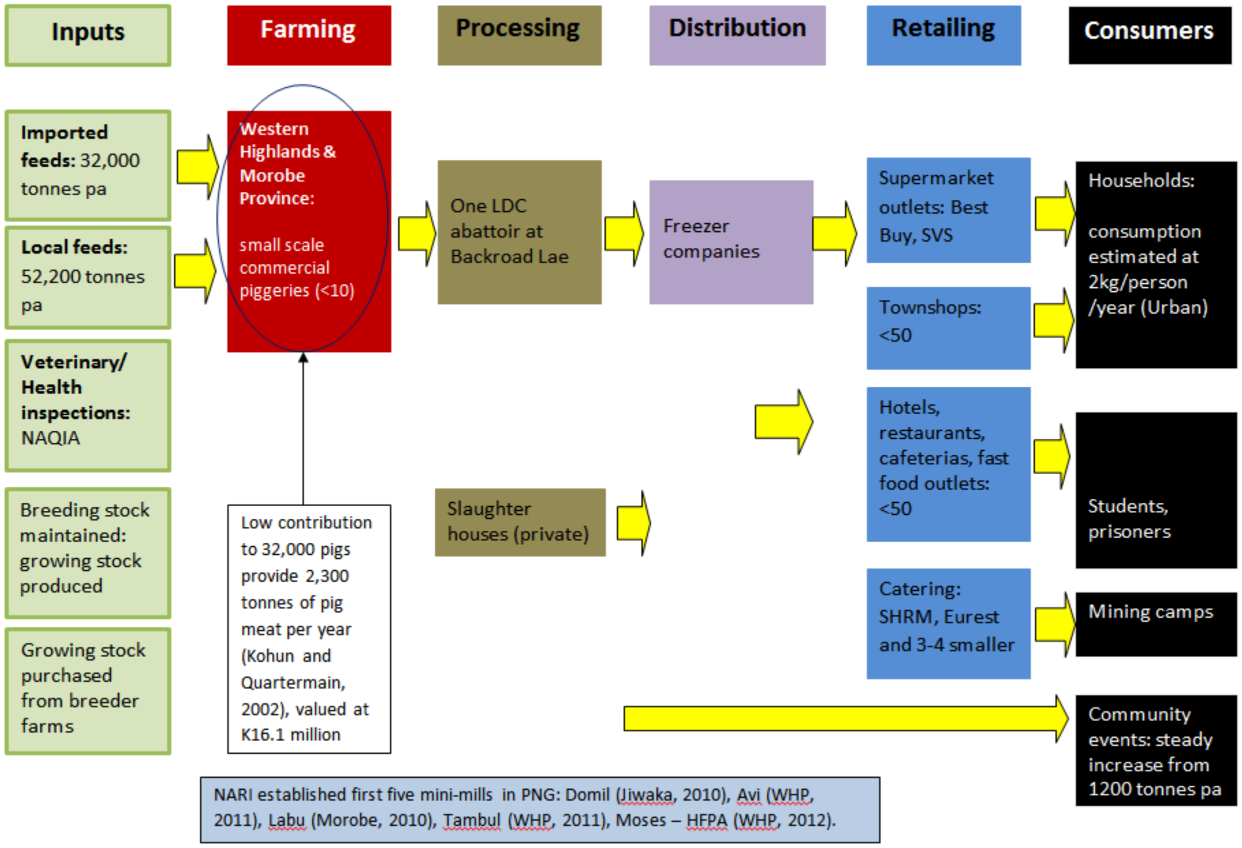

Figure 1. An example of a value chain map for small-scale pig production in Lae (Morobe) and Mount Hagen (Western Highlands). Source: Michael Dom and Theo Simos, for ACIAR project ASEM/2010/053.

Tables 3 and 4 give selected data on meat production and consumption from the 1996 National Household Survey. Total (commercial) meat production in 2005 was estimated to be 58,000 tonnes with an additional 30,000 tonnes in imports, giving total meat consumption of 88,000 tonnes (Bourke and Harwood 2009). On that basis, Bourke and Harwood (2009) calculated average meat consumption of about 15 kg per person per year. But Gibson (2001) used the PNG Household Survey data to show that 60,000 tonnes of pork were produced and valued at 243 million kina (Table 3). Originally, Gibson and Rozelle (1998) had estimated the value of meat produced by households at 263 million kina or A$122 million. FAOSTAT 2013 figures extrapolated pork meat production to 68,000 tonnes per annum (Table 1), but given the recent population census figures and an average pig meat consumption of 11 kg per person per annum (Gibson 2001), the total supply falls short by 10,000 tonnes. This indicates that an extra 38 million kina (A$18 million) worth of pig meat is required to satisfy the market demand. At an average carcass weight of 50 kg that means an additional 200,000 pigs, which is beyond the capacity of the large-scale commercial piggeries.

Table 3. Selected data for meat production from the 1996 National Household Survey.

Meat	Quantity		Value (million kina ± SE)
	(‘000 tonne)	(kg/person)	
Pork	60 ± 11	12	243 ± 47
Chicken	4 ± 1	1	20 ± 7
Other meat (incl. bush meat)	16 ± 4	3	26 ± 7
Fish (fresh, dried, shellfish)	50 ± 12	10	60 ± 17

Source: Gibson (2001).

Table 4. Selected data for meat consumption from the 1996 National Household Survey.

Meat	Total value (million kina)			Quantity (kg/person/year)		
	PNG	Rural	Urban	PNG	Rural	Urban
Lamb and mutton	59	36	24	5	4	10
Pork	162	158	5	11	13	2
Chicken	113	72	42	6	5	13
Bush meat and other unspecified meat	33	27	6	5	5	3
Fish (fresh, frozen, dried, incl. shellfish)	60	34	26	10	8	21

Source: Gibson (2001).

Table 5 shows available feed for livestock, although the list is not exhaustive, for example rice bran and spent brewer’s grain are not included. Imports of wheat, soybean meal and sorghum for feed are significant, and more data need to be gathered from PNG and Australian customs, local companies importing feed/food ingredients and local food/feed factories. Estimated volume and retail value of imported and locally manufactured livestock feeds are shown in Table 6. Pigs, poultry and inland fish are the main livestock groups given milled feed. Using the average retail value of pig and poultry feed, Bourke and Harwood (2009) calculated that pigs consume only 20% of stock feeds while the bulk may be assumed to go to feeding poultry. Feed demand for inland fish farms is not yet determined.

Table 5. Available feeds for domestic pigs, poultry and fish.

Feed	Protein content (%)	Volume (tonnes)
PNG millrun	12	33,000
PNG copra meal	21	21,000
PNG oil palm kernel meal	18	31,000
PNG fishmeal	58	6,000
Imported sorghum	Unknown	26,000
Rumion maize	11	5,800
Total available feed material	-	122,800

Source: Bourke and Harwood (2009).

Table 6. Feed supplied in PNG and estimated retail value using Lae and Mount Hagen pricing.

Source	Volume (tonnes)	Retail value in Mount Hagen (000's kina)	Retail value in Lae (000's kina)
Three Lae feed mills local*	52,200	128,542	116,177
Rumion maize local**	5,800	4,060	4,060
Complete feed imported*	37,000	91,112	82,348
Feed supplied	95,000	223,715	202,585
Feed used in pig production (20%)	19,000	44,743	40,517

Source: Bourke and Harwood (2009).
Note: Estimates of retail values are based on average cost of feeds at *2.46 kina and **0.70 kina per kg.
Feed supplied is not the actual total available feed in the country, but the off-take that mills in PNG take from the available and imported feed resources.

The estimate by Bourke and Harwood (2009) that only 20% of stock feed in the country is used for pig production is very low considering the number of herds. Papua New Guinea produces 91,000 tonnes of by-product (protein) concentrate feed (Table 5), 52,200 tonnes of stock feed from local mills and imports 37,000 tonnes of feed (Table 6). Improved feeding practices in the dominant smallholder livestock sector will demand more use of local feed resources and this may be achieved at commercially competitive rates or may require policy intervention to favour local feed manufacturing. Quartermain and Kohun (2002) emphasised that feed is 80% of the cost of raising livestock and is the number one priority for livestock research. Given that a growing proportion of agro-industrial by-products with good feeding values (copra meal, millrun) are being exported, an analysis of the market value of exported feed resources would be a valuable contribution to better understanding the macroeconomic impact of importing feeds.

At the smallholder level, farmers are able to source the bulk of energy feed from their own crops or from local markets. The two main energy feed crops are sweet potato and cassava. Annual production of sweet potato is estimated at 2.8 million tonnes (Bourke and Vlassak 2004), and 30–70% of the roots may be fed to pigs (Hide 2003; Bourke and Vlassak 2004), mainly in traditional unimproved diets on village and small-scale farms. Cassava production is much lower at 271,895 tonnes per annum (Bourke and Vlassak 2004) and is grown mostly in dry areas of the lowlands where it is a valuable drought food and feed crop.

There is good opportunity to make more efficient use of excess and waste/spoiling sweet potato and cassava tubers and foliage for on-farm feed production or for marketing to smallholder piggeries, if simple processing equipment and storage techniques are accessible at smallholder level. Root and foliage ensiling or drying technology may enhance the feed value of these perishable crops. Hansen et al. (2001) suggested that as much as 1.5 million tonnes of sweet potato is used as pig feed annually, a volume which does not include the feed that may be obtained from crop losses to disease damage, unmarketable tubers, damaged tubers and market wastage, and also not including vine yields. By our calculation, converting Bourke and Vlassak's (2004) fresh tuber yield to dry matter feed suggests that as much as 225–630 million kg of sweet potato is available for pig production annually. At the high level offer of 4 kg dry matter diet component for say 200 days, which is enough starch feed for 315,000–735,000 pigs of 60–70 kg finished weight.

Local sweet potato cultivars, including 10 promoted by NARI, are capable of producing 13–15 tonnes of roots per year (Bourke and Vlassak 2004), although yields may be below this due to high pathogen levels in the plant. Cleaning of planting material by tissue culture techniques has been shown to overcome this problem (NARI Aiyura 2011; unpublished data). It is notable that leaf and vine from these cultivars may be almost twice the fresh weight yield of tubers (Dom and Ayalew 2009b).

A number of pig feeding trials by the NARI livestock research program have demonstrated the ability of local mixed-genotype pigs to perform well on mixed diets of sweet potato, giant taro, rice bran, copra meal, wheat millrun and fishmeal. Growth rates improve but vary considerably with nutrient content of the diet. In addition, productivity is markedly improved when better housing is provided and better health status is achieved. Genotype, nutrition and environment are the focus of present research interest, particularly for the local growing pigs produced by commercially oriented smallholder farmers in the highlands and lowlands of PNG.

Pork meat markets

The pig meat market has not been thoroughly assessed in the same way as the red meat industry, for instance (Vincent and Low 2000). This would be a major activity under the suggested value chain assessment and a key step for setting strategic targets for smallholder pig producers. As an example of a domestic market, data from the mini-survey of Mount Hagen town by Dom et al (2010) are given in Table 7. The data include source, cuts of meat found in freezer sections and unit prices, but do not include the volume of meat at each outlet. It is quite feasible to carry out similar surveys in other urban centres nationwide.

The main consumer demand is for pork from 60–70 kg finished pigs, i.e. relatively small pigs.

Whereas the growing-finisher period is recognized as the most costly in terms of feed requirements the lower finishing weight mean shorter feeding periods of up to six months. Hence, improving the feed efficiency using cheaper local ingredients partly supplied on-farm may favour small-scale pig farming. If we extend our earlier calculations the estimated range of potential pork meat production using local feed resources, at an average of 75% carcass yield, is 236,250 to 551,250 kg.If earlier calculations on sweet potato fresh root total production are extended, the estimated range of potential pork meat production using local feed resources, at an average of 75% carcass yield, is 236,250–551,250 kg.

Table 7. Wholesale and retail prices of pork at selected outlets in Mount Hagen town, Western Highlands Province in September 2009.

Supplier	Pork cut	Price (kina)	Quantity	Source
Best Buy	Hock	9.45	Per kg	Imported
	Leg	18.50	Per kg	Lae
	Loin	17.50	Per kg	Lae
	Belly	18.50	Per kg	Lae
	Fillets	26.90	Per kg	Lae
	Tail	10.95	Per kg	Imported
	Jowl	9.75	Per kg	Imported
	Leg ham	31.70	Per kg	Pelgens*
Kera Freezers	Jowl	12.00	Per kg	Imported
Renbo Store	Jowl	9.45	Per kg	Imported
	Tail	9.45	Per kg	Imported
Bintangor	Loin	15.50	Per kg	Imported
	Jowl	11.00	Per kg	Imported
	Head	39.80	Per kg	Imported
	Belly	15.50	Per kg	Imported
Kange Freezers	Jowl	10.00	Per kg	Imported
Main Market Freezers	Jowl	12.00	Per kg	Imported
Plaza Freezers	Jowl	9.80	Per kg	Imported
	Meat cuts	193.00	22.7 kg ctn	Imported
	Jowls (bulk)	115.00	13 kg ctn	Imported

*Pelgens German Smallgoods is the local specialist for bacon and ham products from their own piggery.

Source: Dom et al. (2010).

Smallholder farmers earn income from live pig sales, usually of large (>100 kg) fattened pigs. There is a need for economic assessment of informal live pig sales which contribute the bulk of smallholder business. This market tends to be irregular, to be prone to higher pricing which may not be based on costs of production, less likely to ensure quality product, and to be inconvenient for consumers. Experienced farmers reflect that the much higher average unit prices offered to live sales of fattened pigs is discouraging engagement of smallholder piggeries in the formal pork market, since carcass prices are lower. As a result smallholder farmers are reluctant to produce larger pig herds in continuous cycles. This is compounded by a lack of proper slaughter and freezer facilities available to smallholders. These are business and management aspects that could be addressed by collabodiet of research and extension agents.

Future R&D agenda

The following areas are suggested for further R&D in pig production in PNG. These represent the impression of the authors on the best way forward for improving local pig production.

Genetics

Despite the economic, cultural and historical significance of pigs in PNG, knowledge about genetic attributes, differentiation and production capacity of indigenous pigs is very limited (Ayalew et al. 2011). Recent molecular genetic studies (Nidup 2011) reveal that PNG indigenous pigs retain a reasonably high level of genetic structure and diversity. This is similar to that of feral pigs (Spencer et al. 2006) to the extent that indigenous and feral pigs are considered as a single genetic pool. Decades of well-intended, but poorly designed, government-sponsored programs to promote crossbreeding of indigenous pigs with selected exotic breeds have resulted in a broad admixture of various grades of crossbred pigs in traditional smallholder farms. The rather small average sizes of smallholder pig flocks restricts genetic selection of replacement breeding stock. Regardless of this, the larger body size and faster growth performance of these crosses have attracted strong interest from the rapidly increasing number of smallholder commercial pig growers.

There is a lack of suppliers of breeding stock as well as growing pigs to meet current and immediate future demand. The few major commercial piggeries are opportunistic suppliers of a limited number of breeding boars and gilts at relatively high prices. The establishment of a viable commercial pig breeding enterprise is essential to counteract the continued haphazard spread of exotic and crossbred pig genotypes, not only in market corridors but also in unaffected PNG indigenous pig populations. About 19% of local pigs, even in remote villages, are known through pedigree checks to have an admixture of genotypes with some distant exotic parentage (Ayalew et al. 2011). Long-term indigenous pig genetic evaluation and improvement activities are essential to prevent further genetic erosion of PNG indigenous pigs. This will not only preserve the genetic resource base but also provide parental lines for sustainable crossbreeding programs. Targeted crossing of adapted local genotypes with improved exotic ones is a proven breeding strategy to meet the needs of a rapidly expanding pork markets where commercial piggeries cannot satisfy the demand, as is the case in PNG.

Genetically improved animals need effective nutrition, basic health care and hygiene, and safe housing in order to perform to their full genetic potential. Objectives for improved production performance include improved reproduction, satisfactory growth rate, increased feed efficiency, acceptable back fat depth and greater carcass yield, all of which are influenced by the interplay of genotype and environment.

Nutrition

Local feed resources are available in PNG that could be utilised more effectively for feeding pigs, and include root crops, fruit, forages, bush plants and vines. Farmers could also introduce new crops and use pasture species with higher nutritional value for pigs, for example sorghum, mungbean, pigeonpea, sunflower and amaranth (Cargill 2008; Glatz 2007). Effective diets for village pigs can be devised based on the availability of feeds, and farmers can be educated on feeding management. Three pig feeding strategies could be adopted by smallholders: (1) complete diet formulation using local feed ingredients; (2) development of a concentrated diet that can be blended with local feed ingredients; and (3) dilution of a commercial diet with locally available food products.

In PNG, sweet potato is the main feed source for pigs. The existing sweet potato pig feeding systems exhibit several problems, notably low fertility rates and slow animal growth rates. This may be caused by unbalanced and erratic feeding regimes and health problems. Basic diets containing ensiled sweet potato vines and tubers can be supplemented with a range of locally grown crops and herbage to increase the protein content of the base diet.

Taro (*Colocasia*) foliage is a protein forage option, while giant taro (*Xanthosoma*) is fed in high-rainfall areas where it grows abundantly. Work by ACIAR in West Papua is investigating local resources for pig diets, for example pasture grasses Sundaleka (*Puerasia cephaloides*), Wurikaka (*Centrosema* sp.) and Jirikpuruk (*Calopogonium* sp.) and fodder trees Dadap (*Erythrina variegata*) and Gamal (*Gliricidia sepium*), plus vegetables in season and chopped banana trunks, and is relevant for PNG. Other ingredients, such as kangkong (*Ipmoea aquatic*), mulberry (*Morus* sp.) and kikuyu grass (*Pennisetum clandestinum*) are used by some farmers and are worth investigating.

Health

There is a paucity of updated animal health and disease surveillance reports and research on modern animal diseases which may impact on livestock and zoonosis with implications for human health in PNG. Hide (2003) provides a comprehensive summary of veterinary work in PNG from 1938 to 2002. Brioudes and Gummow (2013) provided a bibliography of domestic animal disease research conducted in Pacific island countries. Brioudes et al. (2014) conducted a detailed assessment of animal disease risk in the Pacific. A number of technical studies found that confinement tends to exacerbate disease at village and smallholder levels. The effect of health status on productivity of smallholder commercial piggeries has not been assessed, but anecdotal accounts indicate it may be significant. While animal health surveillance will identify disease prevalence, individual smallholder farmers are still unable to afford the cost of most common veterinary drugs, even when they are available from local suppliers. For example, Ivermectin® is sold at up to 452.60 kina (A$216.46) for 200 ml. Also, oral Ivermectin®, which may be more effective, is not available. Some innovative means of supplying veterinary drugs needs to be implemented. In addition, the lack of veterinary staff nationwide and the high cost of veterinary services mean that most farmers are not well assisted to administer drugs or manage stock in more effective ways to prevent disease.

Bacterial pneumonia is common and aggravated by poor nutrition and high parasite burdens. Other diseases, such as anthrax, brucellosis, salmonellosis, *Streptococcus suis*, enteric bacterial infections, swine pox and rotavirus, reportedly occur in isolated cases, linked to poorly managed intensive units. There is notable zoonotic threat from Indonesia’s Papuan border for diseases such as rabies and rotavirus. Internal and external parasites are prevalent, and Watt et al. (1977) identified large round worm, kidney worm, stomach worm, nodule worm, lung worm, sarcoptic mange and lice. Infestation by screwworm flies and porcine *Coccidia* are common, whereas *Trypanosoma evansi* is considered to be absent. Watt et al. (1977) also recognised nutrition-related diseases, particularly affecting young piglets, namely deficiencies in calcium, phosphorous, iodine, iron and vitamin A. Brioudes et al. (2014) reached some of the same conclusions in their updated literature review.

Environment

Environmental factors that influence pig performance, including temperature, aediet and space, may be controlled by appropriate housing design. Outputs of gaseous, liquid and solid effluents affect the piggery and surrounding environment, and are an important management considediet when planning to increase the number of stock under commercial production. Integrated farming systems that recycle the nutrients in piggery effluents are potentially very beneficial in small-scale systems and worth investigation. The traditional sweet potato–pig system has done this for centuries. Intensified farming requires research to better understand the environmental impacts for crop nutrition as well as animal and human health within integrated systems.

Housing material and design are important for managing disease in local pigs because disease vectors become more concentrated within intensive units. Early work by Malynicz and Nad (1973) on different aspects of housing native and crossbred pigs should be revised to improve management standards for the current mixed-genotype pigs. Simple recommendations may be made from the exisiting literature and would be valuable for extension training. In particular, the housing and nutrition needs of sows vary according to their reproductive cycle. Sows and gilts are the basic production units, and it is fundamentally important to evaluate their health status, which indicates that of the piglets and thereby the entire herd (ignoring external disease vectors). Mating boars may be shared or feral pigs, and unless appropriate health standards are set, may introduce other diseases to the domestic herd.

Reproduction

Reproductive performance appears to be neglected at the research level, although skilled local farmers are well aware of the need to provide special care and attention to pregnant and lactating sows. According to reports summarised by Hide (2003), gilts are usually about a year old before their first breeding, gestation is up to 120 days and birth is mostly unassisted. The average litter size is three to six piglets for village pigs, whereas on commercial farms litter sizes can be 10 piglets or more. Field observations show that survival after weaning tends to be lower for smallholders. Weaning age is variable, from four weeks to three or even six months, depending on management. Litter intervals and pregnancy ratios are also variable, where traditional husbandry practices also restrict breeding. Assessment of pig reproductive performance in PNG is a potential research area.

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References

Ayalew W., Danbaro G., Dom M., Amben S., Besari F., Moran C. and Nidup K. 2011. Genetic and cultural significance of indigenous pigs in Papua New Guinea and their phenotypic characteristics. Animal Genetic Resources 48, 36–37.

Bourke R.M. and Vlassak V. 2004. Estimates of food crop production in Papua New Guinea. Land Management Group, Australian National University: Canberra.

Bourke R.M. and Harwood T. (eds) 2009. Food and agriculture in Papua New Guinea. ANU E Press, Australian National University: Canberra.

Brioudes A. and Gummow B. 2013. Domestic animal diseases within the Pacific Islands region – bibliography. Secretariat of the Pacific Community: Suva.

Brioudes A., Warner J., Hedlefs R., Gummow B. 2014. A review of domestic animal diseases within the Pacific Islands region. Acta Tropica 132, 23–38.

Cargill C. 2008. Improvement and sustainability of sweet potato-pig production systems to support livelihoods in highland Papua and West Papua, Indonesia. A report on the ACIAR project AH/2007/106. Australian Centre for International Agricultural Research: Canberra.

Dom M. and Ayalew W. 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. Journal of the Institute of Chemists of PNG 2, 77–88.

Dom M. and Ayalew W. 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. Papua New Guinea Journal of Research, Science and Technology 1, 86–96.

Dom M. and Ayalew W. 2010. Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. Journal of South Pacific Agriculture 14, 78–86.

Dom M., Ayalew W. and Amben S. 2010. Development of improved pig feeding systems using ensiled material: on-farm testing of feeding sweet potato silage to growing pigs at Tambul in Western Highlands Province. Science in New Guinea Journal 30, 94–104.

Dom M., Ayalew W. and Tarabu J. 2011. Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG). Journal of South Pacific Agriculture 15, 62–70.

FAOSTAT. 2013. Country data. FAO Statistics Division. Available at http://faostat3.fao.org/browse/Q/*/E

Gibson J. 2001. The economic and nutritional importance of household food production in Papua New Guinea. Department of Economics, University of Waikato: New Zealand.

Gibson J. and Rozelle S. 1998. Results of the household survey component of the 1996 poverty assessment for Papua New Guinea. Population and Human Resources Division, World Bank: Washington, DC.

Glatz P.C. 2007. Poultry feeding systems in PNG. A report on the ACIAR project LPS/2001/077. Australian Centre for International Agricultural Research: Canberra.

Hanson L.W., Allen B.J., Bourke R.M. and McCarthy T.J. 2001. Papua New Guinea rural development handbook. Australian National University/Brown Prior Anderson: Melbourne.

Hide R. 2003. Pig husbandry in New Guinea: a literature review and bibliography. ACIAR Monograph No. 108. Australian Centre for International Agricultural Research: Canberra.

Malynicz G.L. 1973. The productivity of exotic and indigenous pigs under village conditions––Part 1. Papua New Guinea Agricultural Journal 24(1), 16–19.

Malynicz G. and Nad H. 1973. The effect of level of feeding and supplementation with sweet potato foliage on the growth performance of pigs. Papua New Guinea Agricultural Journal. 24, 139–144.

MoAL 2007. National agriculture development plan 2007–2016; implementation plan volume 2. Ministry of Agriculture and Livestock, Government of Papua New Guinea: PNG.

Nidup K. 2011. Genetic structure and biodiversity of pigs (*Sus scrofa*) in South Asia and Papua New Guinea. PhD Thesis. University of Sydney: Sydney.

NSO (National Statistics Office) 2002. PNG Population Census 2000. National Statistics Office of Papua New Guinea: Waigani National Capital District, PNG.

NSPTF 2009. Papua New Guinea vision 2050. National Strategic Plan Taskforce of the Government of Papua New Guinea: Port Moresby.

Peters J. 2001. Local human–sweet potato–pig systems characterization and research in Irian Jaya, Indonesia with limited reference to Papua New Guinea: a secondary literature review – poverty alleviation and food security through improving the sweet potato–pig systems in Indonesia and Vietnam. International Potato Center (CIP). At<www.papuaweb.org/dlib/tema/ubi/peters-2001-sweet potato-pig-ng.pdf>, accessed 6 April 2010.

Quatermain A.R. (ed.) 2004. Pig nutrition research in Papua New Guinea in the 1970’s and early 1980’s. NARI Technical Bulletin No. 10, 1–6. National Agriculture Research Institute: Lae.

Quartermain A.R. and Kohun P.J. 2002. Pig production in Papua New Guinea. Pp. 40–47 in ‘Priorities for Pig Research in Southeast Asia and the Pacific to 2010’, ed. by R. Jones. ACIAR Working Paper No. 53. Australian Centre for International Agricultural Research: Canberra.

Rose C.J. and White G.A. 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. Papua New Guinea Agricultural Journal 31(1–4), 69–72.

Rose C.J. and White G.A. 1983. Ingestion of earthworms, *Pontoscolex corethrurus*, by village pigs, *Sus scrofa papuensis*, in the highlands of Papua New Guinea. Applied Animal Ethology 11, 131–139.

Spencer, P.B.S., Hampton J., Lapidge S.J., Mitchell J., Lee J. and Pluske J.R. 2006. An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea. Journal of Genetics 85(1), 63–66.

Vincent D. and Low S. 2000. A review of Papua New Guinea's red meat industry. ACIAR Monograph No. 66. Australian Centre for International Agricultural Research: Canberra.

Watt I.R., McKillop R.F., Penson P.J. and Robinson N.A. 1977. Pigs, rural development handbook no. 5. Department of Primary Industries Rural Development Series: Port Moresby.

Chapter 2: Literature review - Feeding value of sweet potato and cassava for growing pigs

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Contribution to the Paper	Investigation of the literature, conception of the theme for assessment and development and drafting of the literature review document.		
Overall percentage (%)	80%		
Certification:	This literature review was conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	01/02/2017

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Feeding value of sweet potato and cassava for growing pigs

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Abstract

Sweet potato (SP) and cassava are increasing in importance for livestock production. Feeding high levels of SP and cassava roots and forage to non-ruminant pigs produces variable animal performance mainly because of increased dietary fibre as resistant starch, non-starch polysaccharides and lignin. In addition, other anti-nutrients and their inherent physicochemical variability and interactions with other nutrients, particularly amino acids, in the digestive system impact on pig performance. The impact of dietary fibre on energy digestibility and nutrient utilisation in pigs is an active field of investigation. Growing pigs require a high level of digestible energy which can be supplied by SP and cassava roots, while complementary protein sources can supply the required amino acids. The interaction between dietary fibre and proteins and the different modes of digestion, fermentation and absorption of starch and NSP’s will determine their contribution to growing pig energy and nutrient utilisation. Processing may reduce anti-nutritional factors, and ensiling to store fermented feed may also provide benefits to gut health. Diverse crossbreeds and tropical environments are a challenge to pig production, however, determining the nutrient requirements of local mixed genotype pigs to reduce costs of feed can improve the productivity and profitability of smallholder pig farming in Papua New Guinea (PNG) and other Pacific Island countries and territories (PICT). This review examines the factors influencing nutrient utilisation in the pig digestive system to develop an understanding of the feeding value of SP and cassava in mixed genotype growing pigs under smallholder production in PNG and other PICT.

Keywords: Cassava, digestion, fibre, growing pigs, starch, sweet potato

Introduction

Agricultural production in many tropical countries is characterized by mixed crop-livestock systems where the staple root crops, including sweet potato (*Ipomoea batatas* L. (Lam)) and cassava (*Manihot esculenta* Crantz) are essential food-feed resources for humans and for pigs (Scott et al. 2000a, b). Smallholder farming of local pigs makes a significant contribution to household livelihoods and local economies. In the face of rising costs of grain in pig feed it is vital that the use of local animal feed resources is exploited for maximum economic gain. This is even more critical in the Pacific Island Countries and Territories (PICT) which are heavily reliant on imported goods, including grains which are used in livestock feeds. Common root and tuber crops and tropical forage feeds have a lower nutritional value on a dry matter basis, are higher in dietary fibre (DF) and also contain anti-nutritional components, particularly trypsin inhibitors in sweet potato (SP) and cyanogenic glucosides in cassava. In contrast, the agro-by-products copra meal, palm kernel meal and fish meal are less utilized locally due to their greater income earning as export products. Nevertheless, these food resources may be used cost effectively for local pig production and pigs have thrived on these feeds. A unique opportunity to improve pig production is afforded by the ubiquitous mixed genotype pigs kept by farmers in countries such as Papua New Guinea (PNG), where indigenous pigs have been crossed with introduced breeds for at least 40 years with likely adaptations to the prevailing management and feeding systems. The indigenous and mixed genotype pigs are noted for their resistance to prevalent disease pathogens and parasites (Hide 2001; Ayalew et al. 2011). Acclimatization to cooler locations and adaptation to heat stress in tropical climates contributes to pig performance in feed efficiency for protein and lipid accretion (Renaudeau et al. 2006, 2012). Moreover, DF also influences physiological and morphological adaptations in pigs. Guixin et al (1995) predicted that differences in digestive capacity of genotypes are likely, given the differences in the genetics and environmental conditions where the pigs are farmed. They further emphasized that the interaction between animal genotypes and diet characteristics in the utilisation of feed nutrients is of great importance for effectively using feed resources and accurately formulating diets. Kyriazakis (2011), Noblet et al. (2013) and Lindberg (2014) suggested that growing pigs could be bred for improved digestibility of high fibre diets. Mixed genotype pigs farmed in PNG and other PICT may have enhanced digestive capacity for utilisation of fibre in root and forage crops such as SP and cassava. Additionally, it is imperative to determine the amino acid requirements of mixed genotype pigs compared to commercial breeds, as influenced by the digestion of starch and fibre, because protein feeds are the most costly ingredients and usually sourced off-farm. However, even when provided the best nutrient balance in a diet it is recognized that genotype, environment, management and health factors will determine how effectively dietary nutrients are used for maintenance and production. The components of the pig digestive system, the site of digestion and absorption, their size, the enzymes present, the rate of passage of digesta through the tract, and presence and composition of microflora all have varying effects on the outcome of digestion and hence nutrient utilisation. This review examines the factors influencing nutrient utilisation in the pig digestive system in order to develop an understanding of the feeding value of SP and cassava in mixed genotype growing pigs farmed under smallholder production.

Digestion in growing pigs

Digestive capacity

Digestive capacity is controlled by genotype (viz. fat or lean types), age, weight, sex and exposure to diets. Differing capacities in foregut and hindgut digestion between dissimilar breeds or classes of pigs will influence the digestibility of different types of diets (Freire et al. 1998, 2003; Ngoc et al. 2013). Figure1 illustrates the effect of different DFs (non-starch polysaccharides [NSPs] and lignin) in the stomach and small and large intestines. While there is ample evidence of similar physiology and nutritional needs of pigs across genotypes there is also evidence that diet influences endogenous secretions (Zebrowska et al. 1983; Freire et al. 1998; Low 1989), modifies the physiology and morphology of digestive organs (Jin et al. 1994; Barea et al. 2011; Ngoc et al. 2013) and diversity of microbial populations (Freire et al. 2003; Piva et al. 2006; Metzler et al. 2009). In addition, distinct genotypes may respond differently to dietary manipulation (Fabian et al. 2003). The interactions of the various carbohydrates with digestive sites, enzymes and amino acids and influences on the performance and gut health of growing animals is illustrated in Figure 2.

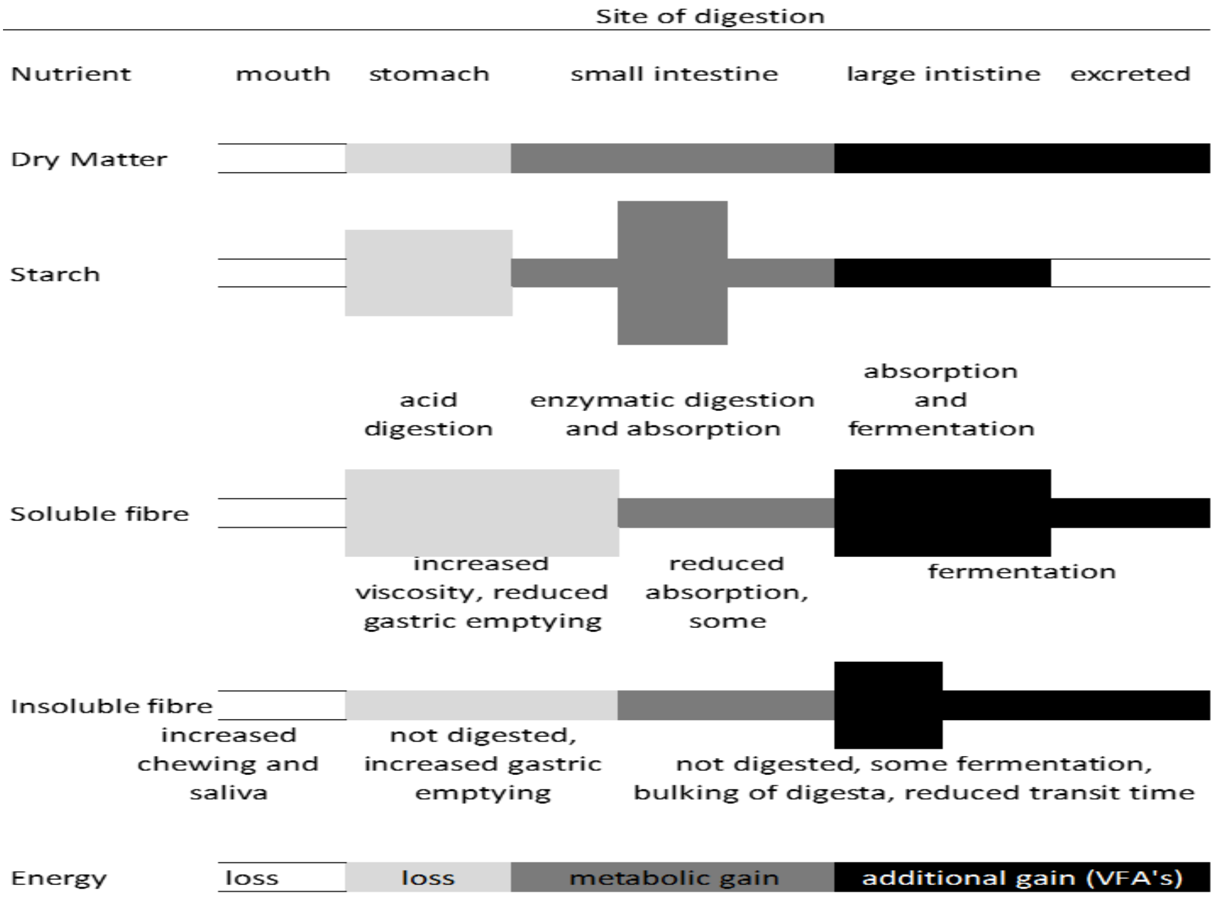


Fig. 1 Effect of sweet potato starch and dietary fibre on nutrient utilisation in the grower pig gut (the thickness of the columns indicates where substrates are retained longer during digestion.)

Improvement in the digestive efficiency of pigs via microbial hindgut digestion may be an advantage on small-holder farms where indigenous breeds and crossbred genotypes pigs are fed diets high in starch and fibre and are generally inbred in small herd sizes (Ayalew et al. 2011). Using high levels (above 50% DM) of SP and cassava roots and forage in pig diets is expected to produce variable animal performance because of the higher starch and dietary fibre (as resistant starch, NSPs and lignin), and their inherent physicochemical variability (Tables 1-3). Therefore, it may be possible to improve pig and herd performance in growth and reproduction by selecting the best performing growing animals for improved energy digestibility using local feed resources, which are also more economical.

Digestion in the stomach

Intensive work by Zebrowska et al. (1983) and Low (1989) established that feeds high in DF will increase secretions from the salivary glands, stomach, liver, exocrine pancreas and the intestinal wall. In general, the rate of digestion and emptying of the stomach contents influences digestive process in the small intestines. Gastric emptying rate into the duodenum was influenced by the presence of soluble fibre (e.g. β-glucans), which may slow gastric emptying of digesta in the liquid phase, but starch digestion was not affected (Johansen et al. 1996). Soluble DF does not affect retention time in the stomach or the small intestine but insoluble fibre (e.g. cellulose and lignin) decreases mean retention time in the ileum (Wilfart et al. 2007a; Ngoc et al. 2013). Then again, increased bulk density and water-holding capacity of high fibre diets leads to early and prolonged satiety (Wenk 2001; Bindelle et al. 2008). The extent of starch digestion and fermentation in the pig stomach may vary depending on the source and type of carbohydrates (Choct 2001; Wilfart et al. 2007b; Metzler et al. 2009). Longer retention time of digesta in the stomach enhances the likelihood of favourable microbial fermentation, which also depends on the source of carbohydrate, how the starch is processed and the species of bacteria present (e.g. at low pH lactobacillus are active) (Ratcliffe 1991; Metzler et al. 2009). Zijlstra et al (2012) concluded that the variable physicochemical composition of DF and starch increases the complexity of their functional and nutritional role in pigs as digestible and fermentable sources of energy. Excess lipids may also slow gastric emptying (Zebrowska et al. 1983), but lipids are readily absorbed in the small intestines. Under smallholder farming, pigs managed in semi-permanent enclosures may obtain considerable amounts of lipids, for example by foraging on earthworms (*Pontoscolexchorethrurus*) (Rose and Williams 1983) and snails (*Achatina* spp.), when offered feeds like avocados (*Persea Americana*) or coconut (*Cocos nucifera*) meat, or from added ingredients such as cooking fats and oils (Freire et al. 1998).

Feeding pigs to satisfaction on SP and cassava with additional forage material provides a diet high in starch and fibre. With additional protein ingredients this will lead to increased digestive fluids, viscosity and digesta retention in the stomach, consequently affecting the digestibility and the rate of nutrient absorption at the small intestine. Provided that the pH in the pig stomach is low an increased gastric retention may provide a suitable environment for beneficial microflora and slower release of digestible nutrients.

Digestion and absorption in the small intestine

Choct et al. (2010) determined that digestion and absorption of nutrients, particularly of amino acids, is affected by viscosity of soluble fibre or non-starch polysaccharides (NSP’s) but the effects were not as obvious in growing pigs as they were in weaned piglets. Energy and nutrient digestibility are lowered when DF level is increased. However, the type of starch (van der Meulen et al. 1997a, b; Li et al. 2008) and presence of soluble or insoluble DF are modifying factors (Schulze et al. 1994, 1995; Rideout et al. 2008). The solubility of starch and DF is dependent upon several physicochemical parameters, only a few of which are shown in Table 1. Two key properties for solubility of the starches are the presence of amylose chains and grain size, which are more advantageous in SP root starch. Dhingra et al. (2012) and Moongnagarm (2013) provide reviews of starch and resistant starch (RS), and DF, respectively. SP roots contains more DF as resistant starch than cassava roots (Table 2). The source of starch, RS and NSPs affects the absorption of amino acids and glucose at the portal vein (van der Meulen et al. 1997a, b). DF (NDF) reduces ileal digestibility of amino acidsbut not the portal flux of digested amino acids, also NDF energy presumably improves utilisation of ileal digested amino acids but absorption is not affected (Lenis et al. 1997). Starch digestion is mostly completed in the small intestine, up to 99% according to Johansen et al (1996). However, Wiseman (2006) noted variations in small versus large intestinal digestibility of starch in pigs. RS and undigested fibre pass into the large intestine where it becomes a substrate for microbial fermentation (Varel et al. 1982; Rideout et al. 2008).

Physicochemical properties of starch and interactions with other nutrients are complex (Tables 1-3 and Fig. 2) but generally, amylose starch molecules are more resistant to enzymatic digestion whereas amylopectin starch is more readily digestible (Keys and DeBarthe 1974; Tian et al. 1991). Furthermore, bacterial populations and their diversity are susceptible to changes in the carbohydrate composition of diets, specifically DF (Varel et al. 1982; Metzler et al. 2009). DF directly interacts with the peristalsis motion and mixing of digesta in the small intestine. Considerable evidence suggests that the transit of digesta in the hindgut is accelerated by DF (Wenk 2001; Wilfart et al. 2007b). DF is also known to cause physiological changes in the organs of the digestive tract of pigs for which adaptations have been identified (Freire et al. 1998; Barea et al. 2011; Ngoc et al. 2013) and likely may be found in PNG’s indigenous crossbred pigs (Rose and White, 1980). The addition of soluble fibre to pig diets increases pepsin, pancreatic trypsin, amylase activity and other digestive juices while insoluble fibre affects gastrointestinal morphology, size and weight (Zebrowska et al. 1983; Low 1989; Rijnen et al. 2001). Effective functioning of the pancreas is particularly vital for protein digestion and regulation of competitive microbial growth on undigested protein (Rerat et al. 1996; Pierzynowski et al. 2006). High starch content in feeds such as SP and cassava will provide DE for improved digestion, however, the presence of different types and levels of NSP’s and RS (Tables 2 and 3) may also affect absorption of nutrients and fermentation in the lower gut (Fig.1 and 2).

Table 1 Some physicochemical properties of sweet potato (SP) and cassava starch

Food source	Protein (%)	Fats (%)	Ash (%)	P (%)	Amylose (%)	Grain Size (µm)	Grain shape	Pasting Temp. (°C)	Peak viscosity (RVU)
SP starch[a]	0.14	0.14	0.21	0.014	22.6	13.9	polygonal	72.4	281
Cassava starch[a]	0.20	0.15	0.21	0.0007	19.8	15.8	round	67.4	263
SP roots (3 cv's)[b]	-	-	-	-	19.8	14.8	-	79.03	141
Cassava roots (4 cv's)[b]	-	-	-	-	26.5	12.7	-	68.05	177
Yam roots (3 cv's)[b]	-	-	-	-	23.1	25.9	-	75.13	372

Sources: Peroni et al. (2006)[a]; Wickramasinghe et al. (2009)[b]

Table 2 Different starch compositions in various foods (g/100g)

Food source	Resistant Starch	Non-Resistant Starch	Total Starch	Amylose
Waxy rice	2.7	72.0	74.8	2.1
Corn (sweet)	1.2	35.1	36.2	19.5
Sweet potato	3.2	49.4	52.5	28.1
Cassava	9.7	56.0	65.7	23.8
White yam	4.3	53.7	58.0	17.3
Lesser yam	23.3	19.5	54.7	26.2
Taro	4.1	59.6	63.7	16.8

Source: Moongnagarm (2013)

Table 3 Dietary fibre of various food sources (g/100g)

Food source	Total	Insoluble	Soluble
Barley (dry)*	36.7	28.7	8.0
Barley	17.3	-	-
Corn	13.4	-	-
Oats	10.3	6.5	3.8
Rice (dry)	1.3	1.0	0.3
Rice (cooked)	0.7	0.7	0.0
Wheat (whole grain)	12.6	10.2	2.3
Soybeans	15.0	-	-
Potato (peeled)	1.3	1.0	0.3
Sweet potato*	9.0	5.7	3.3
Cassava*	1.8	1.1	0.7
Coconuts (raw)	9.0	9.5	0.5

Source: Dhingra et al. (2012); *https://www.prebiotin.com/resources/fiber-content-of-foods/

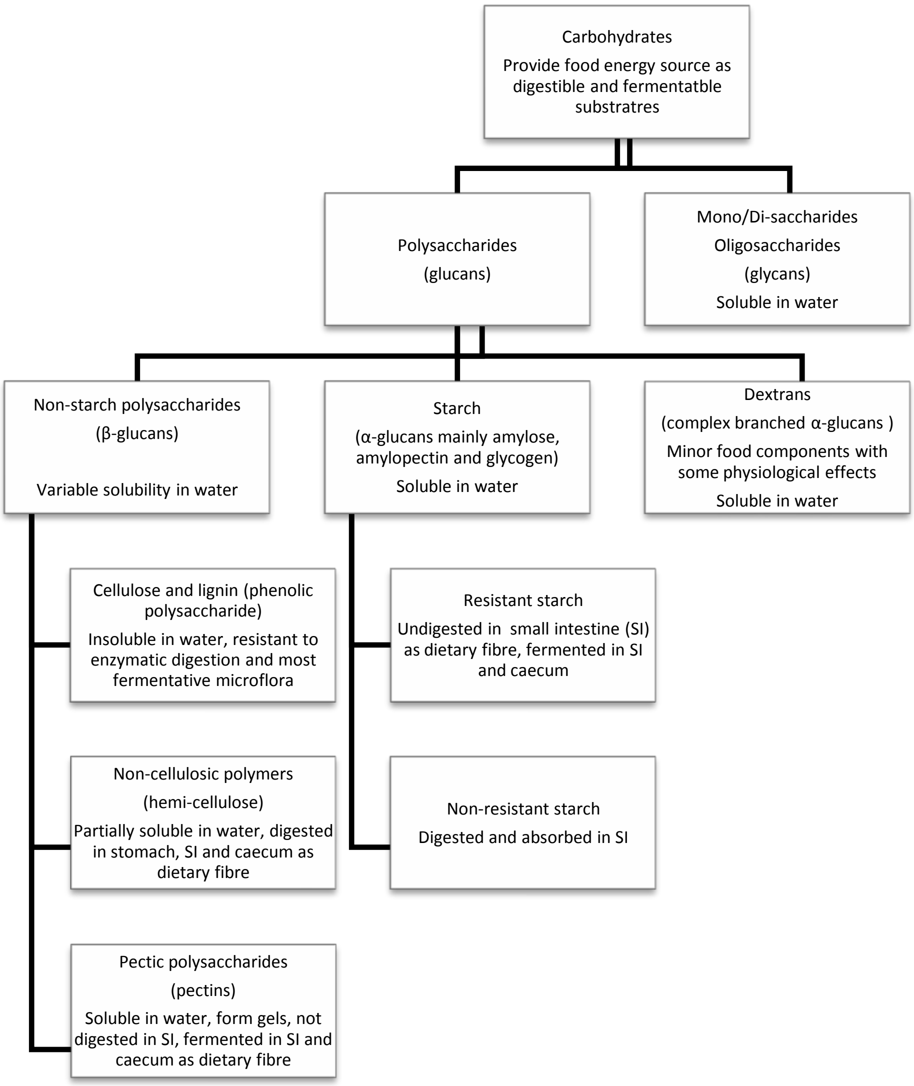


Fig. 2 Classification of carbohydrate feed energy sources as starch and dietary fibre, depending on solubility, absorbed at different sites in the digestive tract

Fluid absorption and fermentation in the small intestine

Knudsen and Hansen (1991) and Johansen et al. (1996) demonstrated that the water holding capacity of soluble fibre increases the viscosity of digesta and the retention time affects improved microbial fermentation in the small and large intestine. Increased soluble fibre in the diet reduces absorption of trace minerals but also provides substrates in which the microbiota may grow (Varel et al. 1982; Wenk 2001). Jin et al (1994) concluded that high DF (insoluble) alters the rate of intestinal cell turnover and morphology. Specifically, the number of enterocytes and the width and depth of the villi increase with high fibre inclusion although most DF is fermented in the caecum (Dierick et al. 1989). Sources of lipids and their level in diets also affect intestinal morphology by increasing villus height (Li et al. 1990). Although lipids are also important stimulants for the exocrine pancreas (Pierzynowski et al. 2006), lipid metabolism in the small intestine is reduced by microflora activities (Ratcliffe 1991). There is evidence of interactions between dietary lipids and fibre levels, but energy digestibility is more closely related to fibre level (Wilfart et al. 2007a; Degen et al. 2009).

The inclusion of high starch and DF provided by SP and cassava roots and forage will modify digesta retention, secretion of digestive juices, nutrient absorption and microbial fermentation throughout the gastrointestinal tract. There is evidence that modern genotypes of growing pigs do not benefit as much from high DF as do indigenous pig breeds. However, a larger body weight, increased age and longer exposure to fibrous diets also improve adaptability to fibre feeds. An appropriate balance may be found between the dietary and animal factors, where improved local genotype pigs have been bred on SP and cassava roots and tropical forages.

Fermentation and absorption in the large intestine

Fermentation of organic matter provides additional metabolic energy through production and subsequent absorption of short chain fatty acids in the large intestine. Short chain or volatile fatty acids (VFAs) are the major product of carbohydrate fermentation, apart from some methane (Bergman 1990; Yen et al. 1991). Volatile fatty acids are absorbed in the portal vein adding to dietary energy supply (Yen et al. 1991; Yen 1997). Mainly acetic, propionic, butyric and lactic acids, are readily absorbed across the luminal mucosa of the gut and may contribute as much as 10% to 24% of dietary energy for maintenance in pigs (Knudsen and Hansen 1991; Yen et al. 1991). Much higher metabolisable energy for maintenance (33% to 44%) was gained from ungelatinised potato starch, which in raw form is less digestible than SP or cassava starch (Mason 1980). VFAs from hindgut microbial fermentation contributes up to 15% net energy in practical situations despite the reduction in ileal DE and mineral absorption (Dierick et al. 1989). The anti-nutritive effect of DF may be balanced by its contribution through fermentation to DE and potential health benefits (Dierke et al. 1989; Choct 2001; Lindberg 2014). Different fermentable fibres may influence bacterial nitrogen uptake depending on the rate of fermentation (Bindelle et al. 2007). DF in SP and cassava roots will provide more fermentable material to the microbial population in the hindgut. However, gut morphology, physiology and specific bacterial populations in pigs farmed in PNG and the PICT are yet to be identified and could be a potentially fertile field of research for animal health and production.

Factors influencing the growing pig nutrient requirements

Genotype

Distinct differences in the partitioning of energy and protein exist between genotypes and their digestive capacity for high fibre feeds (e.g. Chimonyo et al. 2001; Barea et al. 2011; Ngoc et al. 2013). Growth, protein and lipid deposition, digestibility, organ weights and small intestinal structure of Iberian and modern pigs have been investigated (Nieto et al. 2002; Barea et al. 2011). The recent focus has been on indigenous pigs and their crossbreeds. For example, the Vietnamese Mong Cai pig has been well studied in relation to use of tropical forages including SP and cassava roots and foliage (Hang 1998; Ly et al. 2010; An et al. 2004; Giang et al. 2004a). The Zimbabwean Mukota pig performed better on high fibre diets than did Large White pigs (Chimonyo et al. 2001; Ndindana et al. 2002), with similar growth performances reported in PNG village pigs (Rose and White 1980) or their mixed genotype progeny (Dom et al. 2009a, b, 2010). There is particular interest in improving the prediction of nutrient requirements for protein and lipid deposition rates in indigenous breeds fed on high forage feeds (Ngoc et al. 2013; Noblet et al. 2013; Regnier et al. 2013). Recent genetic surveys attested that changes were more than likely to have occurred in the mixed genotype pigs found in PNG (Spencer et al. 2006; Ayalew et al. 2011). Hence, the real benefit of genetic improvements for smallholder production is not measureable. The breeding of local pigs in PNG provides an area of untapped research potential for characterization and preservation of genetic resource with future applications. These local crossbred pigs of mixed genotype kept by the commercially oriented smallholder farmers tend to be leaner but their nutritional requirements have not been thoroughly assessed. It was found that lean and obese type pigs (Duroc×Yorkshire) possessed different gut microbial populations and differed in their response to high DF (Varel et al. 1982; Freire et al. 2003). Soluble fibre (sugar beet pulp) was used as effectively in modern as in older European genotype pigs (von Heimendahl et al. 2010) whereas use of protein and energy differed between European indigenous and exotic breeds when fed high fibre diets (Barea et al. 2011). Traditionally grazing Aletejano genotypes had improved digestive capacity for high fibre feeds compared to Large White (Freire et al. 1998) or Duroc×Landrace crossbreeds (Freire et al. 2003). Previous reports on indigenous pigs in PNG, the so called *Sus scrofa papuensis* (Hide 2001), demonstrated a high digestibility for fibre at over 72% ADF from raw SP diets (Rose and White 1980). This suggested an increased solubility of starch and NSPs and additional fermentation in the digestive tract. Anecdotally and from survey observations (Ayalew et al. 2011; Amben et al. 2013), PNG native pigs thrive on forage feeds such as SP vines, cassava leaves, taro stem and leaves, banana pseudo stems, leguminous forage, grass and creeping vines (e.g. kikukyu grass, mucuna and pueraria), but their digestive capacity for DF is unreported.

The indigenous ancestor of the modern PNG village pigs remains a mystery with no recent observations made of this animal apart from anecdotal reports. However, there is good evidence that local pigs in PNG and possibly other PICT have adapted to higher DF feeds such as SP, cassava, taro roots, tropical legumes and forages. Studying improved fibre digestibility adaptation is more important in areas where long term pig crossbreeding has been in practice and the production system is geared towards commercial sale. A practical first step would be to determine the performance of current crossbred pigs fed nutritionally balanced

SP and cassava diets which are on par to standard commercial feeds fed to commercial breed pigs.

Environment

Thermal regulation is likely to be an important factor in variable climatic conditions under extensive or semi-extensive systems and where management is not standardized and pig housing may be inadequate. The growth of pigs in the warm humid tropics will be constrained by reduced feed intake and although feed intake is reduced pigs may gradually adapt to heat stress (Le Dividich et al. 1985; Rinaldo et al. 2000). Moreover, humidity and ventilation affect feed intake and, depending on ambient temperature, produce marked effects at higher temperatures (Quiniou et al. 2000; Nyachoti et al. 2004). When exposed to cold stress, pigs increase feed intake to provide a higher metabolic rate for producing heat (Verstegen et al. 1982, 1984). Feed intake may decrease but feed efficiency does not decrease at higher temperatures (Lopez et al. 1991).

When pigs have unrestricted access to feed the responses to temperature are more critical for energy efficiency as growth or production, whereas thermal stress could also be a major cause of piglet mortality and lead to mortality or morbidity by other causes such as starvation and diseases (Renaudeau et al. 2012). Quiniou et al. (2000) found that under tropical conditions grower-finisher feeding behaviour was modified at different temperatures and humidity. Feed intake was reduced at temperatures above 27 °C (humidity >80%) and for larger body weights of 45-75kg, but the number of meals per day did not decrease (Quiniou et al. 2000). Quiniou's experiment used Pietrain × Large White barrows fed ad libitum with an all grain diet and resulted in a quadratic relationship between feed intake and temperature; a finding which was in agreement with Nienaber and Hahn (1983) and Le Dividich et al. (1985). They concluded that 24°C was the lowest critical temperature for pigs of 30-90 kg body weight which allowed more efficient use of dietary energy. However, their estimates for energy utilisation were generally lower than National Research Council recommendations which maintained that DE intake was reduced by 1.7% for each 1 °C above the critical temperature experienced by the pig (NRC 1998). Alternatively, reduced feed intake may not be a major concern for growing pigs provided that energy dense diets are fed. Energy dense diets are known to improve the rate of gain when feeding is unrestricted but fibrous diets increase the heat increment from digestion and may be disadvantageous under warm conditions. Environmental temperatures are likely to have an impact on pig performance in the tropics. Recent studies have shown that growth performance of mixed genotype pigs in PNG's warm humid lowlands climate (Dom and Ayalew 2010) and cool wet highlands locations (Dom et al. 2010) differed by as much as 20% while feed efficiency differed by as much as 30% on the same diets. Adjustments to feed energy level would also optimize pig performance under different management conditions of fully enclosed, semi-enclosed or grazing.

Long term and on-going interactions of local pig genotypes with varying tropical environments in PNG will have influenced their health and digestive capacity to some extent by modified physiology and the gut bacterial populations, as well as hardiness to some common diseases from which commercial breeds tend to be protected. There is evidence of improved growth performances of local pigs but the management systems need to be better described or standardised, and feeding based on locally available ingredients. This will also ensure that the nutrition provided to pigs offers a fair assessment of growth performance and profitability of production.

Health

Brioudes et al. (2014) found that apart from endemic leptospirosis and some brucellosis, there were no incidences of major transboundary diseases or economically important diseases such as Foot and Mouth Disease and Classical Swine Fever in the PICT. However, veterinary services, disease surveillance and reporting were limited. They noted that farmers identified endemic diseases caused by endoparasites and ectoparasites as their major concerns for pig production. Earlier PNG government reports noted that bacterial pneumonia was common and was aggravated by poor nutrition and high parasite burdens whereas nutritionally related diseases, particularly affecting young piglets, were caused by deficiency in calcium, phosphorous, iodine, iron and vitamin A (Watt et al. 1977). Quartermain and Kohun (2002) noted that the situation was unchanged at village and semi-commercial levels of production and recommended nutritional intervention. The health of growing pigs is influenced by their nutrition during the early post-weaning stage when rapid changes occur in the digestive system, the type of feed that is offered to piglets and their increased feed intake. In PNG and other PICT, piglets are often naturally weaned (at around 8 weeks) and obtain the full benefit of nutrition, immunity and digestive enzymes as well as microbial population from the sow. Their major nutritional health challenge comes with the changeover from milk to solid food. During this phase piglets are prone to colitis and diarrhoea associated with dietary change and disease vectors (Thomson 2009).

As reviewed by Thomson (2009) feed-associated colitis in growing pigs was due to niacin deficient corn or NSPs from wheat, barley and other cereals. Non-specific colitis occurred during weaning onto pelleted rather than meal feeds, while the effects of high levels of wheat NSPs and resistant starch were countered by the inclusion of enzymes in the feed. Infectious colitis (*Brachyspira pilosicoli*), collibacillosis (*Escherichia coli*), swine dysentery (*B. hyodysenteriae*) and salmonellosis (*S.* Typhimurium) were also reduced by feed processing, enzyme supplementation and the inherent fermentation characteristics in the hind gut of pigs when fed highly digestible diets of different NSP sources and amounts (Pluske et al. 2007; Thomson 2009). The disease stressors may be present at subclinical levels in all modern pig production environments and would certainly be expected at smallholder and village pig production. Under more intensive production systems the feeding of pigs with high levels of fermentable carbohydrates was shown to trigger clinical swine dysentery, and its pathogenesis was also influenced by diverse gut microflora (Pluske et al. 1996; Pluske et al.

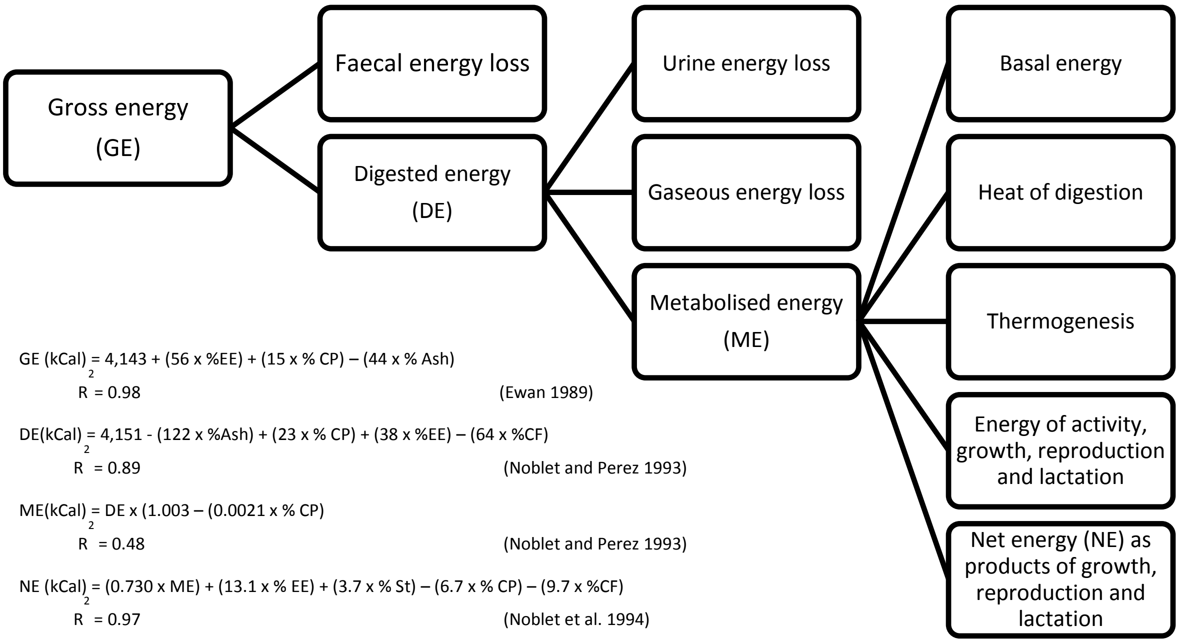
1998). However, modifying the NSP levels or presenting more digestible diets had either a positive effect (Siba et al. 1996) or little clinical effect (Kirkwood et al. 2000) on reducing swine dysentery. It is still uncertain how the diverse gut microflora also interact with different NSP substrates and proteins to inhibit or promote diseases. Recently, there has been revived interest on the use of fermented liquid feeds (FLF) for their prebiotic effect on gut health to all classes of pigs (Lindberg 2014; Missotten et al. 2015). FLF may provide an alternative to antibiotic growth promoters and to probiotic use in animal feeds by increasing acidity in the upper gut in a similar manner to organic acid additives (Piva et al. 2006; Suiryanrayna and Ramana 2015). Missotten et al. (2010, 2015) reviewed the requirements for producing FLF and its advantages and disadvantages in pigs and to production. Reduction of *E. coli* and *Salmonella* spp. and promotion of *Lactobacillus plantarum* was noted at rapid lowering of pH. The presence of yeasts (e.g. *Pichia* spp.) in the fermented feed, the fermentation temperature of liquid feed and the feed:water ratio were also found to modify the feeding value of FLF. A lower pH and higher lactic acid concentdiet in the gut stimulated the production of pancreatic juices, thereby potentially improving digestion. There was evidence that piglets benefited from the microflora of sows fed FLF. Moreover, FLF resulted in improved growth and feed conversion efficiency of weaners and for growers-finishers (Jensen and Mikkelsen 1998). The solubility of carbohydrates and protein in SP and cassava roots and forage may be improved by fermentation during the ensiling process, and when prepared as dried or cooked feeds. The utilisation of these high moisture feeds when blended with other ingredients is an option that needs exploring, particularly for pig production in PNG and the PICT.

Adaptations by pigs to high fibre tropical feeds have occurred naturally in PNG where there is much less feeding of grain feeds and free ranging pigs have had access to wide variety of fibrous feeds. Moreover, most village pig farmers breed pigs with minimal antibiotic inputs, suggesting that the roots and forage feeding systems for local mixed genotype pigs may provide a mode of ‘antibiotic free’ production. The use of fermented feeds may improve nutrition and health in the current pig feeding systems and is an area that should be investigated.

Determining the growing pig nutrient requirements

Voluntary feed intake and energy partitioning

Feed intake increases dramatically during the growing phase and digestion uses a large amount of the dietary energy (Kyriazakis and Whittemore 2006). During the growing phase pigs may be more responsive to variations in their diet, particularly for DE content (NRC 1998). DE influences amino acid digestibility and thereby affects lean muscle development for which the amount and balance of amino acids is critical (De Lange et al. 2012). The grower pig stage is a period defined by rapid lean deposition, bone tissue, and lipid (fat) deposition (MacDonald et al. 2011). The grower-finisher range of 60-110 kg is commercially important in PNG and other PICT, where maintaining larger animals may not be cost effective. Nutrition based on local feeds must be aimed at achieving these finish weights economically.



$$\text{GE (kCal)} = 4{,}143 + (56 \times \%\text{EE}) + (15 \times \%\ \text{CP}) - (44 \times \%\ \text{Ash})$$

$R^2 = 0.98$ (Ewan 1989)

$$\text{DE(kCal)} = 4{,}151 - (122 \times \%\text{Ash}) + (23 \times \%\ \text{CP}) + (38 \times \%\text{EE}) - (64 \times \%\text{CF})$$

$R^2 = 0.89$ (Noblet and Perez 1993)

$$\text{ME(kCal)} = \text{DE} \times (1.003 - (0.0021 \times \%\ \text{CP})$$

$R^2 = 0.48$ (Noblet and Perez 1993)

$$\text{NE (kCal)} = (0.730 \times \text{ME}) + (13.1 \times \%\ \text{EE}) + (3.7 \times \%\ \text{St}) - (6.7 \times \%\ \text{CP}) - (9.7 \times \%\text{CF})$$

$R^2 = 0.97$ (Noblet et al. 1994)

Fig. 3 Energy partitioning diagram adapted from Kyriazakis and Whittemore (2006) and respective formulae for calculating food energy from chemical analysis of nutrient groups

Protein and amino acid requirements of growing pigs

Partitioning of energy and lean (protein) or fat (lipid) deposition after ingestion is the key to understanding nutrient absorption and utilisation (Noblet and van Milgen 2004; Sandberg et al. 2005). Energy, protein and feed intake may be estimated by using partitioning models such as those in Fig. 3, but empirical data is required to make accurate predictions in cost effective feed formulation under different operating environments (Whittemore et al. 2001). The energy value of feed for growing pigs is influenced by source of fibre, body weight and the climate (Noblet and Le Goff 2001). The level of DE intake influences the absorption of lysine for protein deposition over lipid deposition in growing pigs (van Milgen and Noblet 1999). However, the rate of protein retention is influenced by body weight, reflecting the higher maintenance needs of adult versus young pigs. However, protein retention is not influenced by energy intake, genotype or when lysine is limiting (Susenbeth et al. 1999). Metabolic utilisation of starch and lipid is more efficient than protein utilisation for lean deposition in growing pigs where lysine is in limiting supply (van Milgen et al. 2001). Lysine is a limiting amino acid in most feed resources available to livestock farmers in the tropics, including SP and cassava roots, and supplementary amino acids must be supplied by other ingredients in order to balance the shortfall and to maximize growth potential. Since protein accretion is dependent on the amount of DE in a feed it is more instructive to consider the DE to protein (or lysine) ratio of diets (MacDonald et al. 2011). Balancing pig diets to specific protein and energy requirements can help reduce the costs of farming pigs (Adesehinwa 2008). Further nutrition research should determine the lysine:DE requirements for commercial breeds as well as for mixed genotype pigs farmed under local conditions.

Nitrogen (N) balance is a practical method which estimates apparent protein digestibility and retained nitrogen as the difference from metabolic loses in faeces and urine (MacDonald et al. 2011). This is useful for comparing the effects of starch and DF on digestion and fermentation in the gastrointestinal tract where microbial proteins also contribute to faecal N. A positive N balance may indicate an excess of protein or an imbalance of amino acids in the diet, particularly when urinary N excretion is elevated (also an indication of poor health).

NRC (1998) recommended 18% crude protein (CP) and 14.2 MJ DE/kg DM in diets for growing pigs (20-50 kg BW) of commercial genotype with a 17.5 g lysine/day (total basis) requirement, determined by feeding corn-soybean meal diets (90% DM) under temperate climates. In a review of 27 feeding trials which included exotic purebred, indigenous non-descript, indigenous purebred or crossbred pigs fed under tropical conditions Paul et al. (2007) determined a requirement of 17.9% to 15.5% CP with 10.6 to 14.8 g lysine/day and 17.9 to 23.3 MJ DE/day for 20-35 and 35-60 kg BW pigs respectively. But they had identified crossbred pigs with low growth rates of 331 to 337 g/day (Paul et al. 2007). In PNG a commercially available wheat-based feed (88% DM) containing 16% CP, 14 MJ DE/kg DM and a lysine level of 8.6 g/kg DM produced growth rates of 586 to 743 g/day and FCR 2.25 to 2.51 in PNG mixed genotype pigs (14-20 kg BW) bred in a cool highlands (10-20°C) or a warm coastal (~32 °C) climate respectively (Dom et al. 2010, 2011). However, in warm tropical environments providing higher than 16% CP in a corn-soybean meal diet may not result in improved growth performance (Sugahara et al. 1970; cited by Perez 1997). Lower than 14.5% CP in diets without the addition of lysine reduced pig growth rates (Taylor et al. 1979; cited by Perez 1997).

The protein and amino acids requirements for pigs in tropical climates is not well established, particularly for the combination of various root and forage species with grain based protein concentrates, and the farming of local mixed genotype pigs. Pig nutritional models such as the NRC (1998, 2012) need empirical data to provide accurate recommendations for pig diets using local feed resources and maintained under the current production systems in tropical countries. Metabolic studies on growing pigs are needed to evaluate the effect of sweet potato and cassava starch and DF on energy, protein and amino acid utilisation, and provide effective pig nutrition with potential cost savings.

Table 4 Nutrients and anti-nutrients composition of different sweet potato and cassava varieties in fresh form and as dry flour with maize and wheat grain

Nutrient (%)	Bitter Cassava[a] (chips)	SweetCassava[a] (chips)	Sweet Potato[b] roots	Maize (white)[b]	Maize (yellow)[b]	PICT Sweet potato[c]	PICT Cassava[c] roots	Sweet potato[d] meal	Cassava[d] meal	Wheat grain[d]
Moist.	0.14	0.82	62.50	10.20	20.04	71.1	62.8	-	-	-
Ash	1.85	2.71	4.60	1.24	1.76	0.74	0.84	-	-	-
CF	4.61	4.40	1.02	1.54	1.82	1.64	1.48	2.9	3.1	2.4
N	-	-	0.73	1.30	1.41	-	-	-	-	-
CP	3.37	2.69	4.57	6.49	8.79	1.43	0.53	4.4	3.6	14.6
EE	3.82	3.92	1.20	8.34	9.42	0.17	0.17	0.6	0.4	1.8
Starch	-	-	-	-	-	20.1	31.0	73.1	80.5	67.4
Sugars	-	-	-	-	-	2.38	0.83	7.3	4.9	3.1
NFE	86.2	85.5	26.1	70.8	57.5	-	-	88.9	90.3	79.5
OM	-	-	-	-	-	-	-	96.9	97.4	98.2
NDF	-	-	-	-	-	-	-	6.9	6.9	11.1
ADF	-	-	-	-	-	-	-	4.2	4.2	3.4
ADL	-	-	-	-	-	-	-	0.7	0.8	1.1
WICW	-	-	-	-	-	-	-	6.6	6.7	11.0
Energy (kJ/100g)	-	-	-	381	350	438	580	17.1/14.6*	17.2/16.6*	18.5/16.2*
Minerals (mg/100g)										
Ca	33	30	-	-	-	29	20	-	-	-
P	52	80	-	-	-	51	46	-	-	-
Mg	-	-	-	-	-	26	30	-	-	-
Na	-	-	32	28	22	52	7.2	-	-	-
K	-	-	201	174	264	260	302	-	-	-
S	-	-	-	-	-	13	6.4	-	-	-
Fe	30	18	-	-	-	0.49	0.23	-	-	-
Cu	-	-	0.0	0.37	0.38	0.17	0.14	-	-	-
Zn	-	-	0.21	0.35	0.45	0.59	0.48	-	-	-
Pb	-	-	0.0	0.0	0.0	-	-	-	-	-
Mn	-	-	0.0	0.0	0.16	0.11	0.06	-	-	-
Al	-	-	-	-	-	0.82	1.83	-	-	-
B	-	-	-	-	-	0.10	0.07	-	-	-
Vitamins (mg/100g)										
A	-	-	0.0	0.127	0.151	0.011	-	-	-	-
B_1	-	-	0.09	0.32	0.32	0.086	-	-	-	-
B_2	-	-	0.05	0.1	0.12	0.031	-	-	-	-
B_3	-	-	-	-	-	0.60	-	-	-	-
C	-	-	2.2	0.034	0.056	24	14.9	-	-	-
D	-	-	-	-	-	0.0	-	-	-	-
E	-	-	0.82	0.52	0.72	-	-	-	-	-
Anti-nutrients (mg/100g)										
Oxalate	44	22	1.07	2.5	2.48	89	39	-	-	-
Phytate	304	216	0.03	2.6	2.5	-	-	-	-	-
Tannins	0.6	0.4	6.22	1.5	1.8	-	-	-	-	-
HCN	0.65	0.46	-	-	-	-	3.10	-	-	-
TIU	4.0	1.0	-	-	-	13.4	<0.1	-	-	-

Sources: Sarkiyayi and Agar (2010)[a]; Sarkiyayi and Hamman (2015)[b]; Bradbury and Holloway (1988)[c]; Noblet et al. (1993)[d].*Gross energy/Digestible energy in MJ/kg DM.Moisture (Moist.), crude fibre (CF), nitrogen (N), crude protein (CP), ether extracts (EE), carbohydrates calculated as nitrogen-free extracts (NFE), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), water insoluble cell wall.

Meeting the nutrient requirements of the growing pig

Roots and foliage as carbohydrate sources

The nutrients, anti-nutrients and amino acid contents of SP and cassava roots and forage are shown in Tables 4, 5 and 6, respectively. A survey by Hoover (2001) documented that root and tuber crops contain 70 to 80% water, 16 to 24% starch and trace quantities (<5%) of proteins and lipids. SP and cassava roots contain less DM nutrients compared with equivalent amounts of dry grain feed such as corn or wheat at around 80% DM, but the latter also contains more DF (Table 4). SP contains less starch than cassava but more monosaccharide sugars. On a fresh weight basis SP contains less starch but higher amylose content and higher DF than cassava roots (Tables 1 and 2). Amylose starch is less susceptible than amylopectin to enzymatic digestion by α-amylase and glucoamylase (Tian et al. 1991). This may suggest that SP root-starch would contribute more to fermentation of DF and undigested (resistant) starch in the pig gut. A high value of 38% amylose in SP was reported by Tian et al. (1991) but 12.9% to 29.7% were found in 44 SP varieties grown in the Philippines (Collado et al. 1999). In Sri Lankan and Thailand varieties, cassava starch contained more resistant starch and amylose than SP starch (Wickramasinghe et al. 2009; Moongngarm 2013). By comparison, starch contents of 30 to 58 g/100 g of solids was reported in 25 SP varieties grown in PNG and Australia, with most varieties low in amylose content (<30%) (Waramboi et al. 2011). SP and cassava roots may provide up to 17 MJ/kg gross energy and 14-16 MJ/kg DE (Table 4). Fermentation of undigested starch reduces the efficiency of starch use (Gerrits et al. 2012). However, the prebiotic effect of both rapidly and slowly fermentable carbohydrates may improve gastrointestinal health (Bauer et al. 2006) and contribute to energy status by absorption of VFAs. Sauer et al. (1991) suggest that VFAs may provide as much as 15% of the energy supply to pigs. Table 5 shows the nutrient composition of SP and cassava foliage prepared in fresh, dried or ensiled form. Whereas the SP vines provide much less energy (Table 5) they also have amino acid profiles comparable with alfalfa, ground nut foliage, and leucaena (Table 6). The effects on energy digestibility and nutrient utilisation of diets based on high proportions of fibrous feeds available in tropical countries, such as SP and cassava roots and foliage, has been and continues to be an active field of investigation.

Roots and foliage as sources of amino acids, vitamins and minerals

SP and cassava roots contain low and variable amounts of crude protein (CP) (Nwokolo 1990). Bradbury et al. (1984, 1985) found 0.5 to 2.0% crude protein in SP roots from cultivars grown in the highlands of PNG and the CP contents of cassava roots were similarly poor. Limiting amino acids in both roots were methionine, cysteine, lysine and leucine (Table 6). Nwokolo (1990) suggested that fish meal, meat meal or synthetic methionine and lysine will need to be included in SP-based diets and the same for cassava-based diets. On the other hand, the foliage of both crops may contain less than 10% DM but the leaves, stems and vine of both crops contain more DF, amino acids and anti-nutritional factors (Table 1 and 2). SP vine alone contains 18% CP and the leaves of both crops contain as much as 24% CP (Dominguez 1992; Nwokolo 1990). An et al. (2005) determined 25-30% CP in SP leaves where lysine was the first limiting amino acid. Similarly, the average protein content in cassava foliage was 20-32% but was deficient in both methionine and lysine (Tables 5 and 6). SP and cassava roots and foliage are good sources of vitamins and minerals (Bradbury and Holloway 1988; see Table 4). Cassava is rich in vitamins A, C and riboflavin (Ravindran 1992), but SP roots are superior in all vitamins, particularly the B group vitamins (Bradbury and Holloway 1988; Table 4). The roots (Table 4) and foliage (data not shown) also contain appreciable amounts of Ca, P, K, Mg, Fe, Mn and Zn (Glatz et al. 2009). The contribution of these micronutrients may be amplified by the use of additional micronutrients in feed pre-mixtures. Moreover, the form of presentation may affect micronutrient availability to pigs (Bradbury and Holloway 1988; Metzler and Mosenthin 2009).

Table 5 Nutrient content of fresh, dried and ensiled sweet potato and cassava leaves

Forage (%DM)	**DM**	**OM**	**CP**	**EE**	**CF**	**NDF**	**ADF**	**ME**
Fresh SPL[a]	18.0	98.6	26.8	0.7	12.8	28.5	18.2	9.5
Dried SPL[a]	95.0	98.6	26.9	0.7	12.8	25.4	17.1	9.5
Ensiled SPL[a]	32.8	98.5	23.4	1.2	12.5	24.7	13.7	9.7
Ensiled SPL[b]	-	86.6	20.1	3.3	-	29.2	-	-
Sun dried SPL[b]	-	89.9	20.6	2.5	-	28.4	-	-
Sun dried CL(A)[b]	-	92.8	32.4	6.4	-	27.5	-	-
Sun dried CL(B)[b]	-	91.4	33.3	7.2	-	24.4	-	-
Oven dried CL(60°C)[b]	-	92.4	32.7	7.5	-	25.3	-	-
Oven dried CL(105°C)[b]	-	92.8	32.2	8.2	-	37.6	-	-
Ensiled CL[b]	-	92.8	31.7	8.1	-	24.8	-	-

Sources: An et al. (2004)[a]; Phuc et al. (2001)[b].

Table 6 Amino acid composition of the protein in sweet potato and cassava roots and foliage

Forage feed	**Amino acid (g/16g N)**												
	Arg	Cys	Gly	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Tyr	Val
Alfalfa[a]	4.1	-	-	2.2	4.0	7.1	4.3	2.5	4.9	4.1	-	3.3	5
Ground nut foliage[a]	5.2	-	-	1.9	3.7	7.0	4.1	0.9	5.4	4.0	-	3.8	5.1
Leucaena[a]	5.7	-	-	2.0	4.1	7.9	5.8	1.2	5.6	4.0	-	4.3	5.3
SPL[c]	6.1	-	-	2.8	4.5	7.5	4.1	1.8	6.6	4.4	-	4.6	5.1
FSPL[c]	5.2	3.4	4.1	2.2	3.7	8.6	4.5	1.5	7.1	5.2	-	4.1	5.6
DSPL[c]	5.2	3.2	3.5	2.0	4.2	8.8	4.1	1.6	6.9	5.2	-	4.0	5.7
ESPL[c]	5.0	2.3	2.7	1.9	3.6	9.0	3.9	1.2	7.1	5.2	-	3.7	5.4
CL60[b]	6.3	-	-	2.2	4.1	8.7	5.1	1.6	6.3	4.4	-	4.3	5.9
CL105[b]	5.9	-	-	1.9	4.4	8.0	5.6	1.5	5.7	4.0	-	4.0	5.3
SPR[d]	-	0.11	-	-	0.37	-	0.34	0.17	0.39	0.38	0.0	0.23	0.45
SPR[e]	-	-	-	-	0.42	0.78	0.42	-	-	0.55	-	0.08	0.68
SPR[e]	-	-	-	-	1.01	0.92	0.72	-	-	0.63	-	0.12	0.83
SPR[f]	0.26	0.1	0.27	0.13	-	-	-	0.1	0.32		-	0.18	-
SPR[g]	0.17	-	-	-	-	0.33	0.25	0.04		0.29	-	-	-
CR[g]	0.48	-	-	0.09	0.33	0.35	0.39	0.04	0.22	0.24	0.03	-	0.28
CR[d]	-	0.14	-	-	0.28	-	0.41	0.13	0.25	0.26	0.12	0.16	0.33

Sources: Phuc (2006)[a]; Phuc and Lindberg (2001)[b]; An et al. (2004)[c]; FAO (1970)[d]; Purcell et al. (1972)[e]; Bradbury et al. (1985)[f]; Heuzé et al. (2015)[g]; Zjilstra et al. (1999)[h].
SP = sweet potato, C = cassava (oven dried at 60°C and 105°C), D = dried, E = ensiled, F = fresh, L = leaves, R = roots

Anti-nutritional factors

Several anti-nutrients are present in SP and cassava, namely cyanogenic glucosides, trypsin inhibitors (TIs), oxalates, phytates and tannins (Table 4). Dietary fibre is considered an anti-nutrient when it reduces the energy digestibility of feeds. The TIs are plant proteins which reduce the enzyme activity of trypsin and chymotrypsin. They are found in the roots and foliage where they act as a defence mechanism against pest infestation (Wang and Yeh 1996). TIs are more abundant in SP than cassava. However, Bradbury et al. (1985) found that TI activity did not appear to be related to protein content in SP varieties grown in the highlands of PNG and TI activity was negligible. Although SP may contain slightly more oxalate than cassava roots (Bradbury et al. 1985), the majority of anti-nutrients are of greater concern in cassava and processing of cassava as food is well studied. Cassava contains cyanogenic glucosides (linamarin and loutaustralin) that convert to hydrogen cyanide (HCN) which in high doses may cause death of pigs (Cereda and Mattos 1996). Cassava leaves and peels contain higher amounts of HCN (Bokanga 1994). The ‘sweet’ yellow cassava varieties are grown in PNG (Bradbury et al. 1985) while the bitter cassava (white-fleshed) varieties tend to contain more cyanogenic glucosides, TI’s, oxalates, phytates and tannins than sweet varieties (Table 4).

Where smallholder farms use the recommended SP and cassava dual food-feed crop varieties and production practices there is less likelihood of anti-nutritional factors being a serious problem in animal feed. Moreover, practical methods of drying, cooking and fermenting feed are appropriate for reducing the anti-nutrient effects in prepared pig feeds (Peters et al. 2001; Giang et al. 2004b; Teka et al. 2014). The use of dried farm-grown feed products may be more problematic for the logistics of processing and storage under tropical conditions which are conducive to insect pests and microbial growth. However, fermenting by ensiling has been promoted as a resource efficient and cost effective means of feed storage under tropical climates (Peters et al. 2001; Dom et al. 2010, 2011).

Improving SP and cassava as feed for growing pigs

In many studies there was an emphasis on using roots for starch energy and the foliage as a protein replacement for grain feeds or in combination with alternative protein feed from agro-industrial by-products such as fish meal, copra meal, and palm kernel cake. The local ingredients provide adequate protein sources when they are available and are valuable substitutes for grain feeds. TI activity may be destroyed by boiling and baking until cooked (Lin and Tsu 1987; Bradbury et al. 1988) and reduced by ensilage (Lin et al. 1988). Small amounts of HCN in cassava may be efficiently detoxified in the liver, kidneys and skeletal muscle but methionine is lost in the process (Oke 1978; Devlin et al. 1989; Aminlari et al. 2007). HCN may be reduced by boiling, roasting, soaking, ensiling and sun drying the roots (Cooke and Maduagwu 1978; Bokanga 1995; Teka et al. 2013). Pigs find high levels of cassava leaves less appealing (Peters et al. 2001) while SP vines are relished by pigs, and together with SP roots or cassava roots, may be the sole feed offered to pigs at village level and a major portion of the feed in smallholder piggeries (Dom and Ayalew 2010; Dom et al. 2010). However, the high and variable DF in the foliage of both crops limits the level at which they may be included in more complex feed diets (Noblet et al. 1994; An et al. 2004). Dominguez (1992) determined that 10% DM of feed, about 1.0 kg fresh or 300 g DM, may be a limit for inclusion of fresh SP vines and Ravindran (1993) recommended less than 15 g/kg for cassava leaf meal. Higher foliage use increases the indigestible fibre content potentially reducing digestibility of other nutrients and diluting energy efficiency by switching from digestion to fermentation. The microbial fermentation of carbohydrates affects the ileal and faecal digestibility and absorption of P and Ca (Metzler and Mosenthin 2008). Additionally, undigested plant proteins may affect microbial fermentation in the colon.

Although the roots provide high levels of starch, blending SP and cassava roots with other ingredients provides additional nutrients and anti-nutrients. Nutrient requirements of growing pigs fed large amounts of SP and cassava feed may be strongly influenced by soluble DF (resistant starch and NSPs) and entails determining the levels of DE and N balance.

Processing roots and foliage

Milling, cooking, ensiling or drying roots and foliage reduces their anti-nutritional factors and improves the dry matter content, palatability and digestibility of cassava (Phuc et al. 1995; Pascual-Reas 1997; Hang and Preston 2005) and SP (Tomita et al. 1985; Dominguez and Ly 1997; Dom and Ayalew 2009a, b). Milling, grating or chopping roots and foliage may affect how well the feeds are digested, because of differences in the particle size and the extent to which the cell walls and fibres are broken up, increasing the surface area for enzymatic digestion. Drying is vital for reducing the high moisture content and bulkiness of the roots and foliage. However, depending on local climate and the weather, drying and storage of dry feeds may be an impractical option. SP roots contain amylase enzymes which become active during storage (Hagenimana et al. 1992; Takahata et al. 1995) and after cooking and baking (Reddy and Sistrunk 1980). Starch is reduced and sugars (maltose) and DF (pectins) increase when boiling SP roots but not cassava roots, although there is more mineral loss from boiling of cassava roots (Bradbury et al., 1988). Solubility of DF may be improved by cooking and processing (Dhingra et al. 2012; de Vries et al. 2012) but retrograde starch and other carbohydrate-protein complexes resistant to α-amylase may also form (McDougall et al. 1996). Boiling in water will also remove much of the soluble vitamin and mineral content (Bradbury and Holloway 1988) and to a lesser extent when fermenting (Giang et al. 2004b; Teka et al. 2013). Fermenting cassava roots was more effective than boiling in reducing anti-nutritional factors as well as improving bulk density and water holding capacity (Teka et al. 2013). Grating or crushing improves HCN loss through the hydrolysing enzyme linamarase in the root parenchyma while air drying may be less effective for cassava with higher HCN content (Cardoso et al. 2005). Boiling roots before feeding to pigs is a common practice, whereas appropriate storage facilities for dry product may be challenging for smallholder pig producers to secure. Ensiling techniques have been tested and adapted as effective and efficient for storing fermented feed and feeding to growing pigs (Peters et al. 2001; Phuc et al. 2001; Giang et al. 2004a).

Different forms of feed presentation may afford better nutrient utilisation to growing pigs depending on how the physicochemical properties of DF and nutrients are affected by the prepadiet methods such as cooking, ensiling or drying and milling.

Nutritional studies on SP and cassava

The feeding value of SP and cassava to grower-finisher pigs has been studied as-fed either fresh (Rose and White 1980, Ochetim 1993b), as dried meal (Phuc et al. 2000; Tzudir et al. 2012), ensiled (Dom and Ayalew 2009a, b; Ly et al. 2010) or cooked (Dom and Ayalew 2009a, b). Sweet potato and cassava foliage have been used as sources of protein in pig diets (An et al. 2004; Hang et al. 2009, Regnier et al. 2013). In recent times there is more interest in the use of ensiled SP and cassava because of the relative simplicity of processing high moisture forages and storage of fermented silage under tropical climates. Studies on feeding SP and cassava roots to indigenous and crossbred pigs provide varying digestibility and growth performance results with different types and amounts of protein ingredients including the foliage of both crops. The various tested diets also differed in their grain and animal protein ingredients.

For example, digestibility in and growth of Creole pigs were depressed when dried foliage of SP and cassava was fed at 200 g/kg (Regnier et al. 2013) while this was not the case for Large White-Landrace x Duroc crossbred pigs fed ensiled SP roots and vines or cooked roots with fresh vines (Dom and Ayalew 2009a, b). N retained was lower on the SP silage diet (11.8 g N/day) compared to the boiled SP roots fed with fresh vines (20.3 g N/day) but the average daily weight gain (ADG) and feed efficiency (FCE) were comparable to when fed a standard wheat based feed (Dom and Ayalew 2009b). Giang et al. (2004a) found lower dry matter, crude protein and crude fibre digestibilities for similar SP silage diets than those documented by Dom and Ayalew (2009a) and the resulting ADG and FCR were poorer.

Giang et al. (2004a) used a basal feed containing a higher proportion (48%) of maize and, therefore, the effect of different protein ingredients combined with SP or cassava may be an important considediet. Indeed, increased protein blended with ensiled SP root and vine led to a markedly better ADG (Dom et al. 2010) compared to similar diets based on dried SP root meal alone (Gonzalez et al. 2002) and cassava leaf and root meals (Phuc et al. 2000). Ensiled cassava roots with fish meal provided about 90% DM and 85% CP digestibility, even when cassava leaves were included at 50% of the silage (Hang 1998) and the N retention in cassava based diets was better than in SP silage based diets. Ospina et al. (1995) reported acceptable growth performance and high digestibility when cassava root meal was the sole energy source and soybean as protein source. When the cassava leaf meal substituted for soybean at graded levels with cassava root meal basal feed the regression coefficients were superior for organic matter, crude protein, crude fibre, fats (as ether extracts, EE) and carbohydrate (as N-free extracts, NFE) digestibility (Phuc et al. 2000) but the N balance in growing pigs varied. In growing pigs N retained (g/day) of cassava and SP-based diets was lower than 20 g/d in the reports by Phuc et al. (2000) and Giang et al. (2004a). Whereas, Dom and Ayalew (2009a) found 20 g/day and 12 g/day respectively for the use of boiled SP roots and fresh vines and ensiled roots and vines when replacing half a corn-soybean meal diet. But when the same growing pigs were fed the sole fed corn-soybean meal from Dom and Ayalew (2009a) N retained was 29 g/day. There is some margin for improvement in the use of roots and forage and this may partially depend on processing and blending with protein concentrates. While SP and cassava roots provide readily digestible starch for energy, the various DF portions in tropical forages such as cellulose and lignin as well as anti-nutrients like tannin and phytates, tend to reduce protein digestion and absorption in the small intestine (Wenk 2001; Regnier et al. 2013). Processing may reduce the impact of DFs and anti-nutrients. Blending with concentrates that also contain animal protein ingredients provides higher density of nutrients which potentially may overcome losses in the digestive process. Alternatively, lower protein content may not necessarily be a drawback when pigs are fed to satisfaction and with the inclusion of synthetic lysine. These options should be investigated for the locally bred mixed genotype pigs farmed in the PICT.

Conclusion

Growing pigs require a high level of DE that can be supplied by SP and cassava roots, while complementary protein sources can supply the required amino acids. The interaction between DF and protein and the different modes of digestion, fermentation and absorption of starch and NSPs will determine their contribution to growing pig energy and nutrient utilisation. Processing may reduce anti-nutritional factors and ensiling to store fermented feed may also provide benefits to gut health. Diverse crossbreeds and tropical environments are a challenge to pig production, however, determining the nutrient requirements of local mixed genotype pigs to reduce costs of feed can improve the productivity and profitability of smallholder pig farming in PNG and other PICT.

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References

Adesehinwa AOK (2008) Energy and protein requirements of pigs and the utilization of fibrous feedstuffs in Nigeria: A review. Afr J Biotechnol 7:4798-4806

Aminlari M, Malekhusseini A, Akrami F, Ebrahimnejad H, (2007) Cyanide-metabolizing enzyme rhodanese in human tissues: comparison with domestic animals. Comp Clin Pathol 16:47-51

An LV, Hong TTT, Lindberg JE (2004) Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (Ipomoea batatas L. (Lam.)) leaves. Anim Feed Sci Tech 114:127-139

An LV, Hong TTT, Ogle B, Lindberg JE (2005) Utilization of Ensiled Sweet potato (Ipomoea batatas L. (Lam.)) Leaves as a Protein Supplement in Diets for Growing Pigs. Trop Anim Health Prod 37:77-88

Ayalew W, Danbaro G, Dom M, Amben S, Besari F, Moran C, Nidup K (2011) Genetic and cultural significance of native pigs in PNG and their phenotypic features. Anim Genet Resour 48:37-46

Barea R, Nieto R, Vitari F, Domeneghini C, Aguilera JF (2011) Effects of pig genotype (Iberian v. Landrace x Large White) on nutrient digestibility, relative organ weight and small intestine structure at two stages of growth. Animal 5:547-557

Bauer E, Williams BA, Verstegen MWA, Mosenthin R (2006) Fermentable carbohydrates: potential dietary modulators of intestinal physiology, microbiology and immunity in pigs. In: Mosenthin R, Zentek J, Zebrowska T (eds) Biology of Nutrition in Growing Animals, Elsevier, China

Bergman EN (1990) Energy Contributions of Volatile Fatty Acids From the Gastrointestinal Tract in Various Species. Physiol Rev 70:567-590

Bindelle J, Buldgen A, Wavreille J, Agneessens R, Destain JP, Wathlelet B, Leterme P (2007) The source of fermentable carbohydrates influences the in vitro protein synthesis by colonic bacteria isolated from pigs. Animal 1:1126-1133

Bindelle J, Laterme P, Buldgen A (2008) Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. Biotechnol Agron Soc Environ 12:69-80

Bokanga M (1994) The cyanogenic potential of cassava. In: Akoroda MO (ed) Root Crops and Food Security in Africa, Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

Bokanga M (1995) Biotechnology and cassava processing in Africa. Food Tech 49:86-90

Bradbury JH, Baines J, Hammer B, Anders M, Millar JS (1984) Analysis of sweet potato (Ipomoea batatas) from the Highlands of Papua New Guinea: Relevance to the incidence of Enteritis necroticans. J Agr Food Chem 32:469-473

Bradbury JH, Bradshaw K, Jealous W, Holloway WD, Phimpisane T (1988) Effect of Cooking on Nutrient Content of Tropical Root Crops from the South Pacific. J Sci Food Agric 43:333-342

Bradbury JH, Hammer B, Nguyen T, Anders M, Millar JS (1985) Protein Quantity and Quality and Trypsin Inhibitor Content of Sweet Potato Cultivars from the Highlands of Papua New Guinea. J Agri Food Chem 33:251-285

Bradbury JH, Holloway WD (1988) Chemistry of Tropical Root Crops: significance for nutrition and agriculture in the Pacific. ACIAR MG S 6

Brioudes A, Warner J, Hedlefs R, Gummow B (2014) A review of domestic animal diseases within the Pacific Islands region. Acta Trop 132:23-38

Cardoso AP, Mirione E, Ernesto M, Massaza F, Cliff J, Haque MR, Bradbury JH (2005) Processing of cassava roots to remove cyanogens. J Food Compos Anal 18:451-460

Cereda M.P, Mattos MCY (1996) Linamarin – The toxic compound of cassava. J Venomous Anim Toxins 2(1). http://dx.doi.org/10.1590/S0104-79301996000100002. Accessed 30 March 2016

Chimonyo M, Kanengoni AT, Dzama K (2001) Influence of Maize Cob Inclusion Level in Pigs Diets on Growth Performance, Carcass Traits of Mukota x Large White F1 Crossbred Male Pigs. Asian-Australas J Anim Sci 14:1724-1727

Choct M (2001) Carbohydrate and fibre digestion in monogastric animals. American Soybean Association Technical Bulletin MITA (P) NO. 070/10/2001, AN34-2001.

Choct M, Dersjant-Li Y, McLeish J, Peisker M (2010) Soy Oligosaccharides and Soluble Non-starch Polysaccharides: A Review of Digestion, Nutritive and Anti-nutritive Effects in Pigs and Poultry. Asian-Australas J Anim Sci 23:1386-1398

Collado LS, Mabesa RC, Corke H (1999) Genetic Variation in the Physical Properties of Sweet Potato Starch. J Agr Food Chem 47:4195-4201

Cooke RD, Maduagwu EN (1978) The effects of simple processing on the cyanide content of cassava chips. J Food Technol 13:299-306

Cultivated and Consumed in Yola, Adamawa State Nigeria. Direct Res J Agric and Food Sci 3:106-116

De Lange CFM, Levesque CL, Kerr BJ (2012) Amino acid nutrition and feed efficiency. In: Patience JF (ed) Feed efficiency in swine, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 88-100

De Vries S, Pustjens AM, Schols HA, Hendriks WH, Gerrits WJJ (2012) Improving digestive utilization of fibre-rich feedstuffs in pigs and poultry by processing and enzyme technologies: A review. Anim Feed Sci Tech 178:123-138

Degen L, Halas V, Tossenberger J, Szabo CS, Babinszky L (2009) The impact of dietary fibre and fat levels on total tract digestibility of energy and nutrients in growing pigs and its consequence for diet formulation. Acta Agr Scand 59:150-160

Devlin DJ, Mills JW, Smith RP (1989) Histochemical Localization of Rhodonase Activity in Rat Liver and Skeletal Muscle. Toxicol Appl Pharm 97:274-255

Dhingra D, Michael M, Rajput H, Patil RT (2012) Dietary fibre in foods: a review. J Food Sci Technol. doi: 10.1007/s13197-011-0365-5

Dierick NA, Vervaeke IJ, Demeyer DI, Decuypere JA (1989) Approach to the energetic importance of fibre digestion in pigs. I. Importance of fermentation in the overall energy supply. Anim Feed Sci Tech 23:141-167

Dom M, Ayalew W (2009a) Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. J Inst Chem PNG 2:77-88

Dom M, Ayalew W (2009b) Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. PNG J Res Sci Tech 1:86-96

Dom M, Ayalew W (2010) Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. J S Pac Agr 14:78-86

Dom M, Ayalew W, Amben S (2010) Development of Improved Pig Feeding Systems Using Ensiled Material: On-farm testing of feeding Sweet Potato silage to growing pigs at Tambul in Western Highlands Province. Sci in New Guinea J 30:94-104

Dom M, Ayalew W, Glatz P, Kirkwood R, Hughes P (2014) Effect on nutrient digestibility and nitrogen balance in pigs fed three forms of blended cassava roots. Proceedings of the 16th AAAP Congress, Yogyakarta, 10–14 November 2014, 2:676-679

Dom M, Ayalew W, Tarabu J (2011) Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG). J S Pac Agr 15:62-70

Dominguez PL (1992) Feeding of sweet potato in monogastrics. In: Machin D, Nyvold S, (eds) Roots, tubers, plantains and bananas in animal feeding, FAO Animal Production and Health Paper 95, Food Agriculture Organization, Rome, pp 217-233

Dominguez PL, Ly J (1997) An approach to the nutritional value for pigs of sweet potato (Ipomoea batatas L. (Lam.)). LLRD 9(2). http://www.lrrd.org/lrrd9/2/ly92.htm. Accessed 2 June 2013

Ewan RC (1989) Predicting the energy utilization of diets and feed ingredients by pigs. In: van der Honing Y, Close WH (eds) Energy metabolism. European Association of Animal Production Bulletin No. 43 Pudoc, Wageningen, The Netherlands, pp 271-274

Fabian J, Chiba LI, Kuhlers DL, Frobish LT, Nadarajah K, McElhenney WH (2003) Growth performance, dry matter and nitrogen digestibilities, serum profile, and carcass and meat quality of pigs with distinct genotypes. J Anim Sci 81:1142-1149

Freire JPB, Dias RIM, Cunha LF, Aumaitre A (2003) The effect of genotype and dietary fibre level in the caecal bacterial enzyme activity of young piglets: digestive consequences. Anim Feed Sci Tech 106:119-130

Freire JPB, Peiniau J, Cunha LF, Almeida JAA, Aumaitre A (1998) Comparative effects of dietary fat and fibre in Alentjano and Large White piglets: Digestibility, digestive enzymes and metabolic data. Livest Prod Sci 53:37-47

Gerrits WJJ, Bosch MW, van den Borne JJGC (2012) Quantifying resistant starch using novel in vivo methodology and the energetic utilization of fermented starch in pigs. J Nutr 142:238-244

Giang HH, Ly LV, Ogle B (2004a) Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. LRRD 16(50). http://www.lrrd.org/lrrd16/7/gian16050.htm. Accessed 2 June 2013

Giang HH, Ly LV, Ogle B (2004b) Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. LRRD 16(45). http://www.lrrd.org/lrrd16/7/gian16045.htm. Accessed 2 June 2013

Glatz P, Miao Z, Hughes B, Jansen T, Aleve H, Sandakabatu C (2009) Feeding village poultry in Solomon Islands, Australian Centre for International Agricultural Research, Canberra ACT. http://aciar.gov.au/publication/fr2009-21. Accessed 2 July 2013

Gonzalez C, Díaz I, Milagro, L, Vecchionacce H, Alexia B, Ly J (2002) Growth performance and carcass traits in pigs fed sweet potato (Ipomoea batatas L. (Lam.)) root meal. LRRD 14(6). http://www.lrrd.org/lrrd14/6/gonz146.htm. Accessed 2 June 2013

Guixin Q, Verstegen WA, Bosch MW (1995) Variation of the digestive capacity between genetically different pig populations: a review. J Anim Physiol Anim Nutr 73:233-242

Hagenimana V, Vezina LP, Simard RE (1992) Distribution of Amylases within Sweet Potato (Ipomoea batatas L. (Lam.)) Root Tissue. J Agric Food Chem 40:1777-1783

Hang DT (1998) Digestibility and nitrogen retention in fattening pigs fed different levels of ensiled cassava leaves as a protein source and ensiled cassava root as energy source. LRRD 10 (3). http://www.lrrd.org/lrrd10/3/hang1.htm. Accessed 2 June 2013

Hang DT, Preston TR (2005) The effects of simple processing methods of cassava leaves on HCN content and intake by growing pigs. LRRD 17(9) http://www.lrrd.org/lrrd17/9/hang17099.htm. Accessed 2 July 2013

Hang DT, Quang LN, Preston TR, Everts H, Beynen AC (2009) Effect of supplementary DL-methionine in pig diets with cassava leaves as a major protein source. LRRD 21(15). http://www.lrrd.org/lrrd21/1/hang21015.htm Accessed 2 June 2013

Heuzé V, Tran G, Hassoun P, Renaudeau D, Bastianelli D (2015) Sweet potato (Ipomoea batatas) tubers. Feedipedia. http://feedipedia.org/node/745. Accessed 12 October 12 2015

Hide R (2003) Pig Husbandry in New Guinea. A literature review and bibliography. ACIAR MG S 108

Hill JR, Sainsbury DWB (1995) The Health of Pigs, Longman Singapore Publishers (Pte) Ltd, Singapore

Hoover R (2001) Composition, molecular structure, and physicochemical properties of tuber and root starches. Carbohyd Polym 45:253-267

Jensen BB, Mikkelsen LL (1998) Feeding liquid diets to pigs. In: Garnsworthy PC, Wiseman J (eds) Recent Advances in Animal Nutrition, Nottingham University Press, Nottingham UK, pp 107-126

Jin L, Reynolds LP, Redmer DA, Caton JS, Crenshaw JD (1994) Effects of dietary fibre on intestinal growth, cell prolifediet, and morphology in growing pigs. J Anim Sci 72:2270-2278

Johansen HN, Bach Knudsen KEB, Sandstrom B, Skjoth F, (1996) Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. Brit J Nutr 75:339-351

Keys Jr JE, DeBarthe JV (1974) Site and Extent of Carbohydrate, Dry Matter, Energy and Protein Digestion and the Rate of Passage of Grain Diets in Swine. J Anim Sci 39:57-62

Kirkwood RN, Huang SX, McFall M, Aherne FX (2000) Dietary factors do not influence the clinical expression of swine dysentery. Swine Health and Prod 8:73-76

Kyriazakis I (2011) Opportunities to improve nutrient efficiency in pigs and poultry through breeding Animal. doi:10.1017/S1751731110002545

Kyriazakis I, Whittemore CT (eds.) (2006) Whittemore's Science and Practice of Pig Production, 3rd edn. Blackwell Publishing, India

Le Dividich J, Desmoulin B, Dourmad J-Y (1985) Influence de la tempe´rature ambiante sur les performances du porc en croissance-finition en relation avec le niveau alimentaire. Journées Rech. Porcines en France 17:275-282

Lenis NP, Bikker P, van der Meulen J, van Diepen JT, Bakker JG, Jongbloed AW (1996) Effect of dietary neutral detergent fibre on ileal digestibility and portal flux of nitrogen and amino acids and on nitrogen utilization in growing pigs. J Anim Sci 74:2687-2699

Li DF, Thaler RC, Nelssen JL, Harmon DL, Allee GL, Weeden TL (1990) Effect of fat sources and combinations on starter pig performance, nutrient digestibility and intestinal morphology. J Anim Sci 68:694-3704

Lin Y-H, Huang T-C, Huang C (1988) Quality improvement of sweet potato (Ipomoea batatas L. (Lam.)) roots by ensilage. Brit J Nutr 60:173-184

Lin Y-H, Tsu B-S (1987) Some factors affecting levels of trypsin inhibitor activity of sweet potato (Ipomoea batatas) roots. Bot Bull Acad Sinica 28:139-149

Lindberg JE (2014) Fibre effects in nutrition and gut health in pigs, J Anim Sci Biotechnol 5:15. http://www.jasbsci.com/content/5/1/15. Accessed 4 June 2015

Lopez J, Jesse GW, Becker BA, Ellersieck MR (1991) Effects of temperature on the performance of finishing swine: I. Effects of a hot, diurnal temperature on average daily gain, feed intake, and feed efficiency. J Anim Sci 69:1843-1849.

Low AG (1989) Secretory response of the pig gut to non-starch polysaccharides. Anim Feed Sci Tech 23:55-65

Ly NTH, Ngoan LD, Verstegen MWA, Hendriks WH (2010) Ensiled and Dry Cassava Leaves, and Sweet Potato Vines as a Protein Source in Diets for Growing Vietnamese Large White×Mong Cai Pigs. Asian-Australas J Anim Sci 23(9):1205-1212

MacDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG (2011) Animal Nutrition 7th edn. Pearson Hall, England

Mason VC (1980) Role of large intestine in the process of digestion and absorption in the pig. In: Partridge IG, Low AG (eds) Current concept of digestion and absorption in pigs, Hannah Research Institute, Reading UK, pp 112-129

McDougall GJ, Morrison IM, Stewart D, Hillman JR (1996) Plant Cell Walls as Dietary Fibre: Range, Structure Processing and Function. J Sci Food Agric 70:133-50

Metzler BU, Mosenthin R (2008) A Review of Interactions between Dietary Fibre and the Gastrointestinal Microbiota and Their Consequences on Intestinal Phosphorus and Metabolism in Growing Pigs. Asian-Australas J Anim Sci 21(4):603-615

Metzler BU, Vahjen W, Baumgartel T, Rodehutscord M, Mosenthin R (2009) Changes in bacterial populations in the ileum of pigs fed low-phosphorus diets supplemented with different sources of fermentable carbohydrates. Anim Feed Sci Tech 148:68-89

Missotten JAM, Michiels J, Degroote J, De Smet, S (2015) Fermented liquid feed for pigs: an ancient technique for the future. J Anim Sci Biotechnol 6:4. http://www.jasbsci.com/content/6/1/4

Missotten JAM, Michiels J, Ovyn A, De Smet S, Dierick NA (2010) Fermented liquid feed for pigs. Arch Anim Nutr 64:437-66

Moongngarm A (2013) Chemical compositions and resistant chemical starch content in starchy foods. Am J Agric Biol Sci 8(2):107-113

Ndindana W, Dzama K, Ndiweni PNB, Maswaure SM, Chimonyo M (2002) Digestibility of high fibre diets and performance of growing Zimbabwean indigenous Mukota pigs and exotic Large White pigs fed maize based diets with graded levels of maize cobs. Anim Feed Sci Tech 97:199-208

Ngoc TTB, Len NT, Lindberg JE (2013) Impact of fibre intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. Animal. doi: 10.1017/S1751731112002169

Nienaber JA, Hahn GL (1983) Performance of growing finishing swine in response to the thermal environment. ASAE Meeting, St-Joseph, Missouri, United States Paper MCR 83-137

Nieto R, Miranda A, Garcia MA Aguilera JF (2002) The effect of dietary protein content and feeding level on the rate of protein deposition and energy utilization in growing Iberian pigs from 15 to 50 kg body weight. Brit J Nutr 88:39-49

Noblet J, Fortune H, Dupire C, Dubois S (1993) Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: effect of energy system. Anim Feed Sci Tech 42:131-149

Noblet J, Gilbert H, Jaguelin-Peyraud Y, Lebrun T (2013) Evidence of genetic variability for digestive efficiency in the growing pig fed a fibrous diet. Animal 7(8):1259-1264

Noblet J, Henry Y (1993) Energy evaluation systems for pig diets: a review. Livest Prod Sci 36:121-141

Noblet J, Perez JM (1993) Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J Anim Sci 71:3389-3398

Noblet J, van Milgen J (2004) Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J Anim Sci 82:E229-E238

Noblet, J, Fortune H, Shi XS, Dubois S (1994) Prediction of net energy value of feeds for growing pigs. J Anim Sci 72:344-354

NRC (National Research Council) (1998) Nutrient Requirements of Swine 10th Revised edn. National Academy Press, Washington DC, USA

Nwokolo E, (1990) Sweet potato. In: Thacker PA, Kirkwood RN (eds) Non-traditional feed sources for use in swine nutrition Butterworths, London, pp 481-491

Nyachoti CM, Zijlstra RT, de Lange CFM, Patience JF (2004) Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can J Anim Sci 84:549-566

Ochetim S (1991) The use of cassava in broiler feeding in the South Pacific. Asian Australas J Anim Sci 4(3):241-244

Ochetim S (1993b) Fresh cassava as feed for fattening pig. Asian-Australas J Anim Sci 6(3):361-365

Ochetim S, (1993a) Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. Asian-Australas J Anim Sci 6(3):347-360

Oke OL (1978) Problems in the use of cassava as animal feed. Anim Feed Sci Tech 3: 345-50

Ospina L, Preston TR, Ogle B (1995) Effect of protein supply in cassava root meal based diets on the performance of growing-finishing pigs. LRRD 7(2). http://www.lrrd.org/lrrd7/2/6.htm. Accessed 2 July 2013

Pascual-Reas B (1997) A comparative study on the digestibility of cassava, maize, sorghum and barley in various segments of the digestive tract of growing pigs. LRRD 9(5). http://www.lrrd.org/lrrd9/5/phil95.htm. Accessed 2 July 2013

Paul SS, Mandal AB, Chatterjee PN, Bhar R, Pathak NN (2007) Determination of nutrient requirements for growth and maintenance of growing pigs under tropical condition. Animal. doi: 10.1017/S1751731107284228

Perez R, (1997) Feeding pigs in the tropics, FAO Animal Production and Health Paper 132, Food and Agriculture Organization of the United Nations, Rome

Peroni FHG, Rocha TS, Franco CML (2006) Some Structural and Physicochemical Characteristics of Tuber and Root Starches, Food Sci Technol Int. 12(6):505-513

Peters D, Tinh NT, Minh TT, Ton PH, Yen NT, Hoanh MT (2001) Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam, International Potato Center (CIP), Hanoi, Vietnam

Phuc BHN, Lai N, Preston TR, Ogle B, Lindberg JE (1995) Replacing soya bean meal with cassava leaf meal in cassava root diets for growing pigs. LRRD 7(3). http://www.lrrd.org/lrrd8/3/phuc83.htm. Accessed 2 July 2013

Phuc BHN, Lindberg JE, Ogle B, Thomke S (2001) Determination of the Nutritive Value of Tropical Biomass Products for Monogastrics Using Rats: Effects of Drying Temperature, Ensiling and Level of Inclusion of Cassava Leaves and Sweet potato Vines. Asian-Australas J Anim Sci 14(7):994-1002

Phuc BHN, Ogle B, Lindberg JE (2000) Effect of replacing soybean protein with cassava leaf protein in cassava root meal based diets for growing pigs on digestibility and N retention. Anim Feed Sci Tech 83:223-235

Phuc BHN, Preston TR, Ogle B, Lindberg JE (1996) The nutritive value of sun-dried and ensiled cassava leaves for growing pigs. LRRD (8)3:26-33. http://www.lrrd.org/lrrd8/3/phuc83.htm. Accessed 2 July 2013

Pierzynowski, S. G., D. Kruszewska and B. W. Weström. (2006) The quality of dietary protein digestion affects animal performance and regulates gut bacteria growth: hypotheses and facts. In: Mosenthin R, Zentek J, Zebrowska T Biology of Nutrition in Growing Animals, Elsevier, China

Piva A, Galvano F, Biagi G, Casadeia G (2006) Intestinal fermentation: dietary and microbial interactions. In: Mosenthin R, Zentek J, Zebrowska T Biology of Nutrition in Growing Animals, Elsevier, China

Pluske JR, Montagne L, Cavaney FS, Mullan BP, Pethick DW, Hampson DJ (2007) Feeding different types of cooked white rice to piglets after weaning influences starch digestion, digesta and fermentation characteristics and the faecal shedding of b-haemolytic Escherichia coli. Brit J Nutr 97:298-306

Pluske JR, Siba PM, Pethick DW, Durmic Z, Mullan BP, Hampson DJ (1996) The Incidence of Swine Dysentery in Pigs Can Be Reduced by Feeding Diets That Limit the Amount of Fermentable Substrate Entering the Large Intestine. J Nutr 126:2920-2933

Pluske, JR, Durmic Z, Pethick DW, Mullan BP, Hampson DJ (1998) Confirmation of the Role of Rapidly Fermentable Carbohydrates in the Expression of Swine Dysentery in pigs after Experimental Infection. J Nutr 128:1737-1744

Quartermain AR, Kohun PJ (2002) Pig production in Papua New Guinea. In: Jones R (ed) Priorities for Pig Research in Southeast Asia and the Pacific to 2010, Australian Centre for International Agricultural Research, Canberra, pp 40-47

Quiniou N, Dubois S, Noblet J (2000) Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and bodyweight. Livest Prod Sci 63:245-253

Ratcliffe B (1991) The role of microflora in digestions. In: Fuller MF (ed) In vitro Digestion for Pigs and Poultry, CAB International, Edinburgh, pp 19-34

Ravindran V (1990) Feeding value and digestibility of cassava leaf meals for growing pigs. In: Proceedings Fifth Australasia Animal Production Congress, 3:20

Ravindran V (1992) Prepadiet of cassava leaf products and their use as animal feed. In: Machin D, Speedy AW (eds) Roots, tubers, plantains and bananas in animal feeding, FAO Animal Production and Health Publication 95, pp 111-126

Ravindran V (1993) Cassava Leaves as Animal Feed: Potential and Limitations. J Sci Food Agr 61:41-150

Reddy NN, Sistrunk WA (1980) Effect of Cultivar, Size, Storage and Cooking method on Carbohydrates and some nutrients of Sweet Potato. J Food Sci 45:682-684

Regnier C, Bocage B, Archimède H, Noblet J, Renaudeau D (2013) Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. Anim Feed Sci Tech 180:44-54

Renaudeau D, Bocage B, Noblet J (2006) Influence of energy intake on protein and lipid deposition in Creole and Large White growing pigs in a humid tropical climate. J Anim Sci 82:937-945

Renaudeau D, Collin A, Yahav S, de Basilio V, Gourdine JL, Collier RJ (2012) Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6(5):707-728

Rerat A, Calmes R, Corring T, Vaissade P (1996) Kinetics of amino acid and glucose absorption following pancreatic diversion in the pig. Brit J Nutr 75:175-193

Rideout TC, Liu Q, Wood P, Fan MZ (2008) Nutrient utilisation and intestinal fermentation are differentially affected by the consumption of resistant starch varieties and conventional fibres in pigs. Brit J Nutr 99:984-992

Rijnen MMJA, Dekker RA, Bakker GCM, Verstegen MWA, Schrama JW (2001) Effects of Dietary Fermentable Carbohydrates on the Empty Weights of the Gastrointestinal Tract in Growing Pigs. In: Lindberg JE, Ogle B (eds) Digestive Physiology of Pigs, Proceedings of the 8th Symposium, CAB International, Walingford United Kingdom, pp 17-20

Rinaldo D, Le Dividich J, Noblet J (2000) Adverse effects of tropical climate on voluntary feed intake and performance of growing pigs. Livest Prod Sci 66:223-234

Rose CJ, White GA (1980) Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (Ipomoea batatas) by village pigs. PNG Agr J 31:69-72

Rose CJ, Williams WT (1983) Ingestion of Earthworms, Pontoscolex corethrurus, by Village Pigs, Sus Scrofa papuensis, in the Highlands of Papua New Guinea. Appl Anim Ethol 11:131-139

Sarkiyayi S, Agar TM, (2010) Comparative analysis on the nutritional and anti-nutritional contents of the sweet and bitter cassava varieties. Afr J Food Sci Tech 2(6):328-334

Sarkiyayi S, Hamman BM (2015) Nutritional Evaluation of some Cereals and Tubers

Sauer WC, Mosenthin R, Ahrens F, Den Hartog LA (1991) The effect of source of fibre on ileal and fecal amino acid digestibility and bacterial nitrogen excretion in growing pigs. J Anim Sci 69:4070-4077

Schulze H, van Leeuwen P, Verstegen MWA, Huisman J, Souffrant WB, Ahrens F (1994) Effect of level of dietary neutral detergent fibre on ileal apparent digestibility and ileal nitrogen losses in pigs. J Anim Sci 72:2362-2368

Schulze H, van Leeuwen P, Verstegen MWA, van den Berg JWO (1995) Dietary Level and Source of Neutral Detergent Fibre and Ileal Endogenous Nitrogen Flow in Pigs. J Anim Sci 73:441-448

Scott G, Best G, Rosegrant MW, Bokanga M (2000a) Roots and tubers in the global food system, International Food Policy Research Institute, Washington, USA

Scott G, Rosegrant MW, Ringler C (2000b) Global projections for root and tuber crops to the year 2020. Food Policy 25:561-597

Siba PM, Pethick DW, Hampson DJ (1996) Pigs experimentally infected with Serpulina hyodysentriae can be protected from developing swine dysentery by feeding them a highly digestible diet. Epidemiol Infect 116:207-216

Spencer PBS, Hampton J, Lapidge SJ, Mitchell J, Lee J, Pluske JR (2006) An assessment of the genetic diversity and structure within and among populations of wild pigs (Sus scrofa) from Australia and Papua New Guinea. J Genet 85(1):63-66

Sugahara DH, Baker DH, Harman BG, Jensen AH (1970) Effect of ambient temperature on performance and carcass development in young swine. J Anim Sci 31:59-62

Suiryanrayna MVAN, Ramana JV (2015) A review of the effects of dietary organic acids fed to swine. J Anim Sci Biotechnol. doi 10.1186/s40104-015-0042-z

Susenbeth A, Dickel T, Diekenhorst A, Höhler D (1999) The effect of energy intake, genotype, and body weight on protein retention in pigs when dietary lysine is the first-limiting factor. J Anim Sci77:2985-2989

Takahata Y, Noda T, Sato T (1995) Changes in Carbohydrates and Enzyme Activities of Sweet Potato Lines during Storage. J Agr Food Chem 43:1923-1928

Taylor AJ, Cole DJA, Lewis D (1979) Amino acid requirements of growing pigs. 1. Effect of reducing protein level in diets containing high levels of lysine. Anim Prod 29:327-338

Teka A, Emire AA, Haki GD, Gezmu TB (2013) Effects of processing on physicochemical and anti-nutritional factors of cassava (Manihot Esculenta Crantz) grown in Ethiopia. Int. J. Sci. Innovations Discoveries 3(2):212-222

Thompson J (2009) Feed-associated colitis of growing pigs and its interaction with enteric infections. Acta Sci Vet 37(1):1-9

Tian SJ, Rickard JE, Blanshard JMV (1991) Physicochemical properties of sweet potato starch. J Sci Food Agric 57:479-491

Tomita Y, Hayashi K, Hashizume T (1985) Palatability of pigs to sweet potato-silage and digestion trial by them. Bull. Fac. Agr. Kagoshima Univ. No. 35:75-80

Tzudir I, Savino N, Das KC (2012) Effect of replacement of maize with tapioca (Manihot esculenta) root meal on the performance of growing crossbred pigs. LRRD http://www.lrrd.org/lrrd24/11/tzud24197.htm. Accessed 2 June 2013

Van der Meulen J, Bakker GCM, Bakker JGM, de Visser H, Jongbloed AW, Everts H (1997) Effect of Resistant Starch on Net Portal-Drained Viscera Flux of Glucose, Volatile Fatty Acids, Urea, and Ammonia in Growing Pigs, J Anim Sci 75:2697-2704

Van Milgen J, Noblet J (1999) Energy partitioning in growing pigs: the use of a multivariate model as an alternative for the factorial analysis. J Anim Sci 77:2154-2162

Van Milgen J, Noblet J, Dubois S (2001) Energetic efficiency of starch, protein, and lipid utilization in growing pigs. J Nutr 131:1309-1318

Varel VH, Pond WG, Pekas JC, Yen JT (1982) Influence of high-fibre diet on bacterial populations in gastrointestinal tracts of obese- and lean-genotype pigs. Applied Environmental Microbiology 44(1):107-112

Verstegen MWA, Brandsma HA Mateman G (1982) Feed requirement of growing pigs at low environmental temperature. J Anim Sci 55(1): 88-94

Verstegen MWA, Brandsma HA, Mateman G, von der Hel W (1984) Effect of cold thermal environment on feed requirements, growth rate and slaughter quality in pigs. Archiv Exp Vet 38:431-438

Von Heimendahl E, Breves G, Abel H (2010) Fibre-related digestive processes in three different breeds of pigs. J Anim Sci 88: 972-981

Wang H-Y, Yeh K-W (1996) Cultivar Differences in Trypsin Inhibitory Activities of Sweet Potato Leaves and Tuberous Roots. Taiwania 41(1): 24-27

Waramboi JG, Dennien S, Gidley MJ, Sopade PA (2011) Characterization of sweet potato from Papua New Guinea and Australia: Physiological, pasting and gelatinisation properties. Food Chem 126:1759-1770

Watt IR, McKillop RF, Penson PJ, Robinson NA (1977) Pigs, Rural Development Handbook no. 5, Department of Primary Industries Rural Development Series, Port Moresby

Wenk C (2001) The role of dietary fibre in the digestive physiology of the pig. Anim Feed Sci Tech 90: 21-23

Whittemore CT, Green DM, Knap PW (2001) Technical review of the energy and protein requirements of growing pigs: energy. Anim Sci 73:199-215

Wickramasinghe HAM, Takigawa S, Matsuura-Endo C, Yamauchi H, Noda T (2009) Comparative analysis of starch properties of different root and tuber crops of Sri Lanka. Food Chem 112:98-103

Wilfart A, Montagne L, Simmins H, Noblet J, van Milgen J (2007a) Effect of fibre content in the diet on the mean retention time in different segments of the digestive tract in growing pigs. Livest Sci 107:27-29

Wilfart A, Montagne L, Simmins PH, van Milgen J, Noblet J (2007b) Sites of nutrient digestion in growing pigs: Effect of dietary fibre. J Anim Sci 85: 976-983

Wiseman J (2006) Variations in starch digestibility in non-ruminants, Anim Feed Sci Tech 130:66-77

Yen JT (1991) Surgical techniques. In: Miller D, Ullrey E, Lewis AJ (eds) Swine Nutrition, Butterworth-Heinmann, Boston, pp 649-661

Yen JT (1997) Oxygen consumption and energy flux of porcine splanchic tissues. In: JP Laplace JP, Fevrier C, Barbeau A (eds) Proceedings of VII International Symposium on Digestive Physiology in Pigs, European Association for Animal Production Publication 88, Institut National de la Recherche Agronomique, Paris, pp 260-269

Yen JT, Nienaber JA, Hill DA, Pond WG (1991) Potential contribution of absorbed volatile fatty acids to whole-animal energy requirement in conscious swine. J Anim Sci 69:2001-2012

Zebrowska T, Low AG, Zebrowska H (1983) Studies on gastric digestion of protein and carbohydrate, gastric secretion and exocrine pancreatic secretion in the growing pig. Brit J Nutr 49:401-410

Zijlstra RT, Jha R., Woodward AD, Fouhse J, van Kempen TATG (2012) Starch and fibre properties affect their kinetics of digestion and thereby digestive physiology in pigs. J Anim Sci 90:49-58

Chapter 3: Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat based protein concentrate

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Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate

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ABSTRACT

Sweet potato (SP) roots are highly palatable and digestible for pigs as fresh, boiled, ensiled or dried feed. The form of presentation and blending with other highly digestible protein ingredients could improve nutrient utilization by grower pigs. A metabolic experiment was conducted utilising a 4×4 Latin Square design with four (Landrace×Large White)×Duroc pigs at nine weeks of age (26.5 ± 1.4 kg), where four dietary treatments offered ad libitum over four consecutive eight-day feeding periods tested the hypothesis that there would be no difference in nutrient digestibility and utilization in pigs fed SP roots when prepared as boiled (BR), ensiled (ER) or milled roots (MR) and blended with a complementary protein concentrate, and compared against a standard wheat-based pig feed (STD). SP products were blended with protein concentrate at 570:430 g/kg DM, and provided total lysine:DE ratios of 0.57, 0.58, 0.60 and 0.58 g/MJ DE for BR43, ER43, MR43 and STD respectively. DM intake, ADG and FCR were similar ($p>0.05$) among treatments. Coefficient of apparent total tract digestibility (CATTD) of DM, OM, fibre, calcium, total phosphorus and energy retention (%)

in SP root diets were superior to STD ($p<0.05$). Ash CATTD of ER43 and MR43 were improved over STD whereas BR43 was similar to all three diets. CATTD of fats (EE) was similar. Protein (CP) CATTD of BR43 was superior to MR43 and STD whereas ER43 was similar to the other three diets. N intake (g/d), N digestibility (% intake) and N utilization (% digested) were similar. N retained on STD (30.6 g N/d) and MR43 (30.4 g N/d) were similar. The higher N retention on BR43 (35.4 g N/d) and ER43 (35.8 g N/d) was due to a significant shift in N loss from urine (8.2 and 7.0 g N/d) to faeces (13.7 and 10.1 g N/d) which, combined with greater OM digestibility and energy retention, suggested increased microbial use of N in the hindgut. The SP diets were highly digestible and provided improved nutrient utilization, ADG and FCR in pigs compared to the wheat-based commercial feed.

Keywords: Sweet potato, grower pigs, nutrient utilization

1. Introduction

Sweet potato (Ipomoea batatas L. (Lam)) is a common feed supplement for growing pigs in tropical countries and is economically important in Asia and the Pacific region, e.g., in China, Vietnam, Philippines, Tonga and Solomon Islands (Ochetim, 1993; Peters et al., 2001a). In Papua New Guinea (PNG) sweet potato (SP) is a major staple crop in predominant farming systems practised by about 360,000 rural farming households using SP roots and foliage as livestock feed. SP feed use is influenced by its seasonal availability to rural farmers, shifting food consumption patterns from roots to grains and by the need to replace costly imported feed grains such as wheat and soybean (Scott, 1992 Scott et al., 2000). Current research is aimed at addressing the need to establish appropriate non-ruminant nutrition for production based on local feed resources by adapting suitable technologies for small-scale farmers. A recent technology advance in PNG was the introduction of ensiled sweet potato for feeding to pigs from techniques adapted and proven in Vietnam (Peters et al., 2001b).

Importantly, there is a need to establish benchmark performance for commercial and the local mixed genotype pigs fed local feeds under PNG's varied production environments. Diets based on local feed ingredients may fail to supply the pigs nutrient requirements so benchmarking SP-based diets using commercially bred pigs would provide better assessment of the nutritional requirements of local crossbred pigs fed similar blended diets. A diet containing SP root meal at 350 g/kg DM provided nutrient and energy content on par with complex diets of grain feeds (Noblet et al., 1993), and up to 400 g/kg provided good carcass results (Manfredini et al., 1993), while 540 and 580 g/kg were recommended for grower and fattener phase, respectively (Gonzaléz et al., 2002). Preliminary testing of blended SP diets with either boiled or ensiled roots demonstrated high faecal digestibilities and improved N retained (g/d) at lower protein levels (Dom and Ayalew, 2009a). Nevertheless, feeding SP root diets resulted in variable performances in local mixed genotype pigs (Dom and Ayalew, 2010; Dom et al., 2010; 2011) similar to those reported in the literature (e.g. An et al., 2004; Gonzaléz et al., 2002; Giang et al., 2004). However, improved grower performance can be ensured by better nutrition through the use of complementary protein concentrates.

A concentrate containing protein meals, synthetic amino acids, vitamins, minerals, mould inhibitors, antioxidants and essential medications was formulated to complement SP roots of a popular and abundantly available cultivar commonly referred to as ‘Rachel White’. The blended SP diets used SP roots that were either boiled or ensiled or as dried and milled roots were tested on commercial bred grower pigs for apparent total tract digestibility of nutrients, energy utilization, N-balance, growth, and feed efficiency compared against a standard pellet feed. The experiment tested the hypothesis that there would be no difference in nutrient digestibility and utilization in pigs fed 570 g/kg DM of the diet as SP roots with 430 g/kg DM wheat-based protein concentrate compared to a standard grower pig diet.

2. Methods and Materials

2.1 Experiment location and design

This research was conducted at the PNG National Agricultural Research Institute (NARI) Labu Livestock Research Station, Morobe Province (6° 40’ 27” S, 146° 54’ 33” E). The local climate is typically warm and wet with average daily temperatures averaging 30°C with 84% relative humidity. The metabolic experiment was conducted in a 4×4 Latin Square design with four diets as interchanged treatments fed to four grower pigs over four consecutive 8-day feeding periods

2.2 Experiment animals

Four (Landrace×Large White)×Duroc castrate male grower pigs with similar body weight (26.5 ± 1.4 kg) were selected and placed into individual metabolic cages for experimental feeding. On d 5 and d 8 of consecutive periods each pig was removed from its cage for weighing to an accuracy of 0.01 kg. Pigs were managed according to the animal welfare guidelines (NHMRC, 2013) prescribed the University of Adelaide Animal Ethics Committee.

2.3 Metabolic cages

Metabolic cages 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. Collected urine was removed regularly during each sampling day and stored in sealed glass bottles at 4°C for pooling at the end of three days and freezing of the total pooled samples. Each cage was placed in the centre of a concrete pig pen in an open-sided shed. Four fans were placed at the head of each cage to provide cooling air movement for the pigs for the dudiet of the experiment. During the experiment, minimum and maximum shed temperatures were 21°C and 32°C, respectively. Relative humidity ranged from 77% to 90% (NARI weather station).

2.4 Treatment diets

The experimental treatments diets were formulated according to available nutritional data from NRC (1998), a nutritional database at Carey Animal Nutrition. Wheat grain, soybean meal and essential amino acids and micronutrients were imported products. All other ingredients were available locally to the feed producer. A commercial grower pig pellet feed was used as the standard diet (STD) for comparison with nutritionally balanced diets made from SP blended with Pig Conc.1. Blended diets consisted of 570 g/kg SP feed and 430 g/kg Pig Conc.1 on a DM basis. SP roots from an identified local cultivar, Rachel White, were sourced from Lae Town Main Market. Chemical analysis of the blended ingredients confirmed the nutrient content of the formulated diets (Table 1). Leucine, lysine, methionine,

methionine+cysteine (Met+Cys), threonine and tryptophan and dietary fibre, as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (Lignin), were calculated from the combined formulation ingredients of Pig Conc.1 (Carey Animal Nutrition) and published values for sweet potato roots from Feedipedia.com (Heuzé et al., 2015).

The processing of feed components for each SP diet was as follows. The roots were divided into three groups for boiling, milling and drying into a meal, or for ensiling. SP roots stored in large hessian sacks were briefly soaked in water and the dirt washed off before being chopped into large irregular chunks (<200 g). To prepare SP boiled roots (BR), about 4.5 kg of root were placed into clean water sufficient to cover the pieces; salt was added at ~20 g (0.5% wt/wt) to the total mass, with each boiled root prepadiet reweighed to provide 2 kg DM. The chopped roots were placed in cool water in a 15 L steel pot, placed on a gas stove and cooked for 45 mins. Ensiling methods were modified from Peters et al. (2001b). To prepare the ensiled feed (ER) SP roots were milled using a modified flake mill (Project Support Services (PSS) Ltd, Lae) producing crumbled material of varying sizes less than 1 to 2 cm3, 0.5% w/w salt was added to the freshly milled material, which was then immediately packed and sealed in 80 L plastic bin silos lined with polyethylene Tuffa® garbage bags. Acidity in ensiled SP roots was measured at pH 4.0 when silo bins were opened after at least 14 d of fermentation and was assessed visually to have maintained a good quality for the dudiet of testing. To prepare milled SP roots (MR), cleaned fresh roots were grated using a modified flake mill (Project Support Services Ltd) then sun-dried for an initial period of 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 (PSS Ltd) to provide a coarse crumble texture (~5 mm pieces). Salt (0.5% w/w) was added to MR during mixing with protein concentrate. The standard grower feed pellets were also roller milled to a coarse crumble texture (from ~10 mm to ~5 mm pieces). Dry and ensiled SP feed were stored in silo bins in a cool, dry shed for daily prepadiet. The STD and Pig Conc.1 were stored as received in hessian bags and opened bags were kept in two large bins fitted with lids.

Table 1

Analysed and calculated nutrient composition in the SP roots either boiled (BR), ensiled (ER) or milled (MR) and complementary protein concentrate (Pig Conc.1), blended SP treatment diets BR43, ER43 and MR43, and standard grower pig feed, STD

Nutrients	**Components**				**Treatments**			
	BR	**ER**	**MR**	**Pig Conc.1**	**BR43**	**ER43**	**MR43**	**STD†**
Anaysed composition(g/kg)								
DM (as fed)	377	316	835	879	593	558	854	880
OM	368	304	817	791	550	513	806	816
CP	10	9.7	24	329	147	147	155	165
EE	4.9	3.7	6.8	44	22	21	23	38
CF	9	9	16	41	23	23	27	56
Ash	9	12	18	88	43	45	48	64
Calcium	0.9	0.9	0.9	18.0	83	83	83	92
Total P	1.1	0.9	1.6	9.7	4.8	4.7	5.1	9.7
Total N	1.6	1.6	3.8	52.6	23.5	23.5	24.8	26.4
Calculated composition(g/kg)								
Leucine	0.5	0.5	1.3	23.4	10.8	10.8	11.2	10.3
Lysine	0.4	0.4	0.9	20.3	9.4	9.3	9.6	8.6
Methionine	0.1	0.1	0.3	8.2	3.7	3.7	3.8	2.4
Met+Cys	0.3	0.3	0.6	12.6	5.9	5.9	6.0	5.3
Threonine	0.5	0.5	1.3	11.8	5.6	5.6	6.0	5.1
Tryptophan	0.07	0.07	0.17	3.5	1.6	1.6	1.7	1.7
DE (MJ/kg)	16.9	16.7	16.4	15.6	16.3	16.2	16.1	14.8
Lys:DE (g/MJ)*	0.02	0.02	0.05	1.30	0.57	0.58	0.60	0.58
Ca:P*	0.82	1.00	0.56	1.86	1.72	1.76	1.62	0.94
NDF	43	36	94	179	101	97	131	277
ADF	20	16	43	59	37	35	50	81
Lignin	4	3	9	14	9	8	11	23
Starch	261	219	579	146	212	187	392	312
Total sugars	34	29	76	41	37	34	61	47

Ingredient composition of commercial †standard grower pig feed: Wheat grain 312 g/kg, Meat meal 52.5 g/kg, Fish meal (PNG) 20 g/kg, Wheat millrun (PNG) 600 g/kg, Limestone fine 5 g/kg, Salt 1.5 g/kg, Choline chloride (75%) 0.5 g/kg, Lysine HCl 0.2%, Pig Premix‡ 5 g/kg, Mycostat 0.5 g/kg, Sorbasafe 1 g/kg. Ingredient composition of Pig Conc.1: Wheat grain, 120 g/kg, Meat meal 130 g/kg, Blood meal 50 g/kg, Fish meal (PNG) 100 g/kg, Tallow 40 g/kg, Soybean meal 180 g/kg, Wheat millrun (PNG) 358 g/kg, Salt 30 g/kg, Choline chloride (75%) 1 g/kg, Rhodimet-88 Liquid (Methionine) 4 g/kg, Lysine HCl 1 g/kg, Pig Premix† 10 g/kg, Mycostat 1 g/kg, Sorbasafe 2 g/kg. ‡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, Surmax200 75.0 g, Mold Inhibitor 500.0 g, Rovabio Excel AP T-Flex 50.0 g.

*Ratios calculated on DM basis using the respective nutrient and energy values in this table.

2.5 Feed offer, refusal collection and pig welfare

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 5 ± 0.005 kg) fresh to make blended diet weights equivalent to 2 kg DM diet per offer at the first period, 3 kg DM for the second and 4 kg DM diet in the third and last periods, ensuring that the pigs were fed to satisfaction. 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 down every morning and metabolic cages cleaned daily. Mist spray was provided by hand as required. Clean piped rain water was available at all times through steel-nipple drinkers placed next to the feeding trough.

2.6 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.

2.7 Chemical analysis of samples

Chemical proximate analysis of feed, faeces and nitrogen in urine was 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 determined 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) determined as the ether extracts (EE) in diethyl ether evaporated by Soxhlet apparatus. Fibre was determined as crude fibre (AOAC 978.10) was 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). Calcium (AOAC 927.02) was determined by Atomic Absorption Spectrophotometry (AAS240FS). Phosphorus was determined as total P (AOAC 964.06) by spectrophotometry (Shimadzu UV1800). Organic matter (OM) was calculated by OM%=DM%–Ash%. Digestible Energy (DE) was calculated according to Noblet and Perez (1993), where DE (kCal)=4,151–(122×Ash%)+(23×CP%) +(38×EE%)–(64×CF%), R2=0.89, and converted to MJ/kg.

2.8 Statistical analysis

Suitability of the small sample size, a priori and post hoc power was 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 coefficient of apparent total tract digestibility CATTD 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. N balance (g/d) parameters were determined by using DM intake and N intake as covariates for N intake, N faeces and N digested, and N digested for N urine, and N retained.

3. Results

3.1 Feed intake and growth

The SP diets were 10 to 18 g/kg lower in protein, 0.7 to 1.0 g/kg higher in lysine than STD but provided 1.3 to 1.5 MJ/kg higher DE, with the resulting lysine:DE ratio about 0.6 g/MJ (Table 1). Methionine was 1.4 g/kg lower in STD and there were smaller differences in leucine, methionine+cysteine, threonine and tryptophan. Starch and dietary fibre content of MR43 and STD were much higher than BR43 and MR43. Table 2 displays the results of pig performance, nutrient digestibility, energy utilization and N balance. The overall mean DM feed intake of diets was similar ($p<0.05$) despite bulkiness of the BR43 and ER43 diets. There was 35.6% correlation of DM feed intake to minimum daily shed temperature ($r2=0.1267$, one-tailed $p<.0001$), but only 5.1% correlation for maximum temperature ($r2=0.0026$, one-tailed $p=0.2815$). ADG and FCR were similar among treatments. Faecal DM output was significantly higher on STD. There were no other measurements of faecal consistency. There was a large variation in urine output (cv=32%) with similar means.

3.2 Digestibility and N Balance

Nitrogen intake (g/d) was similar across all diets. MR43 and STD had significantly lower N losses in faeces (g/d), but higher urine N loss than BR43 and ER43. Digested N (g/d) from MR43 and STD was higher but the N retained (g/d) were lower than BR43 and ER43. N digestibility (% intake) and utilization (% digested) were similar across all four diets.

Coefficients of apparent total tract digestibility (CATTD) of DM, OM, fibre, calcium, total phosphorus and energy retention (%) in SP root-based diets were superior to STD. Ash CATTD of ER43 and MR43 were improved over STD whereas BR43 was similar to all three diets. CATTD of fats (ether extracts) was similar on all diets. Protein CATTD of BR43 was superior to MR43 and STD whereas ER43 was similar to the other three diets.

Table 2

Coefficients of apparent total tract digestibility (CATTD) of nutrients and energy utilization and N balance for blended SP root diets fed to (Large White×Landrace)×Duroc grower pigs (26.5 ± 1.4 kg) in metabolic trial

Parameter	**Treatment means**				**SEM**	**Sig.**
	BR43	**ER43**	**MR43**	**STD**		
Coefficients of apparent total tract digestibility						
DM	0.922^{b}	0.909^{b}	0.880^{b}	0.758^{a}	0.0175	*
OM	0.898^{b}	0.865^{b}	0.889^{b}	0.775^{a}	0.0170	**
CP	0.890^{b}	0.853^{ab}	0.810^{a}	0.818^{a}	0.0107	**
EE	0.740	0.803	0.750	0.681	0.0350	ns
Fibre	0.620^{b}	0.703^{b}	0.630^{b}	0.358^{a}	0.0405	**
Ash	0.703^{ab}	0.789^{b}	0.733^{b}	0.595^{a}	0.0262	**
Calcium	0.858^{b}	0.850^{b}	0.846^{b}	0.757^{a}	0.0136	**
Total P	0.774^{b}	0.788^{b}	0.730^{b}	0.616^{a}	0.0185	**
Energy	0.944^{b}	0.934^{b}	0.905^{b}	0.827^{a}	0.0126	**
Feeding and growth performance						
Mean BW (kg)	38.9	35.9	38.0	37.1	1.47	ns
DMI (g/d)	2,390	1,971	2,163	2,222	143.2	ns
ADG (g/d)	1,255	1,239	1,158	1,193	80.4	ns
FCR (DM basis)	1.99	1.67	1.84	1.84	0.137	ns
Faeces DM (g/kg)	268^{a}	273^{a}	264^{a}	460^{b}	28.5	**
Urine output (mL)	2,099	2,148	1,437	1,116	272.6	ns
N balance (g/d)[§]						
N Intake	53.8	51.1	50.3	53.0	4.96	ns
N Faeces	13.7^{b}	10.1^{ab}	8.8^{a}	6.5^{a}	0.72	**
N Digested	38.8^{a}	42.2^{ab}	43.5^{b}	45.9^{b}	0.71	**
N Urine	8.2^{ab}	7.0^{b}	11.2^{bc}	13.9^{c}	0.68	***
N Retained	35.4^{b}	35.8^{c}	30.6^{a}	30.4^{a}	0.05	***
N digestibility (%)[†]	72.5	77.7	71.9	66.3	3.14	ns
N utilization (%)[‡]	82.5	88.7	88.4	80.5	3.29	ns

Means with different superscripts are significantly different at p<0.05.
Significance, ***p<0.001, **p<0.01, *p<0.05, ns is not significant.
[†] N digestibility (%) was N retained (g/d) as a percentage of N intake (g/d).
[‡] N utilization (%) was N retained (g/d) as a percentage of N digested (g/d).
[§] N balance parameters were assessed by covariate analysis.

4. Discussion

Sweet potato root-based diets (BR43, ER43 and MR43) provided equivalent growth rates and feed conversion efficiency to the wheat-based grower pig feed used as a standard (STD). However, the CATTD of nutrients and energy retention (%) by the commercial breed grower pigs fed on boiled, ensiled or milled SP root diets were higher compared to the standard feed. CATTD of nutrients in the tested diets was in agreement with the literature. Similarly, cooked (Canope et al., 1977), ensiled (Tomita et al., 1985) and dried sweet potato chips (Noblet et al., 1990) provided very palatable and highly digestible diets for crossbred grower pigs of improved genotypes. The rate of inclusion of SP root blended was within the recommendation by Gonzaléz et al. (2002). Cooking SP roots improved the digestibility of N (Canope et al., 1977) and although trypsin inhibitors may reduce protein digestibility in ensiled SP roots (Lin et al., 1988) the higher DE improved feed efficiency but at reduced feed intake (Tomita et al., 1985). Whereas SP roots provided the major DE source, the wheat-based protein concentrate (Pig Conc.1) provided a sufficient source of protein, amino acids and micronutrients to complement deficiencies in the SP roots. Nutrient digestibility was probably reduced by higher dietary fibre (NDF, ADF and lignin) in STD and MR43, but not in BR43 and ER43. Insoluble fibre does not affect ileal digestion (Bach Knudsen and Hansen, 1991ab) whereas soluble fibre may reduce nutrient absorption but starch is not affected (Bach Knudsen and Hansen, 1991b; Johansen and Bach Knudsen, 1994). Although not documented, a slower rate of passage was observed for the blended SP roots diets during the sample collection phase, and this may have had implications on nutrient absorption and fermentation in the fore and hindgut (Johansen and Bach Knudsen, 1994; Ngoc et al., 2013). Soluble fibres are fermented in the large intestine thereby contributing to DE (Johansen and Bach Knudsen, 1994) as was reflected in the high energy retention on SP root diets in this work. DM intake on the diets was similar so it is likely that solubility of starch and non-starch polysaccharides was increased in the boiled or ensiled (fermented) roots (Barampama and Simard, 1995; Bradbury et al., 1988). This provided pig growth rate equal to the STD standard feed but at lower dietary protein level.

When offered SP root diets pig growth and feed efficiency as well as N digestibility (%) and utilization (%) were on par with the standard diet. An incrementally higher N excretion (g/d) in the faeces from BR43 and ER43 diets along with a significant reduction in urine N losses (g/d) may indicate increased endogenous N losses (from sloughed cells, bile, gastric juices and enzymes) as a result of the higher DM intake (Moter and Stein, 2004; Low, 1989), or bacterial protein N contribution (Dierick et al., 1989; Tetens et al., 1996). The negative N balance on the SP root diets indicates addition of N to the faeces bulk from microbial sources. Higher OM CATTD on SP root diets also suggested increased hindgut fermentation (Dierick et al., 1990). Moreover, in spite of higher faeces output on the standard diet, the faecal N was less. High N retained (g/d) on the blended SP root diets in the current work compared favourably with grain-based diets containing different dietary fibres (Hansen et al., 2006), fed in either mashed or pellet form (Le Gall., 2009). The commercial grower pig feed, based on 91.2% wheat and wheat by-products, afforded higher fibre content (277 g/kg NDF) than SP roots (36 to 94 g/kg NDF) whereas Pig Conc.1 (179 g/kg NDF) provided much of the dietary fibre (NDF, ADF and lignin) to the blended SP diets. OM CATTD and energy retention (%) was reduced on standard diet and milled SP roots with higher NDF content, which was in agreement with previous findings (Hansen et al 2006; Noblet and Le Goff, 2001).

Digestible energy and lysine were slightly higher in the blended SP root diets than in the standard diet. However, the treatment diets provided about 8.6 - 9.6 g/kg total lysine and 0.6 g total lysine/MJ DE, which corresponds to 0.45 g standard ileal digestible (SID) Lys/ MJ DE. This lysine:DE ratio was much lower than the optimum level recommended for similar crossbred genotypes (Moore et al., 2013a). Nevertheless, the high growth rates and feed efficiencies suggest that it may be possible to reduce the level of protein concentrate blended with SP while maintaining feed efficiency (Dominguéz and Ly, 1997) and pig growth (Kerr et al., 2003), provided that lysine is not limiting (Kyriazakis and Emmans, 1995). Maintaining an adequate supply of amino acids while lowering protein level will reduce N excretion without affecting animal performance and improve energy utilization (Bellego et al., 2001). The improved crossbred pig performance on SP-based diets was supported by improved availability of DE from SP roots at slightly higher lysine and methionine content to STD. Bulky feeds such as SP reduce nutrient intake (Bindelle et al., 2008), but the improved nutrient utilization in pigs fed on ensiled SP roots in particular may be related to a lower energy requirement for digesting fermented carbohydrates (starch and non-starch polysaccharides) (Choct, 2001), a prebiotic effect from lowered gut pH (Lindberg, 2014) and a greater availability of energy from VFAs providing an energy increment for growth (Dierick et al., 1989). The influence of different SP dietary fibre fractions on nutrient digestibility and utilization is an element worth further investigation.

The digestibility of these blended SP root diets fed to the mixed local genotype pigs farmed in PNG may vary and growth is likely to be reduced in different environments. Earlier work with PNG village pigs, which were hybrids of native and introduced genotypes, revealed a natural ability to perform reasonably well on lower nutrient diets of SP forage (Malynicz and Nad, 1973; Rose and White, 1980). However, the modern strains of local mixed genotype pigs may be improved by breeding for enhanced capacity for digesting dietary fibre (Noblet et al., 2013; Lindberg, 2014). While the growth rate of pigs in penned conditions may be lowered from our current caged estimated ADG, blend-feeding has proved economical compared to single feed and phase feeding options (Moore et al., 2013b; Mullan et al., 1997) and this seems likely given the very high feed efficiency achieved by the commercial grower pigs. Economic assessment should be made to determine the incremental benefit-cost of SP blended feed diets which may replace up to 70% in total of the imported wheat grain and wheat millrun used in a commercially available pellet feed, as was found by Gonzaléz et al (2002). There is scope for investigating improved nutrition of local mixed genotype pigs fed on similar diets containing local forage ingredients blended with complementary concentrate feeds. Further SP blended diets should be investigated for gilts/sows and weaner piglets to provide reduced cost feeding options for small-scale producers.

Conclusions

Sweet potato as boiled, ensiled or milled roots blended with a complementary protein concentrate provided highly digestible diets as a result the nutrient utilization provided growth rates and feed efficiency that were similar to a wheat-based commercial feed offered to growing pigs. Production animal performance and economic assessments of feed storage and feeding systems are needed to take advantage of the nutrition afforded by similar blended diets.

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Conflict of interest

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

References

An, L.V., T.T.T. Hong, Lindberg, J.E., 2004. Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (*Ipomoea batatas* L. (Lam.)) leaves. Anim. Feed Sci. Technol. 114, 127–139.

AOAC, 2012. Official Methods of Analysis. 19thed. Association of Official Analytical Chemists, Gaithersburg, Maryland.

Bach Knudsen, K.E., Hansen, I., 1991a. Gastrointestinal implications in pigs of wheat and oat fractions 1. Digestibility and bulking properties of polysaccharides and other major constituents. Br. J. Nutr. 65, 217–232.

Bach Knudsen, K.E., Jensen, B.B., Andersen, J.O., Hansen, I., 1991b. Gastrointestinal implications in pigs of wheat and oat fractions 2. Microbial activity in the gastrointestinal tract. Br. J. Nutr. 65, 233–248.

Barampama, Z., Simard, R.E., 1995. Effects of soaking, cooking and fermentation on composition, in-vitro starch digestibility and nutritive value of common beans. Plant Foods Hum. Nutr. 48, 349–365.

Bellego, L.L., van Milgen, J., Dubois, S., Noblet, J., 2001. Energy utilization of low-protein diets in growing pigs. J. Anim. Sci. 79, 1259–1271.

Bindelle, J., Laterme, P., Buldgen, A., 2008. Nutritional and environmental consequences of dietary fiber in pig nutrition: a review. Biotechnol. Agron. Soc. Environ. 12, 69–80.

Bradbury, J.H., Bradshaw, K., Jealous, W., Holloway, W.D., Phimpisane, T., 1988. Effect of Cooking on Nutrient Content of Tropical Root Crops from the South Pacific, J. Sci. Food Agr. 43, 333–342.

Canope, J., Le Dividich, J., Hedreville, F., Despois, F., 1977. Influence d'un traitement technologique sur l'efficacité alimentaire des principaux produits amylacés tropicaux: patate douce et banane dans l'alimentation du proc. Nouvelles agronomiques des Antilles et de la Guyane. 3(3/4): 310-322.

Choct, M., 2001. Carbohydrate and fiber digestion in monogastric animals, American Soybean Association, Technical Bulletin, MITA (P) NO. 070/10/2001, AN34-2001.

Dierick, N.A., Vervaeke, I.J., Demeyer, D.I., Decuypere, J.A., 1989. Approach to the energetic importance of fiber digestion in pigs. I. Importance of fermentation in the overall energy supply. Anim. Feed Sci. Technol. 23, 141–167.

Dierick, N.A., Vervaeke, I.J., Decuypere, J.A., Hendrickx, H.K., 1990. Bacterial protein synthesis in relation to organic matter digestion in the hindgut of growing pigs; contribution of hindgut fermentation to total energy supply and growth performances. J. Anim. Physiol. A. Anim. Nutr. 63, 220–235.

Dom, M., Ayalew, W., 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. J. Inst. Chem. PNG 2, 77–88.

Dom, M., Ayalew, W., 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. PNG J. Res. Sci. and Technol. 1, 86–96.

Dom, M., Ayalew, W., 2010. Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. JOSPA. 14, 78–86.

Dom, M., Ayalew, W., Amben S., 2010. Development of Improved Pig Feeding Systems Using Ensiled Material: On-farm testing of feeding Sweet Potato silage to growing pigs at Tambul in Western Highlands Province. Sci. New Guinea. 30, 94–104.

Dom, M., Ayalew, W., Tarabu. J., 2011. Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG). JOSPA. 15, 62–70.

Dominguéz, P.L., Ly, J., 1997. An approach to the nutritional value for pigs of sweet potato (*Ipomoea batatas* L. (Lam)), LLRD. 9(2). http://www.lrrd.org/lrrd9/2/ly92.htm/ (accessed 13.06.02).

Giang, H.H., Ly, L.V., Ogle, B., 2004. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. LRRD. 16(50). http://www.lrrd.org/lrrd16/7/gian16050.htm. Retrieved June 2, 2013, Gonzaléz, C., Díaz, I., Milagro, L., Vecchionacce, H., Alexia, B., Ly, J., 2002 Growth performance and carcass traits in pigs fed sweet potato (*Ipomoea batatas* L. (Lam.)) root meal. LRRD. (14)6. http://www.lrrd.org/lrrd14/6/gonz146.htm/ (accessed 13.06.02).

Hansen, J.A., Chwalibog, A., Tauson, A.H., Sawosz, E., 2006. Influence of different fiber sources on digestibility and nitrogen and energy balances in growing pigs. Arch. Anim. Nutr. 60, 390–401.

Heuzé, V., Tran, G., Hassoun, P., Renaudeau, D., Bastianelli, D., 2015. Sweet potato (*Ipomoea batatas*) tubers. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://feedipedia.org/node/745/ (accessed 15.12.15).

Johansen, H., Bach Knudsen, K.E., 1994. Effects of wheat-flour and oat mill fractions on jejunal flow, starch degradation and absorption of glucose over an isolated loop of jejunum in pigs. Br. J. Nutr. 71, 299–313.

Kerr, B.J., Southern, L.L., Bidner, T.D., Friesen, K.G., Easter, R.A., 2003. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. J Anim. Sci. 81, 3075–3087.

Kyriazakis, I., Emmans, G.C., 1995. Do breeds of pig differ in the efficiency with which they use a limiting protein supply? Brit. J. Nutr. 74, 183–195.

Le Gall, M., Warpechowski, M., Jaguelin-Peyraud, Y., Noblet, J., 2009. Influence of dietary fiber level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. Animal. 3, 352–359.

Lin, Y.H., Huang, T.C., Huang, C., 1988. Quality improvement of sweet potato (*Ipomoea batatas* L. (Lam.)) roots by ensilage. Brit. J. Nutr. 60, 173–184.

Lindberg, J.E. 2014. Fiber effects in nutrition and gut health in pigs. J. Anim. Sci. Biotechnol. 5:15. http://www.jasbsci.com/content/5/1/15 (accessed 15.04.04).

Low, A.G., 1989. Secretory response of the pig gut to non-starch polysaccharides. Anim. Feed Sci. and Technol. 23, 55–65.

Malynicz, G., Nad, H., 1973. The effect of level of feeding and supplementation with sweet potato foliage on the growth performance of pigs. PNG Agr. J. 24, 139–144.

Manfredini, A., Badiani, A., Chizzolini, R., 1993. Sweet potato chips in heavy pig production. Livest. Pro. Sci. 35, 329–340.

Moore, K.L., Mullan, B.P., Kim, J.C., 2013b. Blend-feeding of feeding a single diet to pigs has no impact on growth performance or carcass quality. Anim. Prod. Sci. 53, 67–74.

Moore, K.L., Mullan, B.P., Campbell, R.G., Kim, J.C., 2013a. The response of entire male and female pigs from 20 to 100-kg live weight to dietary available lysine. Anim. Prod. Sci. 53, 52–56.

Moter, V., Stein, H.H., 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs.J. Anim. Sci. 82, 3518–3525.

Mullan, B.P., Pluske, J.R., Hooper, J., White, R.H., 1997. Blend feeding-an economic option for growing pigs. Recent Advances in Animal Nutrition in Australia, pp241.

NRC, 1998. Nutrient Requirements of Swine, tenth ed. National Research Council, National Academy Press, Washington DC, USA.

Ngoc, T.T. B, Len, N.T., Lindberg, J. E., 2013. Impact of fiber intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. Animal 7(5), 736–745. doi: 10.1017/S1751731112002169

NHMRC, 2013. Australian code for the care and use of animals for scientific purposes, eighth ed. National Health and Medical Research Council, Canberra, Australia.

Noblet J., Perez, J.M., 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71, 3389–3398.

Noblet, J., Le Goff, G., 2001. Effect of dietary fiber on the energy value of feeds for pigs. Anim. Feed Sci. and Technol. 90, 35–52.

Noblet, J., Fortune, H., Dupire, C., Dubois, S., 1993. Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: effect of energy system. Anim. Feed Sci. and Technol. 42, 131–149.

Noblet, J., Fortuna, H., Dupire, C., Dubois, S., 1990. Valeur nutritionnelle de treize matieres premieres pour le porc en croissance. 1. Teneurs en energie digestible metabolizable et nette. Consequences du choix du systeme energetique. J. Rech Porc en France. 22, 75–184.

Noblet, J., Gilbert, H., Jaguelin-Peyraud, Y., Lebrun, T., 2013. Evidence of genetic variability for digestive efficiency in the growing pig fed a fibrous diet. Animal. 7(8), 1259–1264.

Ochetim, S., 1993. Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. Asian-Aust. J. Anim. Sci. 6, 347–360.

Peters, D., Tinh, N.N., Thuy, T.T., Thach, P.N., 2001a. Fermented sweet potato vines for more efficient pig raising in Vietnam. AGGRIPPA. FAO, Rome, Italy. Available at www.fao.org.docrep/article/agrippa/x9500e10.htm./ (accessed 15.05.21)

Peters, D., Tinh, N.T., Minh, T.T., Ton, P.H., Yen, N.T., Hoanh, M.T., 2001b. Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam. International Potato Center (CIP), Hanoi, Vietnam.

Rose, C.J., White, G.A., 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. PNG Agr. J. 31, 69–72.

Scott, G. J. H., 1992. Sweet potatoes as animal feed in developing countries: present pattern and future perspectives, in: Machin, D., Nyvold, S., (Eds.), Roots, tubers, plantain and bananas in animal feeding FAO Animal Production and Health Paper No. 95. Rome, pp. 183–202.

Scott, G., Best, G., Rosegrant, M.W., Bokanga, M., 2000. Roots and tubers in the global food system, International Food Policy Research Institute, Washington, USA.

Tetens, I., Livesey, G., Eggum, B.O., 1996. Effects of the type and level of dietary fiber supplements on nitrogen retention and excretion patterns. Br. J. Nutr. 75, 461–469.

Tomita, Y., Hayashi, K., Hashizume, T., 1985. Palatability of pigs to sweet potato-silage and digestion trial by them. Bull. Fac. Agr. Kagoshima Univ. No. 35, 75–80.

Chapter 4: Nutrient utilisation in grower pigs fed boiled, ensiled or milled cassava roots blended with a protein concentrate

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Contribution to the Paper	Conception, designed and conducted the experiment. Data collection, compilation, analysis and interpretation. Drafting and revision of the article.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

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

Michael T. Dom[4], Workneh K. Ayalew[5], Philip C. Glatz[6], Roy N. Kirkwood[7], and Paul E. Hughes[8]

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 diets 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 were blended with a wheat-based protein concentrate (DM Pig Conc.1) at a ratio of 55:45 DM basis, 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;

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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.

Keywords: Apparent total tract digestibility, cassava roots, grower pigs, nitrogen balance

INTRODUCTION

Cassava (Manihotesculenta 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 diets fed to pigs (Pacual-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 including tannins, phytates, oxalates and HCN (Marfo et al., 1990; Teka et al., 2013), which can reduce palatability and digestibility of cassava-based diets. 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 diets, 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 diets 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).

METHODS AND MATERIALS

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 (6° 40’ 27” S, 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 dudiet of the experiment. Close observations were made of the pigs in the crates during sample collection days to ensure clean sepadiet of faeces and urine.

Experiment design and treatment 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 diets 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, 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.

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 at 4 °C before pooling at the end of each period. Dried faeces and urine for each period were pooled and duplicate samples stored in 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 and total phosphorus 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), R2 = 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 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.

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 diet	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 will be added at the same proportion to all diets; acidity in ensiled cassava roots was measured at pH 4.0.

Table 2. Analysed and calculated 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**
Analysed composition (% DM)								
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
Calculated composition(% DM)								
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
Met+Cys[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 Feedipedia.com (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 Feedipedia.com (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).

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 DM intake 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 ($P < 0.05$). Difference in the urine output was 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 pigs

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 pigs

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.**	**Sig.**
	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	***
Growth 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 (DM basis)	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

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 with 55% cassava (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, which agreed with the finding that high ambient temperature (above 32 °C) indirectly reduces feed intake during change in fat: lean gain in growing pigs (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 (NSP) 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 pigs

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). In particular, DMI is not reduced despite the slurry feeding of FLF 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.

CONCLUSIONS

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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ONFLICT OF INTEREST

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

REFERENCES

AOAC. 2012. Official Methods of Analysis. 19thedn. Association of Official Analytical Chemists, Gaithersburg, Maryland, USA.

BACH KNUDSEN, K. E. & HANSEN, I. 1991a. Gastrointestinal implications in pigs of wheat and oat fractions 1. Digestibility and bulking properties of polysaccharides and other major constituents. *British Journal of Nutrition*, **65**: 217-232.

BACH KNUDSEN, K. E., JENSEN, B. B., ANDERSON, J. O., & HANSEN, I. 1991b. Gastrointestinal implications in pigs of wheat and oat fractions 2. Microbial activity in the gastrointestinal tract. *British Journal of Nutrition*, **65**: 233-248.

BARAMPAMA, Z., & SIMARD, R. E. 1995. Effects of soaking, cooking and fermentation on composition, in-vitro starch digestibility and nutritive value of common beans. *Plant Foods for Human Nutrition,* **48**: 349-365.

BELLEGO, L. L., VAN MILGEN, J., DUBOIS, S., & NOBLET, J. 2001. Energy utilisation of low-protein diets in growing pigs. *Journal of Animal Science*, **79**: 1259-1271.

BINDELLE, J., LATERME, P., & BULDGEN, A. 2008. Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. *Biotechnology Agronomy Society and Environment*, **12**(1): 69-80.

BOKANGA, M. 1994. The cyanogenic potential of cassava. Root Crops and Food Security in Africa. In:Akoroda, M. O. (Eds.), *Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch*, Kampala, Uganda. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. pp. 75 and pp. 345.

BOOTH, R. 1976. Storage of fresh cassava (*Manihot esculenta*): I. Post-harvest deteriodiet and its control. *Experimental Agriculture,* **12**: 103-111.

BRADBURY, J. H., & HOLLOWAY, W.D. 1988. Chemistry or Tropical Root Crops: significance for nutrition and agriculture in the Pacific. ACIAR Monograph No.6.

CANIBE, N., & JENSEN, B. B. 2003. Fermented and nonfermented liquid feed to growing pigs: Effect on aspects of gastrointestinal ecology and growth performance. *Journal of Animal Science,* **81**:2019-2031.

DENG, D., HUANG, R. L., LI, T. J., WU, G. Y., XIE, M. Y., TANG, Z. R., KANG, P., ZHANG, Y. M., FAN, M. Z., KONG, X. F., RUAN, Z., XIONG, H., DENG, Z. Y., & YIN, Y-L. 2007. Nitrogen balance in barrows fed low-protein diets supplemented with essential amino acids. *Livestock Science*, **109**: 220-223.

DOM, M., AYALEW, W., GLATZ, P., KIRKWOOD, R., & HUGHES, P. 2014. Effect on nutrient digestibility and nitrogen balance in pigs fed three forms of blended cassava roots. *Proceedings of the 16th Asian Australasian Association of Animal Production Science Congress*, **2**: 676-679.

DOM, M. & AYALEW, W. 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. *Journal of the Institute of Chemists PNG*, **2**: 77-88.

DOM, M. & AYALEW, W. 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. *PNG Journal of Research Science and Technology*, **1**: 86-96.

HANG, D. T. 1998. Digestibility and nitrogen retention in fattening pigs fed different levels of ensiled cassava leaves as a protein source and ensiled cassava root as energy source. *Livestock Research for Rural Developmen*t, **10**(24). http://www.lrrd.org/lrrd10/3/hang1.htm Accessed June 2, 2013.

HANSEN, J. A., CHWALIBOG, A., TAUSON, A. H., & SAWOSZ, E. 2006. Influence of different fibre sources on digestibility and nitrogen and energy balances in growing pigs. *Archives of Animal Nutrition*, **60**: 390-401.

HEUZÉ, V., TRAN, G., HASSOUN, P., RENAUDEAU, D., & BASTIANELLI, D. 2015. Sweet potato (*Ipomoea batatas*) tubers. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://feedipedia.org/node/745 Accessed December 15, 2015.

HODGKINSON, S. M., MOUGHAN, P. J., REYNOLDS, G. W., & JAMES, K. C. A. 2000. The effect of dietary peptide concentdiet on endogenous ileal amino acid loss in the growing pig. *British Journal of Nutrition*, **83**: 421-430.

KERR, B. J., SOUTHERN, L. L., BIDNER, T. D., FRIESEN, K. G., & EASTER, R. A. 2003. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. *Journal of Animal Science*, **81**: 3075-3087.

LE GALL, M., WARPECHOWSKI, M., JAGUELIN-PEYRAUD, Y., & NOBLET, J. 2009. Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. *Animal*, **3**: 352-359.

LOC, N. T., OGLE, B., & PRESTON, T. R. 1997. Cassava root silage for crossbred pigs under village conditions in Central Vietnam, *Livestock Research for Rural Development*, **9**(14). http://www.lrrd.org/lrrd9/2/loc922.htm Accessed April 7, 2015.

MARFO, E. K., SOMPSON, B. K., IDOWU, J. S., & OKE, O. L. 1990. Effect of Local Food Processing on Phytate Levels in Cassava, Cocoyam, Yam, maize, Sorghum, Rice, Cowpea, and Soybean. *Journal of Agricultural and Food Chemistry*, **38**: 1580-1585.

MISSOTTEN, J. A. MICHIELS, M., J., OVYNA, A., DE SMETA, S., & DIERICK, N. A. 2010. Fermented liquid feed for pigs. *Archives of Animal Nutrition*, **64**(6): 437-466.

MOREL, P. C. H., LEE, T. S., & MOUGHAN, P. J. 2006. Effect of feeding level, live weight and genotype on the apparent fecal digestibility of energy and organic matter in the growing pig. *Animal Feed Science and Technology*, **126**: 63-74.

NATIONAL RESEARCH COUNCIL. 1998. *Nutrient Requirements of Swine*. 10th edition, National Academy Press. Washington, DC, USA.

NGOC, T. T. B, LEN, N. T., & LINDBERG, J. E. 2013. Impact of fibre intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. *Animal*, **7**(5): 736-745.

NOBLET, J., & PEREZ, J. M. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. *Journal of Animal Science*, **71**:3 389-3398.

NOBLET, J. & HENRY, Y. 1993. Energy evaluation systems for pig diets: a review. *Livestock Production Science*, **36**: 121-141.

NYACHOTI, C. M., DE LANGE, C. F. M., MCBRIDE, B. W., & SCHULZE, H. 1997. Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. *Canadian Journal of Animal Science*, **77**: 149-163.

OCHETIM, S. 1993. Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. *Asian-Australasian Journal of Animal Science*, **6**(3): 347-360.

OPSINA, L., PRESTON, T. R., & OGLE, B. 1995. Effect of protein supply in cassava root meal based diets on the performance of growing-finishing pigs. *Livestock Research for Rural Development*, **7**(2), http://www.lrrd.org/lrrd7/2/6.htm.

PASCUAL-REAS, B. 1997. A comparative study on the digestibility of cassava, maize, sorghum and barley in various segments of the digestive tract of growing pigs. *Livestock Research for Rural Development*, **9**(46). http://www.lrrd.org/lrrd9/5/phil95.htm Accessed April 9, 2016.

PETERS, D., TINH, N. T., MINH, T. T., TON, P. H., YEN, N. T., & HOANH, M. T. 2001. *Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam*. International Potato Centre (CIP), Hanoi, Vietnam.

PHUC, B. H. N., OGLE, B., & LINBERG, J. E. 2000. Effect of replacing soybean protein with cassava leaf protein in cassava root meal based diets for growing pigs on digestibility and N retention. *Animal Feed Science Technology*, **83**:223-235.

SAUER, W. C., MOSENTHIN, R., AHRENS, F., & DEN HARTOG, L. A. 1991. The effect of source of fibre on ileal and fecal amino acid digestibility and bacterial nitrogen excretion in growing pigs. *Journal of Animal Science*, **69**: 4070-4077.

SCHULZE, H., VAN LEEUWEN, P., VERSTEGEN, M. W. A., & VAN DEN BERG, J.W.O. 1995. Dietary Level and Source of Neutral Detergent Fibre and Ileal Endogenous Nitrogen Flow in Pigs. *Journal of Animal Science*, **73**: 441-448.

SCOTT, G. J., ROSEGRANT, M. W., & RINGLER, C. 2000. *Roots and tubers for the 21st century: Trends, projections, and policy options*. Food, Agriculture, and the Environment Discussion Paper No. 31. A copublication of the International Food Policy Research Institute (IFPRI) and the International Potato Centre (CIP), Washington, D.C.

TEKA, A., EMIRE, A. A., HAKI, G. D., & GEZMU, T. B. 2013. Effects of processing on physicochemical and anti-nutritional factors of cassava (*Manihot Esculenta* Crantz) grown in Ethiopia. *International Journal of Science Innovations and Discoveries*, **3**(2): 212-222.

TETENS, I., LIVESEY, G., & EGGUM, B. O. 1996. Effects of the type and level of dietary fibre supplements on nitrogen retention and excretion patterns. *British Journal of Nutrition*, **75**: 461-469.

TEWE, O. O. 2004. *Cassava for livestock feed in sub-Saharan Africa*, United Nations Food and Agriculture Organization and International Fund for Agriculture Development, FAO Rome, Italy. pp. 2-3.

TREZONA, M., NOGUEIRA, E.T., MCCULLOUGH, S. M., D'SOUZA, D. N., WILLIAMS, I. H. & MULLAN, B. P. 2002. The Effects of Hot Environments on the Growth

Performance and Carcass Characteristics of Growing Pigs, *Animal Production in Australia*, 24: 364.

VAN BARNEVELD, R. J., & HUGHES, R. J. 1994. The nutritive value of lupins for pigs and poultry. In: Dracup, M, & Palta, J. (Eds.) *Proceedings of the First Australian Lupin Technical Symposium*. Department of Agriculture and Food, Perth, Western Australia. pp. 49-57.

VAN DER MEULEN, J., & JANSMEN, J. M. 1997. Nitrogen metabolism in gastrointestinal tissue of the pig, *Proceedings of the Nutrition Society*, **56**: 535-545.

Chapter 5: Nutrient utilisation in grower pigs fed sweet potato roots either boiled or ensiled with or without vines blended with a protein concentrate

Statement of Authorship

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Contribution to the Paper	Conception, designed and conducted the experiment. Data collection, compilation, analysis and interpretation. Drafting and revision of the article.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Nutrient utilisation in grower pigs fed sweet potato roots either boiled or ensiled with or without vines blended with a protein concentrate

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Abstract

Blending sweet potato (*Ipomoea batatas*, L. (Lam)) with a protein concentrate for pig feed is a common strategy used by small-scale livestock farmers across Africa, Asia and the Pacific. However, high dietary fibre in sweet potato (SP) forage may reduce nutrient utilization and energy metabolism and reduce the growth rate of young pigs. A 32 d metabolic trial with grower pigs using a 4 × 4 Latin Square design tested the hypothesis that there would be no difference in Apparent Total Tract Digestibility (ATTD) of nutrients, energy and N-balance in 25 kg grower pigs (Large White × Landrace × Duroc) fed diets based on a blend of 43-40% protein supplement with 57-60% of dry matter as SP roots either boiled (BR43) or ensiled alone (ER43) or ensiled with vines (ERV40). Blended SP diets provided about 14-15% CP, 16.1-16.3 MJ DE/kg DM and 0.54-0.58 g lysine/MJ DE. The control diet (STD) contained 16.5% CP, 14.8 MJ DE/kg DM, 0.58 g lysine/MJ DE. The major findings were: 1) DM intake was higher ($P < 0.05$) for BR43 than ER43, ERV40 and STD diets, which were similar; 2) DM ATTD and energy utilization were higher ($P < 0.05$) in pigs fed SP diets; 3) Carbohydrate (Nitrogen Free Extracts) ATTD was higher ($P < 0.05$) in pigs fed BR43 and ER43 diets while crude protein ATTD of both these diets was similar to STD and higher than ERV40; 4) ATTD of fats (Ether Extracts), CP, carbohydrates (NFE) and total phosphorus was lower ($P < 0.05$) on ERV40, but fibre ATTD was higher; 5) N intake and N retained were similar ($P > 0.05$) for pigs fed BR43, ER43 and STD diets but lower for ERV40 ($P < 0.05$). Boiled or ensiled SP roots provided high nutrient and energy utilisation in growing pigs but the inclusion of SP vines lowered ATTD, energy utilisation and N retained from the mixed diet (ERV40).It is concluded that boiled or ensiled SP root are equally valuable as blended feed for grower pigs. However, at 30%DM, ensiled SP vine in blended feed led to reduced grower pig performance.

Key words: blend feeding, grower pigs, nutrient utilisation, N retained, sweet potato

Introduction

Sweet potato (*Ipomoea batatas*, L. (Lam)) forage is abundantly available to small-scale pig farmers across Africa, Asia and the Pacific where the crop may be used a staple food or as a cover crop (Ochetim 1993; Peters *et al*. 2001; Okereke *et al*. 2012). Sweet potato (SP) roots are high in carbohydrates and when fed in complex diets (4% to 35% inclusion) may provide up to 80% digestible DM and 14 to 15MJ/kg DE (Noblet *et al*. 1993). SP vine and foliage contain 18 to 21% crude protein on a dry matter basis (Nwokolo 1990) and apart from other forages and protein by-products such as fish meal, copra meal, millrun and rice bran, provides an alternative source of protein to grain based commercial pig feeds (An *et al*. 2005; Ly *et al*. 2010). Processing by drying, boiling or ensiling is able to reduce naturally occurring protease inhibitors and anti-nutrients such as tannins, phytates and oxalates (Bradbury and Holloway 1988; Lin *et al*. 1988; Dominguez 1992). SP varieties with low trypsin inhibitor content are cultivated in Papua New Guinea (Bradbury *et al*. 1984) where, as in other countries of the wet-humid tropics such as Laos, and Vietnam, ensiling SP forage is an effective means of storing feed over the long term, increasing protein levels for pigs and making full use of crop yield available to small-scale farmers (Peters *et al*. 2001).

The use of SP forage as pig feed is well studied but the nutritional value of ensiled mixtures of SP forage to grower pigs remains of interest because of the potential for partially replacing more costly protein feed inputs and to assess the influence of dietary fibres on energy metabolism and gastrointestinal health. The ileal and total tract apparent digestibility of CP of SP vine have been reported to be variable (Dominguez and Ly 1997; Giang *et al*. 2004a) and improved by ensiling(An *et al*. 2004). Ensiling SP root and vine also improved the digestibility of other nutrients (Dom and Ayalew 2009a; Ly *et al*. 2010). However, N retention was lowered by the inclusion of SP roots, leaves and vines, making it doubtful if grower pigs in particular would benefit from high levels of SP fibre (Dom and Ayalew, 2009a). Nevertheless, the use of fresh, dried or ensiled SP vines combined with SP or cassava roots provided sufficient nutrition for economically competitive grower-fattener performance (Gonzalez *et al*. 2003; Dom and Ayalew 2010; Ly *et al*. 2010).

Our overall objective was to replace a higher portion of imported grain feed using SP roots as the major source of starch and fermentable dietary fibre in blended diets used by small-scale pig farmers. It was hypothesized that SP roots boiled or ensiled with or without vines, and blended with a complementary protein concentrate, would provide similar feeding value for grower pigs as a commercial grower feed. The protein concentrate (Pig Conc.1) was based on wheat (48%), animal protein meals (28%), soybean (18%) and tallow (4%) and formulated to complement the nutrient shortages in SP roots and foliage, particularly for lysine and methionine. The SP based diets were balanced to provide similar crude protein (CP), total lysine and DE content. The hypothesis that including SP at 57% or 60% of diet DM would have no effect on apparent nutrient digestibility and support similar N retention was tested in a 32 d metabolism experiment.

Methods and Materials

Experiment location

The experiment was conducted at the Papua New Guinea (PNG) National Agricultural Research Institute (NARI), Labu Livestock Research Station in Morobe Province (Lat. 6° 40’ 27” S Long. 146° 54’ 33” E). The local climate is typically warm and wet with average daily temperatures of 30°C and 84% relative humidity (NARI, Bubia Station records). Shed temperature was measured using a glass thermometer placed at pig level adjacent to the cages. Minimum and maximum temperatures during the trial period were 23.3°C and 35.5°C, respectively, and relative humidity measured in station surroundings ranged from 77% to 90% during the same period.

Pigs and metabolic cages

A group of six (Large White × Landrace) × Duroc castrate male grower pigs from the same farrowing and weighing 20 to 24 kg were selectedrandomly from a large pool of weaned pigs at Rumion Piggery Ltd (PNG). The pigs were maintained on standard Pig Grower feed for 10 d after which 4 pigs weighing 25.5 ± 0.5 kg were allocated to four metabolic cages. The cages were two double-caged, steel units of dimensions 1.0 m × 1.0 m × 1.5 m on stands 0.7 m above floor level placed in the centre of an open sided shed with the cages positioned face-to-face for visual contact. The pigs remained in the cages for the entire 32 d experiment.

Treatment diets

The protein concentrate Pig Conc.1 was formulated using the ingredients listed in Table 1 mixed as a dry meal by Associated Mills Ltd., Lae, PNG. Soybean, wheat and minerals and other micronutrients were imported products. All other ingredients were available from local producers. Flame Stock feeds Pig Grower pellet feed, ground in a roller mill (PSS Ltd) from 10 mm to < 5 mm pellet sizewas used as the reference standard (STD). A local SP cultivar (commonly known as Rachel White, for the red skin and white flesh colour respectively) was used in this experiment. The highlands grown SP roots, harvested at maturity, were bought at the Lae Main Market in packed 90 kg bags. Fresh vine from no specific SP variety was harvested from local gardens around Labu Station. Processing and ensiling was done immediately the roots and vines were received and silage was fermented for 14 d before feeding to pigs. Bags of SP roots were stored for up to two weeks for the boiled prepadiet. SP roots were grated, SP vine were diced into 0.5 to 1 cm pieces, and leaves shredded into variable strips, using a manually operated chopper and mixed with raw roots for ensiling. Ensiling methods were modified from Peters *et al*. (2001) using table salt (NaCl) at 0.05% w/w of feed as a preservative, while roots and vines were not pre-dried or wilted before ensiling. Processed material was mixed and promptly packed and compressed into large 80L bin silos. Two silage treatments were SP roots ensiled alone and SP roots ensiled with vines at a ratio of 1:1 kg DM. Salt was added at the same proportion to the boiled diet; acidity in ensiled sweet potato roots was measured at pH 4.0 (unpublished data, M. Dom). Stored mature roots were washed and boiled for 45 min in water sufficient to cover the surface of the chopped roots, and with salt added at 0.05% w/w, then allowed to cool before blending as feed. Four Treatment diets were prepared by weighing fresh components calculated to provide 2,000 g DM on each feed offered, blended with Pig Conc.1 at 43% for boiled (BR43) or ensiled SP roots (ER43) and 40% for ensiled mixed SP roots and vines (ERV40). SP vine blended in ERV40 provided 30% DM. Blending of the feed offered was done twice daily by hand in large containers.

Experimental procedures

The experimental design was a 4 × 4 Latin Square with four diets fed to grower pigs over four consecutive 8 d feeding periods, with 5 d of adaptation feeding before 3 d feeding for sampling. Treatments were arranged in an orthogonal matrix by row and column and the test diets were interchanged according to the randomized schedule. The test diets were offered *ad libitum* and refusals collected every 24 hours on each morning. Feed offered and refused was weighed on a digital scale (ASDA 692/240; 5000 ± 0.1 g). Fresh piped town water was readily available from nipple drinkers, and four overhead fans (Air Monster 18” id) were directed at the cage and clear of the feeding trough and operated at full volume throughout the feeding period. Manual mist spraying was applied during exceptional heat (30°C) and was also helpful during humid periods based on the pig behaviour. Body weights were measured on d 1, 6 and 8 of each period using a digital platform balance (Xiangshan® T3811-JE2; 200 ± 0.02 kg). Pigs were managed according to prescribed Australian animal welfare guidelines (NHMRC, 2013) with specific methods approved by The University of Adelaide Animal Ethics Committee (Approval Number 0000016426). The pigs were attended all day and regularly inspected at night with measurement of body surface temperature using a digital thermometer. Close observations were made of the pigs and cage set-up during sample collection days to ensure clean sepadiet of faeces and urine. There were no indications of diarrhoea or other abnormality of body condition, temperature, or behaviour and standing in cages did not negatively affect the feeding behaviour.

Sample collections

Dry pellet feed and the protein concentrate meal were sampled as received from the mill. SP roots were delivered as fresh roots and in dry milled form. SP vines were delivered fresh on the day received. Ensiled SP forage was delivered as wet silage after 14 d of fermentation. All feed was sampled as 1 kg duplicates. Total collection of faeces and urine was achieved through steel floor bars with 5 mm spacing, onto steel sliding trays, angled to allow urine to drain off while solid contaminants were trapped by a wire coil allowing urine to be funnelled through a fine metal-sieve into 2.5 L sealed brown glass bottles. Faeces were weighed before drying in a Labec® forced air oven at 105°C, milled and stored in a cool, dry location in Snap-lock® sealed plastic sampling bags. Urine was stored in 500 mL PET bottles in an upright Westinghouse freezer. Sampling was done over 3 d for each 8 d period and faeces and urine samples from each test diet were pooled for the collection period.

Nutrient analytical testing

Chemical proximate analysis of feed, faeces and nitrogen in urine was conducted at the National Analytical and Testing Services Laboratory Ltd (Lae, PNG) by AOAC Official Methods (2012). Moisture was determined by drying 2 g samples for 2 hours at 135°C in a forced-air oven (Thermoline Scientific) and dry matter (DM) calculated as DM% = 100% - Moisture%. Protein was estimated as crude protein (CP) = N × 6.25 (or 5.70 for wheat based feeds). Nitrogen was determined as Total Kjeldahl Nitrogen by digestion of 0.5 to 1.0 g samples in concentrated sulphuric acid (FOSS Tecator^{TM}) and subsequent nitrogen determination on Kjeltec^{TM} 8200 distiller (FOSS). Crude fibre was determined as the difference of weighed residue on a frittered-glass crucible, after sulphuric acid digestion and ashing at 500°C. Ash was determined by weighing the resulting inorganic residue from a dried, ground sample ignited in a muffle furnace at 600°C (SEM SA Pty Ltd). Calcium was determined by ashing, acid digestion and testing aliquot solutions by flame spectrophotometry (AAS240FS). Potassium was determined by ashing, acid digestion and testing aliquot solutions by spectrophotometry (Shimadzu UV1800). Organic Matter (OM) was calculated as OM% = DM% – Ash%. Nitrogen-free extract (NFE) was calculated from tested feed proximate data as, NFE% = DM% – CP% – CF% – EE% – Ash%. Essential amino acids, leucine, lysine, methionine+cysteine, threonine and tryptophan, and dietary fibre as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (Lignin) were calculated from combined formulation ingredients of Pig Conc.1 (Carey Animal Nutrition) and published values (Heuzé et al., 2015). Digestible Energy (DE) was calculated according to Noblet and Perez (1993), where DE (kCal) = 4,151 – (122 × Ash%) + (23 × CP%) + (38 × EE%) – (64 × CF%), R2 = 0.89 and converted to MJ/kg.

Statistical analysis

Suitability of the small sample size was confirmed, a priori and post hoc power was determined using G*Power Version 3.1.9.2 (Franz Faul, Universitat Kiel, Germany) on preliminary data from published work under very similar treatments and experimental conditions (Dom and Ayalew, 2009a).For example, at $P < 0.05$, expected power was 99.95% (n = 16), 99.19% (n = 8) and 99.99% (n = 8) for estimating CATTD of DM and CP, and N retained, respectively. Statistical testing was conducted at 95% significance level. All data sets were analysed by ANOVA of the Latin Square design using GenStat 15th Edition (VSN Ltd) where the means were separated by Least Significant Differences.

Table 1. Nutrient composition of Sweet potato components and treatment diets, as boiled roots (BR43), ensiled roots (ER43) and ensiled root and vine (ERV40) blended with 43% or 40% Pig Conc.1 and tested against a standard commercial pig feed (STD)

Nutrients	**Components**				**Treatment diets**			
	BR	ER	ERV	Pig Conc.1	BR43	ER43	ERV40	STD
Chemical analysis(% DM)								
DM (as fed)	37.7	43.5	26.9	87.9	59.3	62.6	51.3	88.0
OM	36.8	41.8	25.5	79.1	55.0	57.8	46.9	81.6
Ash	0.9	1.7	1.4	8.8	4.30	4.75	4.36	6.4
CF	0.9	1.2	2.2	4.1	2.28	2.45	2.96	5.6
Fats (EE)	0.5	0.5	0.3	4.4	2.18	2.18	1.94	3.8
CP	1.0	1.3	1.7	32.9	14.7	14.9	14.2	16.5
NFE*	34.4	38.8	21.3	37.7	35.8	38.3	27.9	55.7
Calcium	0.09	0.12	0.12	1.80	0.83	0.84	0.79	0.92
Total P	0.11	0.12	0.1	0.97	0.48	0.49	0.45	0.97
Total N	0.16	0.21	0.27	5.26	2.35	2.38	2.27	2.64
Calculated (% DM)								
Leucine**	0.05	0.07	0.12	2.34	1.03	1.04	1.00	1.03
Lysine**	0.04	0.05	0.06	2.03	0.90	0.90	0.85	0.86
Methionine**	0.01	0.01	0.02	0.82	0.36	0.36	0.34	0.24
Met+Cys**	0.03	0.04	0.04	1.26	0.56	0.57	0.53	0.53
Threonine**	0.05	0.06	0.08	1.18	0.53	0.54	0.52	0.51
Tryptophan**	0.01	0.01	0.01	0.35	0.15	0.16	0.15	0.17
DE (MJ/kg DM)*	16.9	16.4	16.3	15.6	16.3	16.1	16.0	14.8
Lys:DE(g/MJ)*	0.02	0.03	0.04	1.30	0.57	0.58	0.54	0.58
Ca:P*	0.82	1.00	1.20	1.86	1.26	1.37	1.46	0.94
NDF**	4.3	4.9	7.3	17.9	10.1	10.5	11.5	31.5
ADF**	2.0	2.3	5.0	5.9	3.7	3.8	5.3	9.2
Lignin**	0.4	0.5	1.3	1.4	0.9	0.9	1.3	2.6
Starch**	26.1	30.1	18.6	14.6	21.2	23.4	17.0	35.4
Total sugars**	3.4	4.0	2.4	4.1	3.7	4.0	3.1	5.3

Note: Protein concentrate (Pig Conc.1), pig grower and Treatment formulations were provided by Carey Animal Nutrition Ltd, 3 Walnut Grove, Cherrybrook, NSW, Australia, 2126.
Ingredient composition of commercial grower pig feed: 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%, 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.

* Nitrogen Free Extracts (NFE), Digestible Energy (DE), Lysine: digestible energy ratio (Lys:DE), Calcium:Phosphorus diet (Ca:P) were estimated from chemical proximate analysis values in this table.

**Calculated for each of the Treatment components using data from Carey Animal Nutrition formulation of Pig Conc.1 and standard pellet feed (STD) and for sweet potato roots and vine forage using updated data on Feedipedia (Heuzé et al., 2015).

Results

The pigs remained in good health throughout the experiment.DM feed intake was not correlated to changes in daily shed temperatures (data not shown). The DM and nutrient content of the standard feed (STD) was superior to the SP Treatment diets. Total lysine in all the diets was about 0.9%, whereas methionine was at least 0.1% higher and DE about 1% higher, in the blended SP diets (Table 1).

The results for apparent total tract digestibility (ATTD) of nutrients, N utilization, DM feed intake, daily growth and feed conversion efficiency are given in Table 2. Dry matter intake (DMI) was higher ($P< 0.05$) for pigs fed the BR43 than SP test diets and STD. Pigs fed the ER43, ERV40 and STD diets had similar DMI ($P> 0.05$). There was a 3 to 12°C difference in shed temperatures measured at pig level during the 32 d experiment. Average daily gain (ADG, $P = 0.069$) and feed conversion ratio (FCR, $P = 0.059$) differences approached significance being best for pigs fed ER43 and worst for pigs fed ERV40.

DM ATTD and energy utilization were higher ($P< 0.05$) for pigs fed the SP diets than the standard grower diet. OM ATTD was reduced on ERV40 ($P< 0.05$) whereas BR43 and ER43 were similar to STD. Carbohydrate (NFE) digestibility was higher ($P< 0.05$) for BR43 and ER43 but both had similar protein digestibility as STD. Fat (EE), fibre, CP, carbohydrate (NFE), calcium and total P digestibility were reduced ($P< 0.05$) on ERV40. N intake and digested was lower ($P< 0.05$) for ERV40 while BR43 and ER43 were similar to STD. N losses in faeces were similar ($P> 0.05$). N-urine was higher on BR43 and STD and reduced on the two ensiled SP diets. N-retained was similar ($P> 0.05$) for BR43, ER43 and STD and higher than ERV40 ($P< 0.05$).

Table 2. Total tract apparent digestible nutrients (%), N balance (g/d), DM intake (g/d), average daily gain (g/d) and feed conversion ratio (kg/kg) for blended sweet potato diets fed to (Large White × Landrace) × Duroc grower pigs in metabolic trial

Parameter	**Grand mean**	**Treatment means**				**sed**	**lsd**	***F* pr.**
		BR43	ER43	ERV40	STD			
Apparent total tract digestibility (%)								
DM	78.3	82.6^{a}	82.9^{a}	77.7^{b}	69.8^{c}	0.96	2.35	<.001
Ash	44.5	40.9^{c}	58.9^{a}	36.3^{d}	41.8^{b}	0.09	0.22	<.001
OM	67.5	71.9^{a}	74.5^{a}	50.4^{b}	73.4^{a}	3.15	7.72	<.001
EE*	43.4	35.7^{b}	51.0^{a}	27.6^{b}	59.1^{a}	6.20	15.17	0.008
CF	27.8	33.0^{a}	28.1^{b}	23.2^{c}	27.1^{b}	1.24	3.04	0.001
CP	69.6	73.1^{a}	70.7^{a}	57.6^{b}	76.9^{a}	3.02	7.40	0.003
NFE**	80.1	83.6^{a}	85.3^{a}	73.6^{c}	77.7^{b}	1.11	2.71	<.001
Calcium	27.2	19.0^{b}	46.5^{a}	23.1^{b}	20.0^{b}	8.72	21.34	0.057
Total P	42.6	42.0^{b}	53.9^{a}	30.4^{c}	44.1^{ab}	4.44	10.85	0.011
Energy	84.3	87.5^{a}	86.8^{a}	82.3^{c}	80.8^{d}	0.53	1.29	<.001
Growth performance								
DMI (g/d)	1877	2297^{a}	1924^{b}	1350^{c}	1938^{b}	127.7	312.4	0.002
ADG (g/d)	784	1004^{a}	761^{c}	555^{d}	817^{bc}	60.4	147.7	0.002
FCR (DM basis)	2.36	2.22	2.37	2.43	2.44	0.136	0.332	0.390
N Balance (g/day)								
N intake	49.2	60.0^{a}	51.4^{a}	33.8^{b}	51.7^{a}	3.98	9.73	0.003
N faeces	13.8	14.7^{a}	14.6^{a}	14.3^{a}	11.6^{a}	1.58	3.87	0.252
N digested	35.4	45.3^{a}	36.8^{a}	19.5^{b}	40.2^{a}	3.74	9.14	0.002
N urine	12.7	16.2^{a}	7.5^{b}	8.5^{b}	18.5^{a}	2.96	7.60	0.008
N retained	23.2	27.1^{a}	26.8^{a}	10.8^{b}	28.0^{a}	2.49	6.09	0.001
NR%NI†	45.0	45.3^{a}	51.5^{a}	29.2^{b}	54.1^{a}	5.62	13.75	0.016
NR%ND‡	63.2	61.5^{a}	72.4^{a}	49.3^{b}	69.7^{a}	7.29	17.83	0.068

Means with different superscripts are significantly different at $P < 0.05$.
Treatments: 57% DM as sweet potato boiled roots (BR43) or ensiled roots (ER43) or ensiled roots and vines (ERV40), blended with Pig Conc.1 at 43% or 40% DM.

*EE is Ether Extracts estimate for fat content in feed. **NFE is Nitrogen Free Extracts, calculated as NFE% = DM% - (EE% + CF% + CP% + Ash%) as an estimate for carbohydrates. †NR% of NI is N retention as a percentage of N Intake. ‡NR% of ND is N retention as a percentage of N Digested.

Discussion

Our findings that nutrient utilization in grower pigs fed SP roots, either boiled (BR43) or ensiled (ER43), was generally higher than the wheat based commercial feed (STD) agrees with previous data for grower pigs fed sweet potato or cassava roots either boiled or ensiled or as dry meal blended using the same protein concentrate (Dom *et al.* 2014, 2017; Chapters 3 and 4). Higher fibre content from SP vine inclusion in the silage (ERV40) dramatically reduced the nutrient utilization, providing ATTD of 50.4%, 57.6%, 27.6% and 23.2%, for organic matter (OM), CP, fats (EE), and CF respectively. The CF ATTD was considerably much lower (44.6%) than other SP diets (67.8%) reported by Dom and Ayalew (2009) using the same genotype and bodyweight pigs fed on ensiled SP blended with corn-soybean feed where SP vines provided only 12.5% DM. The higher SP vine content (20% DM) in ERV40 was a disadvantage to digestibility in growing pigs. Dung *et al*. (2002) report much higher ATTD for OM (82%), CP (70%) and fats (77%) than those reported here but SP vine in their diets provided 35%DM, and contained highly digestible cassava starch, fish meal and soybean oil. Moreover, their Yorkshire pigs were at 45 to 50 kg body weight and were conditioned on the diets for 14 d before each sample collection period, which allowed pigs more time to adapt to the high fibre feed. STD Body weight, exposure to diets and genotype of pigs influences their ability to digest high fibre diets (Guixin et al., 1991; Ngoc et al., 2013; Regnier et al., 2013).

In similar work, Giang *et al*. (2004a) used a 1:1 ratio for ensiling SP roots to SP vine, but in their blended feed the vines provided only 7.2%DM. Their basal feed was composed of maize meal (48.2%), fish meal (5.0%), soybean meal (10.0%), rice bran (23.0%) and cassava root meal (12.0%) and they predicted that, apart from superior ATTD for OM (77.9%), nutrient digestibility for the ensiled mixed SP roots and vine would be similar to the mixed dry meal form if either feed is offered alone. This suggests that mode of prepadiet does not affect digestibility when SP vines are included either as dry meal or ensiled at a lower DM contribution. However, DM, OM, CF and CP digestibility in their Mongcai × Yorkshire F1 crossbred pigs (35 kg) was superior to our results for blended SP silage feed. We report a lower feeding value for ensiled SP roots with SP vines in 1:1 ratio. Our results show that at 30%DM SP vine inclusion lowered DM digestibility by about 5%, reduced CP and N digestibility (NR% ingested N) by about 16%, while N-retention (10.8 g/d) was reduced by 60%, compared to boiled (27.1 g/d) or ensiled roots (26.8 g/d) blended alone. The N utilisation (NR% digested N) on ERV40 was 12% lower than BR43 and 23% lower than ER43. It is plausible that PNG's indigenous crossbred pigs may have different adaptations similar to the Mongcai pigs for the use of dietary fibre (Ngoc *et al*. 2013). Rose and White (1980) report 95.3%, 96.1%, 94.2% and 72.4% for DM, OM, energy and ADF respectively for chopped raw SP roots, whereas protein digestibility was 42.3% and 57.2% for 10 and 14 month old village pigs respectively.

Nutrient utilization

Crude protein digestibility of BR43 and ER43 were similar to the commercial pig feed, STD. Nitrogen intake of pigs fed the BR43 was in excess of requirements and more N was excreted in urine, while urine N was lower on ER43 resulting in similar N retention and N digestibility to BR43. Nitrogen intake was 43% and 34% lower on ERV40 than BR43 and ER43, respectively. Sweet potato vines markedly reduced CP and N digestibility when included in the mixed ensiled diet (ERV40), indicating that protein absorption was reduced along the entire digestive tract. A shift in N excretion from urine to faeces reflects greater microbial fermentation for ER43 and ERV40 (Tetens *et al*. 1996; Wenk, 2001). Nitrogen retained by pigs fed BR43 (27.1 g/N/d) and ER43 (26.8 g N/d) were on par with the standard feed (28.0 g N/d). However, N retained by pigs fed ERV40 (10.8 g N/d) was similar to Giang *et al*. (2004a) for dried (9.8 g N/d) and for ensiled SP vines (7.5 g N/d). An and Lindberg (2004) report similar N retention for Large White × Mong Cai grower pigs fed diets containing 45% ensiled SP leaves blended with SP root meal (11.3 g N/d) or cassava root meal (11.6 g N/d) or sugar cane molasses (13.4 g N/d). The similar N retention on ERV40 despite much lower CP and N digestibility may be attributed to the genetic ability for protein retention in the crossbred (Large White × Landrace) × Duroc (25 kg) grower pigs used in this work.

Sweet potato vine blended with highly digestible ingredients used by Giang *et al*. (2004) and Dung *et al*. (2002), or with casein (An *et al.* 2004) provide far better nutrient digestibility to grower pigs. However, CP total tract digestibility was lowered by SP leaves more than by cassava residue, groundnut hulls and rice bran blended with maize meal, soybean meal and fish meal (Len *et al*. 2007). The amount and type of dietary fibre affects nutrient utilisation (Stanogias and Pearce, 1985). Ileal digestibility is not affected by insoluble dietary fibre (Bach Knudsen and Hansen, 1991a, b) but soluble fibre reduces nutrient absorption although starch is not affected (Johansen and Bach Knudsen, 1994). Increased soluble fibre from pectin lowers protein digestibility but N utilisation in crossbred grower pigs compensates for lower amounts of digested N (Hansen *et al.* 2006). This same result of increased soluble fibre in SP forage was evident in the present results.

Sweet potato forage contains as much as 38% dietary fibre on DM basis (Mosha *et al*. 1995) and more than twice the amount found in SP roots on fresh weight basis (Almazan and Zhou, 1995). The vines have a different composition of soluble and insoluble fibres to the roots but their other anti-nutritional effects are reduced by ensiling (Lin *et al.* 1988; Giang *et al.* 2004b). However, the standard diet contained higher NDF (31.5%) than ERV40 (11.5%) and as a result ATTD of DM and energy was lower. It is clear that at 30%DM the dietary fibre in SP leaves and vines had a more marked effect than the higher levels of NDF, ADF and lignin in the standard feed. The soluble fibre in SP had a greater effect on nutrient utilisation in the 25 kg pigs, most likely through increased viscosity of digesta in the stomach, binding the nutrients and thereby reducing their absorption in the small intestine. Dietary fibre alsoaffects pig gut physiology (Len *et al.* 2009). While it may be possible that fermentation resulted in the relatively high energy value of ERV40 there was clearly a marked adverse effect on N digestibility and N retention.

Starch solubility and digestion

Changes in starch functional properties and content of other dietary fibres from SP roots and vines are expected to impact on energy availability and nutrient absorption in the pig. Boiling SP roots causes gelatinization of starch thereby increasing its solubility (Valetudie *et al.* 1995; Sagum and Arcot, 2000). We observed loss of nutrients in the hot water (colouring and thickening) discarded when preparing SP roots and these were probably the soluble mineral salts, sugars and some leached starch. However, this did not appear to disadvantage the BR43 diet. Mature SP roots contain more sugars so fermentation proceeds rapidly without inoculants or additives. Fermenting SP roots by ensiling uses up the simple sugars, releases organic acids and increases starch solubility (Giang *et al.* 2004b). The pungent aroma from our SP silage liquid effluent indicated organic acids in the silo, where pH 4.0 was measured, but no other tests were performed. The presence of α-amylase in SP roots may also aid rapid fermentation (Tester and Karkalas, 2006; Nabubuya *et al.* 2012). Digestively, starch susceptibility to α-amylase and *in vitro* absorption increased when rice was cooked but this did not increase CP ATTD (Sagum and Arcot, 2000). On the other hand, α-amylase resistant starch or retrograded starch also acts as a dietary fibre in the pig digestive tract, reducing apparent ileal and total tract digestibility of OM, starch and CP more than course fibre in sugar beet pulp or wheat bran, even when combined with very highly digestible starch sources such as rice (Wang *et al.* 2002).

Starch molecules in boiled SP roots crystallize on cooling and the smaller crystalline SP starch granules are more rapidly hydrolysed by porcine pancreatic α-amylase andis correlated with the amylopectin structure (Tian *et al.*1991; Srichuwong *et al.* 2005a, b). Amylopectin is more susceptible to enzymatic digestion than amylose (Singh *et al.* 2010) and is as much as 70% of starch solids in SP roots (Waramboi *et al.* 2011). The higher SP root carbohydrates (NFE) feed intake on BR43 and ER43 provided higher ATTD than in STD or ERV40. Our results demonstrate that SP roots alone either boiled or ensiled, blended with the complementary protein concentrate were a better nutrient delivery system than offering the wheat based pellet feed. ERV40, however, provided equally effective energy utilization as STD.

Feed intake, growth and efficiency

The low growth rate on ERV40 reflected a considerably lower DM intake and N retention. However, the feed efficiency of ERV40, BR43 and ER43 were on par with the standard pellet feed, indicating that the SP roots provided a sufficient source of digestible energy for growth despite reduced feed intake. Lower DM intake of pigs fed on ERV40 may be due to the bulkiness (Kyriazakis and Emmans, 1995) and early or prolonged satiety caused by dietary fibres (Wenk, 2001; Bindelle *et al.* 2008). This was observed when pigs were offered ERV40. They either stopped feeding sooner and/or consumed a large meal on one day then less on the next day. Dietary fibre reduces nutrient digestion in younger or lower body weight pigs(Fernandez and Jorgensen, 1986; Le Goff and Noblet, 2001), both of which were true for the pigs in this work.

The method of prepadiet did not affect digestibility for boiled or ensiled SP roots. Pelleting has a minor effect on energy and nutrient digestibility in fibre-rich (5.9-12.6% CF on as fed basis) diets (Le Gall *et al.* 2008) and by comparison fibre was higher in STD (5.6% CF) than ERV40 (2.8% CF). Ensiling SP roots prolonged the storage life and increased the solubility of nutrients and was more resource efficient than preparing boiled roots. However, for village based farmers with less need for bulk feed storage by ensiling, blending boiled SP roots affords superior nutrition, particularly for young pigs. The use of fibrous feeds would also reduce the maintenance feeding costs for breeding age pigs. Moreover, indigenous and crossbred pigs may have improved capacity for digesting diets which are high in fibre of different types (Guixin *et al.* 1995; Freire *et al.* 2003; Lindberg, 2014). Pigs farmed in PNG are admixtures of indigenous and introduced breeds with varying performance (Spencer *et al.* 2006; Ayalew *et al.* 2011) and their nutrient requirements have not been fully assessed.

Recent growth trials have revealed adequate performance in the modern mixed genotype pigs (Dom and Ayalew, 2010).

Conclusion

The evidently higher nutrient utilisation for SP roots in either boiled or ensiled form when combined with the complementary protein concentrate was an important finding for advancing the nutritional options for small-scale pig production. These two blended SP diets should be recommended to small-scale pig farmers. The higher CP digestibility and N retention found for pigs fed the SP root diets could have implications with respect to the amount of supplementary protein (source) required to meet the pigs N requirement and warrants follow up. The inclusion of SP vines in the ensiled feed reduced nutrient utilisation and N retention, probably due to the fibre content. However, there are options for improving its use such as processing, reduced inclusion levels, combination with more readily digestible ingredients, controlled feeding, increased total protein or available lysine and essential amino acids, feeding to larger pigs, and feeding to indigenous pigs and their crossbreeds with commercial lines. Nevertheless, the marked reduction in ATTD of CP and N elicited by the vines suggests further research is required.

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References

Almazan AM, Zhou X (1995) Total dietary fibre content of some green and root vegetables obtained at different ethanol concentdiets. *Food Chemistry* **53**, 215–218.

An LV, Hong TTT, Ogle B, Lindberg JE (2005) Utilization of ensiled sweet potato (*Ipomoea batatas* (L.) Lam.) leaves as a protein supplement in diets for growing pigs. *Tropical Animal Health and Production* **37**, 77–88.

An LV, Hong, TTT, Lindberg, JE (2004) Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (*Ipomoea batatas* (L.) Lam.) leaves. *Animal Feed Science and Technology* **114**, 127–139.

An LV, Lindberg, JE (2004) Ensiling of sweet potato leaves (*Ipomoea batatas* (L.) Lam) and the nutritive value of sweet potato leaf silage for growing pigs. *Asian-Australasian Journal of Animal Science* **17,** 497–503.

Association of Official Analytical Chemists (2012) 'Official Methods of Analysis (19th edn).' (AOAC International: Gaithersburg, Maryland)

Ayalew W, Gariba D, Dom M, Amben S, Besari F, Moran C, Nidup K (2011) Genetic and cultural significance of native pigs in PNG and their phenotypic features. Food and Agriculture Organization of the United Nations.*Animal Genetic Resources***48,** 37–46. (Available at http://www.fao.org/docrep/014/i2200t/i2200t00.htm.)

Bindelle J, Leterme P, Buldgen A (2008) Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. *Biotechnology, Agronomy, Society and Environment* **12**, 69–80.

Bradbury JH, Baines J, Hammer B, Anders M, Millar J (1984) Analysis of sweet potato (*Ipomoea batatas*) from the Highlands of Papua New Guinea: Relevance to the incidence of *Enteritis necroticans*. *Journal of Agricultural and Food Chemistry***32**, 469–473.

Bradbury JH, Holloway WD (1988) Chemistry of Tropical Root Crops: significance for nutrition and agriculture in the Pacific. Australian Centre for International Agricultural Research, Monograph Series No.6, Canberra.

Dom M, Ayalew W (2009b) Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. *Papua New Guinea Journal of Research, Science and Technology* **1**, 86–96.

Dom M, Ayalew W (2010) Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. *Journal of South Pacific Agriculture* **14,** 78–86.

Dom M, Ayalew W (2009a) Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. *Journal of the Institute of Chemists PNG* **2**, 77–88.

Dom M, Ayalew W, Glatz P, Kirkwood R, Hughes P (2014) Effect on nutrient digestibility and nitrogen balance in pigs fed three forms of blended cassava roots. *Proceedings of the 16th Asian-Australian Association of Animal Production Animal Science Congress* **2**, 676–679.

Dom MT, Ayalew, WK, Glatz, PC, Kirkwood RN, Hughes PE (2017) Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate. *Animal Feed Science and Technololgy* **223**, 82–89.

Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate. Anim. Feed Sci. Technol. 223, 82–89.

Dominguez PL (1992) Feeding of sweet potato in monogastrics. In: ‘Roots, tubers, plantains and bananas in animal feeding (Eds D Machin, S Nyvold) pp. 217–233. (FAO: Rome) (Available at http://www.fao.org/ag/aga/agap/frg/AHPP95/95-217.pdf)

Dominguez PL, Ly J (1997) An approach to the nutritional value for pigs of sweet potato (*Ipomoea batatas L.* (lam.)), *Livestock Research for Rural Development* **9**(2). (Retrieved July 2, 2013, from http://www.lrrd.org/lrrd9/2/ly92.htm.)

Dung NNX, Manh LH, Uden P (2002) Tropical fibre sources for pigs–digestibility, digesta retention and estimation of fibre digestibility in vitro. *Animal Feed Science and Technology* **102,** 109–124.

Freire JPB, Peiniau J, Cunha LF, Almeida JAA, Aumaitre A (1998) Comparative effects of dietary fat and fibre in Alentjano and Large White piglets: Digestibility, digestive enzymes and metabolic data. *Livestock Production Science* **53,** 37–47.

Giang HH, Ly LV, Ogle B (2004a) Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. *Livestock Research for Rural Development* **16**(50).(Retrieved July 2, 2013, from http://www.lrrd.org/lrrd16/7/gian16050.htm.)

Giang HH, Ly LV, Ogle B (2004b) Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. *Livestock Research for Rural Development* **16**(45).(Retrieved July 2, 2013, from http://www.lrrd.org/lrrd16/7/gian16045.htm.)

Gonzalez C, Díaz I, Vecchionacce H, Ly J (2003) Performance traits of pigs fed sweet potato (*Ipomoea batatasL*.) foliage ad libitum and graded levels of protein. *Livestock Research for Rural Development* **15**(9). (Retrieved July 2, 2013, from http://www.lrrd.org/lrrd15/9/gonz159.htm.)

Guixin Q, Verstegen WA,Bosch MW (1995) Variation of the digestive capacity between genetically different pig populations: a review. *Journal of Animal Physiology and Animal Nutrition* **73,** 233–242.

Hansen JA, Chwalibog A, Tauson AH, Sawosz E (2006) Influence of different fibre sources on digestibility and nitrogen and energy balances in growing pigs. *Archives of Animal Nutrition***60**, 390–401. doi: 10.1080/17450390600884385

Heuzé V, Tran G, Hassoun P, Renaudeau D, Bastianelli D (2015) Sweet potato (*Ipomoea batatas*) tubers. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. (Available at http://feedipedia.org/node/745)

Johansen H, Bach Knudsen KE (1994) Effects of wheat-flour and oat mill fractions on jejunal flow, starch degradation and absorption of glucose over an isolated loop of jejunum in pigs. *British Journal Nutrition* **71**, 299–313.

Kyriazakis I, Emmans GC (1995) Do breeds of pig differ in the efficiency with which they use a limiting protein supply? *British Journal of Nutrition* **74,** 183–195.

Le Gall M, Warpechowski M, Jaguelin-Peyraud Y, Noblet J (2009) Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. *Animal* **3**, 352–359. doi:10.1017/S1751731108003728

Len NT, Hong TTT, Ogle B, Lindberg JE (2009) Comparison of total tract digestibility, development of visceral organs, and digetive tract of Mong Cai and YorkShire × Landrace piglets fed diets with different fibre sources. *Journal of Animal Physiology and Animal Nutrition* **93,** 181–191. doi: 10.1111/j.1439-0396-2007.00804.x

Len NT, Lindberg JE, Ogle B (2007) Digestibility and nitrogen retention of diets containing different levels of fibre in local (Mong Cai), F1 (Mong Cai × Yorkshire) and exotic (Landrace × Yorkshire) growing pigs in Vietnam. *Journal of Animal Physiology and Animal Nutrition* **91,** 297–303. doi: 10.1111/j.1439-0396.2006.00653.x

Lin YH, Huang TC, Huang C (1988) Quality improvement of sweet potato (*Ipomoea batatas* L. Lam.) roots by ensilage, *British Journal of Nutrition***60,** 173–184.

Lindberg, JE (2014) Fiber effects in nutrition and gut health in pigs. *Journal of Animal Science and Biotechnology* **5**. (Available at http//:www.jasbsci.com/content/5/1/15)

Ly NTH, Ngoan LD, Verstegen WA, Hendriks WH (2010) Ensiled and dry cassava leaves and sweet potato vines as a protein source in diets for growing Vietnamese Large White × Mong Cai pigs. *Asian-Australasian Journal of Animal Science* **23**, 1205–1212.

Mosha TC, Pace, RD, Adeyede S, Mtebe K, Laswai H (1995) Proximate composition and mineral content of selected Tanzanian vegetables and the effect of traditional processing on the retention of ascorbic acid, riboflavin and thiamine. *Plant Foods for human Nutrition* **48**, 235–245.

Nabubuya A, Namutebi A, Byaruhanga Y, Narvhus J, Stenstrom Y, Wicklund T (2012) Amylolytic activity in selected sweet potato (*Ipomoea batatasL.* (Lam)) varieties during development and in storage. *Food and Nutrition Sciences* **3,** 660–668. (Available at http://dx.doi.org/10.4236/fns.2012.35090)

Nahm KH, (2003) Influences of fermentable carbohydrates on shifting nitrogen excretion and reducing ammonia emission of pigs. *Critical Reviews in Environmental Science and Technology* **30**(2), 165–186. doi: 10.1080/10643380390814523

National Health and Medical Research Council (2013) 'Australian code for the care and use of animals for scientific purposes, 8th edition.' (National Health and Medical Research Council: Canberra)

Ngoc TTB, Len NT, Lindberg JE (2013) Impact of fibre intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. *Animal* **7**, 736–745. doi: 10.1017/S1751731112002169

Noblet J, Perez JM (1993) Prediction of digestibility nutrients and energy values of pig diets from chemical analysis. *Journal of Animal Science* **71,** 3389–3398. (Available at http://jas.fass.org/content/71/12/3389)

Nwokolo, E. 1990. Sweet potato. In: 'Non-traditional feed sources for use in swine nutrition' (Eds PA Thacker, RN Kirkwood) pp 481–491. (Butterworths: London)

Nyachotti CM, de Lange CFM, McBride BW, Schulze H (1997) Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. *Canadian Journal of Animal Science* **77**. 149–16.

Ochetim S, (1993) Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. *Asian-Australasian Journal of Animal Science* **6**, 347–360.

Okereke CO, (2012) Utilization of cassava, sweet potato and cocoyam meals as dietary sources for poultry. *World Journal of Engineering and Pure and Applied Science* **2**, 63–68. Retrieved July 2, 2013, from http://www.rrpjournals.org/wjepas/en_wjepas_vol_2_iss_2_pg_63_68.pdf.

Peters D, Tinh NN, Thuy TT, Thach PN (2001) Fermented sweet potato vines for more efficient pig raising in Vietnam. AGGRIPPA. FAO, Rome, Italy. (Available at www.fao.org.docrep/article/agrippa/x9500e 10.htm. (Verified 21 May 2015)

Phuc BHN, Ogle B, Lindberg JE (2000) Effect of replacing soybean protein with cassava leaf protein in cassava root meal based diets for growing pigs on digestibility and N retention. *Animal Feed Science and Technology* **83,** 223–235.

Regnier C, Bocage B, Archimede H, Noblet J, Renaudeau D (2013) Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. *Animal Feed Science and Technology* **180,** 44–54. http://dx.doi.org/10.1016/j.anifeedsci.2012.12.07

Rose CJ, White GA (1980) Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. *Papua New Guinea Agricultural Journal* **31**, 69–72.

Sagum R, Arcot J (2000) Effect of domestic processing methods on the starch, non-starch polysaccharides and in vitro starch and protein digestibility of three varieties of rice with varying levels of amylose. *Food Chemistry* **70**, 107–111.

Singh J, Dartois A, Kaur L (2010) Starch digestibility in food matrix: a review. *Trends in Food Science & Technology* **21,** 16–180. doi: 10.1016/j.tifs.2009.12.001

Spencer PBS, Hampton J, Lapidge SJ, Mitchell J, Lee J, Pluske JR (2006) An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea. *Journal of Genetics* **85**, 63–66.

Srichuwong S, Sunarti TC, Mishima T, Isono N, Hisamatsu M (2005a) Starches from different botanical sources I: Contribution of amylopectin fine structure to thermal properties and enzyme digestibility. *Carbohydrate Polymers* **60,** 529–538. doi: 10.1016/j.carbpol.2005.03.004

Srichuwong S, Sunarti TC, Mishima T, Isono N, Hisamatsu M (2005b) Starches from different botanical sources II: Contribution of starch structure to swelling and pasting properties. *Carbohydrate Polymers* **62,** 25–34. doi: 10.1016/j.carbpol.2005.07.003

Stanogias G, Pearce GR (1985) The digestion of fibre by pigs: 1. The effects of amount and type of fibre on apparent digestibility, nitrogen balance and rate of passage. *British Journal of Nutrition* **53**, 513–530.

Tetens I, Livesey G, Eggum BO (1996) Effects of the type and level of dietary fibre supplements on nitrogen retention and excretion patterns. *British Journal of Nutrition* **75**, 461–469.

Tian SJ, Rickard JE, Blanshard JMV (1991) Physicochemical properties of sweet potato starch. *Journal of the Science of Food and Agriculture* **57**, 479–491.

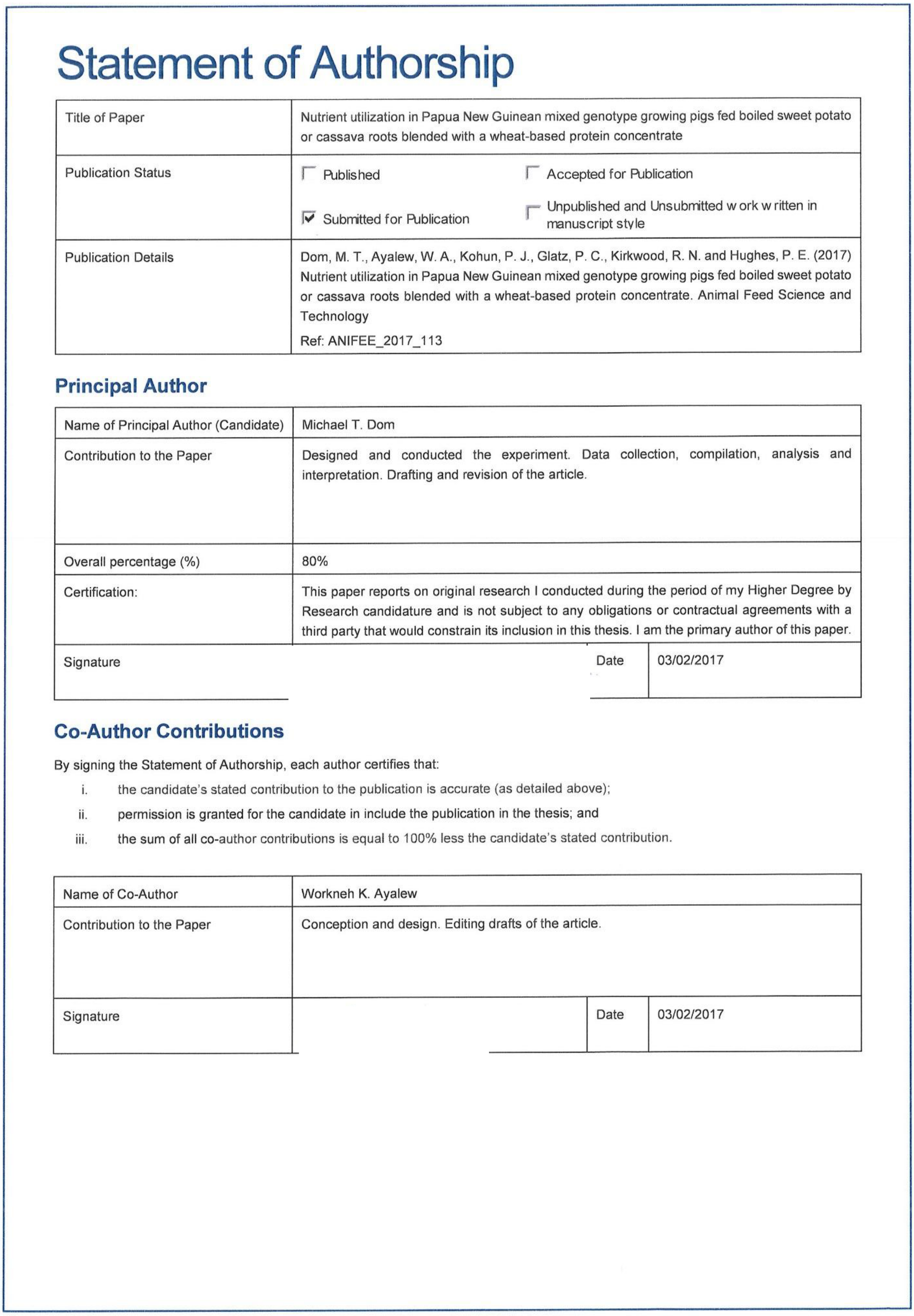
Valetudie JC, Colonna P, Bouchet B, Gallant DJ (1995) Gelatinization of sweet potato, tania and yam tuber starches. *Starch* **47,** 298–306.

Wang JF, Jensen BB, Jorgensen H, Li DF, Lindberg JE (2002) Ileal and total tract digestibility, and protein and fat balance in pigs fed rice with addition of potato starch, sugar beet pulp or wheat bran. *Animal Feed Science and Technology* **102,** 125–136.

Waramboi JG, Dennien S, Gidley MJ, Sopade PA (2011) Characterization of sweet potato from Papua New Guinea and Australia: Physiological, pasting and gelatinisation properties. *Food Chemistry* **126,** 1759–1770. doi: 10.1016/j.foodchem.2010.12.077

Wenk C, (2001) The role of dietary fibre in the digestive physiology of the pig. *Animal Feed Science Technology* **90,** 21–23.

Chapter 6: Nutrient utilization in Papua New Guinean mixed genotype growing pigs fed boiled sweet potato or cassava roots blended with a wheat-based protein concentrate



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Overall percentage (%)	80%		
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i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

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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

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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 intake 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), 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 higher on the root-based diets, but Ash, Ca and Total P CTTAD were reduced ($p<0.05$) compared with STD. In both experiments 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; digestibility; growing pigs; nitrogen balance; sweet potato

1. 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 and Kohun, 2002) and animal protein (Gibson, 2001). SP and cassava crops serve a dual food-feed purpose with locally popular cultivars originating from clones supplied by the International Potato Centre which were recommended for human consumption. Anti-nutritional factors such as tannins, phytates, and cyanogenic glucosides in cassava, and trypsin inhibitors in sweet potato (SP), are relatively lower in cultivars grown in PNG and the roots are usually boiled in water, which improves the digestibility of root starch and other nutrients (Bradbury et al., 1988; Marfo et al., 1990; Barampama and 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 (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 and Kohun, 2002). Improving the nutrient 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, was tested against a commercially available pig grower feed, used as a proxy standard. The current experiment tested locally bred MG pigs from a highlands based 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.

2. Methods and Materials

2.1 Experiment location

Two consecutive metabolic experiments were completed from 15 January to 19 February and 20 February to 24 March 2015 at the National Agricultural Research Institute (NARI)

Labu Livestock Research Station (6° 40’ 27” S 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.

2.2 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 (5° 52’ 9” S, 144° 41’ 50” E), approximately 30 min by road from Banz township (1,606 m altitude). 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 (Pers. comm. Robinson Kale). Eight growing pigs were selected from a large pool (>100 piglets) of separate farrowing’s 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 the wheat-based pellet feed (STD). The pigs were divided 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 withholding feed for 24 hrs to measure empty body weight. The remaining four pigs (30.46 ± 2.15 kg BW) were maintained on the limited pellet feed offer and used after another 32 d. All feed was offered ad libitum to pigs in the crates for 24 hours 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. 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).

2.3 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. 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 crate was placed in the centre of a concrete pig pen in an open-sided shed. Four fans were placed at the head of each crate to provide cooling air movement for the pigs for the dudiet 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).

2.4 Treatment diets

A protein concentrate, Conc.1, was formulated by Carey Animal Nutrition (Australia) and produced in PNG from local and imported products. Conc.1 was designed to complement nutritional imbalances in SP and cassava roots to provide the treatment diets (Table 1). Chemical analysis provided proximate nutrient content of the formulated diets. Leucine, lysine, methionine, methionine + cysteine (Met + Cys), 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 (Carey Animal Nutrition) 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 dudiet of feeding. Cassava roots were cured by the clamp method (Booth, 1976) in the pig trail 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.

2.5 Feed offer, refusal collection and pig welfare

The feeding and collection procedure followed previous experimental work with similar diets fed to commercial breed growing pigs (Dom et al., 2014, 2017). The four eight-day feeding periods included five days for adaptation to the test diets and three days 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 down every morning and metabolic crate 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.

Table 1

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

Nutrients	**Components**				**Treatment diets**			
	SBR*	**CBR***	**CMR***	**Conc.1***	**SBR43**	**CBR45**	**CMR45**	**STD**
Analysed composition (g/kg DM)								
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 composition (g/kg DM)								
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
Met+Cys**	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).

2.6 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.

2.7 Chemical analysis of samples

Chemical 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 determined 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.

2.8 Statistical analysis

Suitability of the small sample size, a priori and post hoc power was 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).

3. Results

3.1 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%), was 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%).

3.2 Experiment 1

3.2.1 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 intake 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. However, the mean growth rate (ADG) were similar between the pigs for all four diets however 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.

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 output. 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).

3.2.2 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 higher 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 higher 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 was 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.

3.2.3 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) was higher 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.

3.3 Experiment 2

3.3.1 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 was lower. There was higher urine output 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).

3.3.2 Nutrient digestibility to 46 kg MG pigs

Coefficients of apparent total tract digestibility (CATTD) for DM, OM and carbohydrate (NFE) were higher 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.

3.3.3 N balance in 46 kg MG pigs

N intake (g/d) in pigs fed the boiled-root diets were almost twice that to 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 high 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 2

Growth performance of MG 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; * $p<0.05$; ** $p<0.01$, *** $p<0.001$.

Table 3

Coefficients of apparent total tractdiigestibility of nutrients for MG 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

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

4. Discussion

4.1 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. 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 and 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., 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 reports on SP and cassava diets fed to grower-finisher pigs of mixed genotype (e.g. 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% higher DM and OM digestibility for root-based diets compared to commercial genotype pigs (Dom et al 2014, 2017; Chapters 3 and 4). Boiling roots increases the solubilisation of starch and dietary fibre (Bradbury et al., 1988; Barampama and Simard, 1995). An increased fibre digestibility in the root-based diets may also be related to previous exposure of these animals to high fibre diet and a better 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 and Simard, 1995; Teka et al., 2013) however the SP roots were not peeled and may be expected to contribute more dietary fibre (Dhingra et al., 2012). Dietary fibre may reduce the 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 intake, but that at lower feed intake digestibility would improve and this was irrespective of diet or breed of pig. Restricting the feed offered 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 compared to commercial genotype pigs used in previous work (Dom et al 2014, 2017; Chapters 3 and 4). 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). In PNG village pigs fed raw chopped SP roots digestibility coefficients were 0.97, 0.57, 0.75 and 0.95 for OM, protein, ADF and energy (Rose and White, 1980). The current MG pigs were crossbred from village pig stock from the PNG highlands and appear to have inherited the same digestive capacity for fibre. Crossbreed pigs of other indigenous genotypes, 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 for diets much higher in dietary fibre but also had lower protein digestibility. When pigs are fed to satisfaction on root-based diets the higher intake of soluble fibre (resistant starch and non-starch polysaccharides) may reduce protein digestibility (Bach Knudsen and Hansen, 1991; Hansen et al., 2006) but this did not appear to be the case for the diets in this work. Protein digestibility 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 and 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 digestibility coefficients for 33 kg compared to 45 kg MG pigs was probably more to do with the greater requirements for skeletal development in young pigs at the lower starting body weight.

4.2 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 was 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 this 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 and Stein, 2004). Digestible energy of root-carbohydrates may increase 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 and 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.

Apart from the very low N retained in 46 kg BW MG pigs fed the milled cassava-roots (16.4 g N/d) the MG pigs here 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).

On the other hand, Dom and 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 and 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 improved on the root-based blended diets than the wheat-based pellet feed however 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.

5. Conclusions

SP and cassava roots blended with the complementary protein concentrate was highly digestible to mixed genotype growing pigs. 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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Conflict of interest

All authors report no conflict of interest with this study.

References

An, L.V., Hong, T.T.T., Lindberg, J.E., 2004. Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (Ipomoea batatas L. (Lam.)) leaves. Anim. Feed Sci. Technol. 114, 127–139.

AOAC, 2012. Official Methods of Analysis. 19thed. Association of Official Analytical Chemists, Gaithersburg, Maryland.

Ayalew, W., Gariba, D., Dom, M., Amben, S., Besari, F., Moran, C., Nidup, K., 2011. Genetic and cultural significance of native pigs in PNG and their phenotypic features. FAO Animal Genetic Resources.

Bach Knudsen, K.E., Hansen, I., 1991a. Gastrointestinal implications in pigs of wheat and oat fractions 1. Digestibility and bulking properties of polysaccharides and other major constituents. Br. J. Nutr. 65, 217–232.

Bach Knudsen, K.E., Jensen, B.B., Andersen, J.O., Hansen, I., 1991b. Gastrointestinal implications in pigs of wheat and oat fractions 2. Microbial activity in the gastrointestinal tract. Br. J. Nutr. 65, 233–248.

Barampama, Z., Simard, R.E., 1995. Effects of soaking, cooking and fermentation on composition, in-vitro starch digestibility and nutritive value of common beans. Plant Foods Hum. Nutr. 48, 349–365.

Bindelle, J., Laterme, P., Buldgen, A., 2008. Nutritional and environmental consequences of dietary fiber in pig nutrition: a review. Biotechnol. Agron. Soc. Environ. 12, 69–80.

Bradbury J.H., Holloway, W.D., 1988. Chemistry of Tropical Root Crops: significance for nutrition and agriculture in the Pacific. ACIAR MG S No.6.

Bradbury, J.H., Bradshaw, K., Jealous, W., Holloway, W.D., Phimpisane, T., 1988. Effect of Cooking on Nutrient Content of Tropical Root Crops from the South Pacific. J. Sci. Food Agr. 43, 333–342.

Choct, M., Dersjant-Li, Y., McLeish, J., Peisker, M., 2010. Soy Oligosaccharides and Soluble Non-starch Polysaccharides: A Review of Digestion, Nutritive and Anti-nutritive Effects in Pigs and Poultry. Asian-Australas. J. Anim. Sci. 23, 1386–1398.

Dom, M., Ayalew, W., 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. J. Inst. Chem. PNG 2, 77–88.

Dom, M., Ayalew, W., 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. PNG J. Res. Sci. and Technol. 1, 86–96.

Dom, M., Ayalew, W., Amben, S., 2010. Development of Improved Pig Feeding Systems Using Ensiled Material: On-farm testing of feeding Sweet Potato silage to growing pigs at Tambul in Western Highlands Province. Sci. New Guinea. 30, 94–104.

Dom, M., Ayalew, W., Glatz, P., Kirkwood, R., Hughes, P., 2014. Effect on Nutrient Digestibility and Nitrogen Balance in Grower Pigs Fed Three Forms of Blended Cassava Roots. Sustainable Livestock Production in the Perspective of Food Security, Policy, Genetic Resources and Climate Change, Proceedings of the 16th AAAP Animal Science Congress Vol. II, pp. 676–679.

Dom, M.T., Ayalew, W.K., Glatz, P.C., Kirkwood, R.N., Hughes, P.E., 2017. Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate. Anim. Feed Sci. Technol. 223, 82–89.

Dominguez, P.L., Ly, J., 1997. An approach to the nutritional value for pigs of sweet potato (*Ipomoea batatas* L. (Lam)), LLRD 9, 2. http://www.lrrd.org/lrrd9/2/ly92.htm (accessed 02.06.2013)

Freire, J.P.B., Dias, R.I.M., Cunha, L.F., Aumaitre, A., 2003. The effect of genotype and dietary fibre level in the caecal bacterial enzyme activity of young piglets: digestive consequences. Anim. Feed Sci. Technol. 106, 119–130.

Giang, H.H., Ly, L.V., Ogle, B., 2004. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. LRRD 16, 50. http://www.lrrd.org/lrrd16/7/gian16050.htm (accessed 02.06.2013)

Gonzaléz, C., Díaz, I., Milagro, L., Vecchionacce, H., Alexia, B., Ly, J., 2002 Growth performance and carcass traits in pigs fed sweet potato (*Ipomoea batatas* L. (Lam.)) root meal. LRRD 14, 6. http://www.lrrd.org/lrrd14/6/gonz146.htm (accessed 02.06.2013)

Guixin, Q., Verstegen, W.A., Bosch, M.W., 1995. Variation of the digestive capacity between genetically different pig populations: a review. J. Anim. Physiol. Anim. Nutr. 73, 233–242.

Hang, D.T., 1998. Digestibility and nitrogen retention in fattening pigs fed different levels of ensiled cassava leaves as a protein source and ensiled cassava root as energy source. LRRD 10, 24. http://www.lrrd.org/lrrd10/3/hang1.htm (accessed 02.06.2013)

Hansen, J.A., Chwalibog, A., Tauson, A.H., Sawosz, E., 2006. Influence of different fiber sources on digestibility and nitrogen and energy balances in growing pigs. Arch. Anim. Nutr. 60, 390–401.

Hegarty, R.S., 2012. Livestock nutrition – a perspective on future needs in a resource-challenged planet, Animal Production Science, 52: 406–415.

Heuzé, V., Tran, G., Hassoun, P., Renaudeau, D., Bastianelli, D., 2015. Sweet potato (*Ipomoea batatas*) tubers. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://feedipedia.org/node/745 (accessed 15.12.2015)

Johansen, H., Bach Knudsen, K.E., 1994. Effects of wheat-flour and oat mill fractions on jejunal flow, starch degradation and absorption of glucose over an isolated loop of jejunum in pigs. Br. J. Nutr. 71, 299–313.

Johansen, H.N., Bach Knudsen, K.E.B., Sandstrom, B., Skjoth, F., 1996. Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. Brit. J. Nutr. 75, 339–351.

Kyriazakis, I., 2011. Opportunities to improve nutrient efficiency in pigs and poultry through breeding. Animal 5, 821–832. doi:10.1017/S1751731110002545

Le Gall, M., Warpechowski, M., Jaguelin-Peyraud, Y., Noblet, J., 2009. Influence of dietary fiber level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. Animal 3, 352–359.

Lindberg, J.E., 2014. Fiber effects in nutrition and gut health in pigs. J. Anim. Sci. Biotechnol. 5, 15. http://www.jasbsci.com/content/5/1/15 (accessed 04.04.2015)

Low, A.G., 1989. Secretory response of the pig gut to non-starch polysaccharides. Anim. Feed Sci. and Technol. 23, 55–65.

Ly, J., Ty, C., Samkol, P., 2003. N balance studies in young Mong Cai and Large White pigs fed high fibre diets based on wheat bran. LRRD 15, 1. http://www.lrrd.org/lrrd15/1/ly151.htm (accessed 02.06.2013)

Malynicz, G., Nad, H., 1973. The effect of level of feeding and supplementation with sweet potato foliage on the growth performance of pigs. PNG Agr. J. 24, 139–144.

Moore, K.L., Mullan, B.P., Campbell, R.G., Kim, J.C., 2013. The response of entire male and female pigs from 20 to 100-kg live weight to dietary available lysine. Anim. Prod. Sci. 53, 52–56.

Moter, V., Stein, H.H., 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs. J. Anim. Sci. 82, 3518–3525.

Ndindana, W., Dzama, K., Ndiweni, P.N.B., Maswaure, S.M., Chimonyo, M., 2002. Digestibility of high fibre diets and performance of growing Zimbabwean indigenous

Mukota pigs and exotic Large White pigs fed maize based diets with graded levels of maize cobs. Anim. Feed Sci. Technol. 97, 199–208.

Ngoc, T.T.B, Len, N.T., Lindberg, J.E., 2013. Impact of fiber intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. Animal 7, 736–745. doi: 10.1017/S1751731112002169

NHMRC, 2013. Australian code for the care and use of animals for scientific purposes, eighth ed. National Health and Medical Research Council, Canberra, Australia.

Noblet, J., Fortune, H., Dupire, C., Dubois, S., 1993. Digestible, metabolizable and net energy values of 13 feedstuffs for growing pigs: effect of energy system. Anim. Feed Sci. Technol. 42, 131–149.

Noblet, J., Gilbert, H., Jaguelin-Peyraud, Y., Lebrun, T., 2013. Evidence of genetic variability for digestive efficiency in the growing pig fed a fibrous diet. Animal. 7(8), 1259–1264.

Noblet, J., Le Goff, G., 2001. Effect of dietary fiber on the energy value of feeds for pigs. Anim. Feed Sci. Technol. 90, 35–52.

Noblet, J., van Milgen, J., 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82, 229–238.

NRC, 1998. Nutrient Requirements of Swine, tenth ed. National Research Council, National Academy Press, Washington DC, USA.

Ochetim, S., 1993. Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. Asian-Aust. J. Anim. Sci. 6, 347–360.

Ospina, L., Preston, T.R., Ogle, B., 1995. Effect of protein supply in cassava root meal based diets on the performance of growing-finishing pigs. LRRD 7, 2. http://www.lrrd.org/lrrd7/2/6.htm (accessed 02.06.2013)

Pascual-Reas, B., 1997. A comparative study on the digestibility of cassava, maize, sorghum and barley in various segments of the digestive tract of growing pigs. LRRD 9, 5. http://www.lrrd.org/lrrd9/5/phil95.htm (accessed 02.06.2013)

Peters, D., Tinh, N.T., Minh, T.T., Ton, P.H., Yen, N.T., Hoanh, M.T., 2001. Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam. International Potato Center (CIP), Hanoi, Vietnam.

Quartermain, A.R., Kohun, P.J., 2002. Pig production in Papua New Guinea, in: Jones, R., (Ed), Priorities for Pig Research in Southeast Asia and the Pacific to 2010, ACIAR Working Paper No. 53, Australian Centre for International Agricultural Research, Canberra, pp. 40–47.

Regnier, C., Bocage, B., Archimède, H., Noblet, J., Renaudeau, D., 2013. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. Anim. Feed Sci. Technol. 180, 44–54.

Renaudeau, D., Bocage, B., Noblet, J., 2006. Influence of energy intake on protein and lipid deposition in Creole and Large White growing pigs in a humid tropical climate. J. Anim. Sci. 82, 937–945.

Rose, C.J., White, G.A., 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. PNG Agr. J. 31, 69–72.

Rose, C.J., Williams, W.T., 1983. Ingestion of Earthworms, *Pontoscolex corethrurus*, by Village Pigs, *Sus Scrofa papuensis*, in the Highlands of Papua New Guinea. Appl. Anim. Etho. 11, 131–139.

Schulze, H., van Leeuwen, P., Verstegen, M.W.A., Huisman, J., Souffrant, W.B., Ahrens, F., 1994. Effect of level of dietary neutral detergent fiber on ileal apparent digestibility and ilealnitrogen losses in pigs. J. Anim. Sci. 72, 2362–2368.

Schulze, H., van Leeuwen, P., Verstegen, M.W.A., van den Berg, J.W.O., 1995. Dietary Level and Source of Neutral Detergent Fibre and Ileal Endogenous Nitrogen Flow in Pigs. J. Anim. Sci. 73, 441–448.

Scott, G., Rosegrant, M.W., Ringler, C., 2000. Global projections for root and tuber crops to the year 2020. Food Policy 25, 561–597.

Scott, G.J.H., 1992. Sweet potatoes as animal feed in developing countries: present pattern and future perspectives, in: Machin, D., Nyvold, S., (Eds.), Roots, tubers, plantain and bananas in animal feeding, FAO Animal Production and Health Paper No. 95, Rome, pp. 183–202.

Spencer, P.B.S., Hampton, J., Lapidge, S.A., Mitchell, J., Lee, J., Pluske, J.R., 2006. An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea. J. Genet. 85, 63–66.

Teka, A., Emire, A.A., Haki, G.D., Gezmu, T.B., 2013. Effects of processing on physicochemical and anti-nutritional factors of cassava (*Manihot Esculenta* Crantz) grown in Ethiopia. Int. J. Sci. Innovations Discoveries 3, 212–222.

Tetens, I., Livesey, G., Eggum, B.O., 1996. Effects of the type and level of dietary fiber supplements on nitrogen retention and excretion patterns. Br. J. Nutr. 75, 461–469.

Tomita, Y., Hayashi, K., Hashizume, T., 1985. Palatability of pigs to sweet potato-silage and digestion trial by them. Bull. Fac. Agr. Kagoshima Univ. No. 35, 75–80.

Tzudir, I., Savino, N., Das, K.C., 2012. Effect of replacement of maize with tapioca (*Manihot esculenta*) root meal on the performance of growing crossbred pigs. LRRD 24, 197. http://www.lrrd.org/lrrd24/11/tzud24197.htm (accessed 02.06.2013)

Wenk, C., 2001. The role of dietary fibre in the digestive physiology of the pig. Anim. Feed Sci. Technol. 90, 21–23.

Wilfart, A., Montagne, L., Simmins, H., Noblet, J., van Milgen, J., 2007. Effect of fibre content in the diet on the mean retention time in different segments of the digestive tract in growing pigs. Livest. Sci. 107, 27–29.

Chapter 7: Nutrient utilization in local mixed genotype grower pigs fed sweet potato roots ensiled with or without vine blended with wheat-based protein concentrates

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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Nutrient utilization in local mixed genotype growing pigs fed wheat-based protein concentrates blended with sweet potato roots ensiled with or without vines

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Short title: Nutrient utilization in local mixed genotype pigs

Abstract

Sweet potato (SP) roots and vines are an important feed resource for smallholder pig production, providing digestible energy and protein to pigs. Although dietary fibre may reduce nutrient utilization and N balance in growing pigs offering SP as ensiled feed may improve the feeding value to indigenous crossbred (mixed genotype, MG) growing pigs. Two metabolic trials tested the total tract apparent digestibility (TTAD) of nutrients and N balance in MG growing pigs fed ensiled SP roots (ER) or roots and vines (ERV), blended with two protein concentrates at 380, 400, 430 and 500 g/kg DM into four treatment diets, ER380, ER430, ERV400 and ERV500, compared against a standard wheat-based commercial pellet diet (STD). The trials were conducted using a 4 × 4 Latin Square design with two sets of four MG pigs at 23 kg (Trial 1) and 27 kg (Trial 2) starting BW. The trial pigs were offered one of four diets interchanged during four 8 d periods, with a 5 d adaptation phase and 3 d for total collection of faeces and urine. Pigs were housed in all-steel metabolic cages (1.0 m × 1.0 m × 1.5 m) on stands 0.7 m above floor level. DMI was higher (2,290-2,739 g/d) for pigs on the SP-based diets ($P<0.05$), ADG in Trial 1 was lower (686-718 g/d) but in Trial 2 was similar (944-1072 g/d) to pigs fed STD ($P>0.05$), while the FCR (2.72-3.70) was higher than STD ($P<0.05$) in both trials. DM, OM, CF, fats (EE), carbohydrates (NFE) and energy coefficients of TTAD were superior on the SP-based diets, but Ash, Ca and Total P CTTAD were reduced compared to STD ($P<0.05$). N retained (g N/d) differed between the diets; 27.1 (ERV400), 20.8-24.8 (ER430), 27.7-29.0 (ERV500), 30.8-31.2 (STD); and did not reflect dietary CP or amino acid levels, dietary fibre content, or energy digestibility. However, N retention (NR% intake) and utilization (NR% digested) was inferior to STD for all SP-based diets except ER380 (Trial 2). Higher faecal N (g/d) ($P<0.05$) suggested increased hind gut fermentation in pigs fed on SP-based diets, whereas higher urine N (g/d) ($P<0.05$) indicated a lower N requirement. Dietary fibre in SP vines reduced nutrient utilization for growth but MG pigs adapted over time. Reduced protein and amino acid supplementation is recommended for MG pigs.

Key words: blended diets, ensiled sweet potato, growing pigs, nutrient utilization

Implications

Feeding sweet potato (SP) and other tropical forages to indigenous pigs is advantageous to smallholder farming. Local crossbred or mixed genotype (MG) pigs demonstrated a high digestive capacity for ensiled SP root and vine in blended diets. The fibre in SP vines was well digested by growing MG pigs and may increase energy supply through hind-gut fermentation. SP-based diets may conveniently supplement or replace wheat-based commercial pellet diets for growing pigs managed by smallholder farmers. Further work is required to evaluate MG pig protein and amino acid requirements and the effects of SP dietary fibre on digestion and gut microflora.

Introduction

Feeding sweet potato (*Ipomoea batatas*, L. (Lam)) roots and forage to pigs is characteristic of smallholder farming in tropical countries (Scott et al., 2000) and particularly the use of indigenous breeds and their crossbred progeny (Rodriguez and Preston, 1997). Ensiling sweet potato (SP) enables long term preservation of valuable nutrients in the perishable roots and foliage (Giang *et al.*, 2004a). Fermented feed provides advantages to smallholder pig production but an added complexity to factors influencing pig nutrition, physiology and gut health (Giang *et al.*, 2004b; Ngoc *et al.*, 2013; Missotten *et al.*, 2015). Dietary fibre in forage based diets reduces energy and protein digestibility digestion in growing pigs (Regnier *et al.*, 2013) although the protein N from SP leaves is well utilized (An *et al.*, 2004 and 2005). Providing effective nutrition for pigs requires blending with grain-based protein concentrates which contain a balance of essential amino acids and micronutrients to complement lower nutrients in ensiled SP feed. There is a need to further study the effect of fermented SP roots and vines in blended diets.

Additionally, there is interest in the farming of indigenous crossbred pigs fed on tropical forage diets (Lindberg, 2014). The modern progeny of Papua New Guinean (PNG) village pigs, differentiated here from unimproved pigs as ‘mixed genotype’ (MG) pigs, are an important component of smallholder farming systems for household food security and income (Hide, 2001; Ayalew *et al* 2011). There is a paucity of research on MG pigs, although it is recognized that these animals have survived on minimal health, nutrition and management inputs and thrive on the most basic improvements (Ayalew *et al.*, 2011). One advantage is that indigenous and crossbred pigs have greater capacity for utilizing high fibre feeds, for example, the Zimbawean Mukota pigs (Kanengoni *et al.*, 2002) and the Vietnamese Mong Cai crosses with Large White pigs (Giang *et al.*, 2004b; Ngoc *et al.*, 2013). PNG village pigs demonstrated high nutrient digestibility when fed raw chopped SP roots (Rose and White, 1980). The digestive capacity of modern MG pigs fed ensiled SP feed as the major feed component has not been studied to date. Two metabolic trials were conducted using eight MG growing pigs to determine nutrient utilization when fed SP roots ensiled with or without vines blended with two formulated wheat-based protein concentrates. The experiments tested the hypothesis that there would be no difference to nutrient digestibility, growth performance and N balance between growing MG pigs fed blended SP-based diets or a wheat-based commercial pellet feed.

Methods and Materials

Location

Two 32 d metabolic trials were conducted using facilities at the PNG National Agriculture Research Institute's (NARI) Labu Station (6° 40' 27" S 146° 54' 33" E) in Morobe Province, where the climate is tropical humid. Minimum and maximum temperatures during the trials were 24 °C to 31 °C (Trial 1) and 21 °C to 33 °C (Trial 2), at 40% to 100% RH during the trials.

Experimental pigs and metabolic crates

Two groups of six castrated male growing MG pigs at body weights (BW) 20.2 ± 1.95 kg and 24.1 ± 3.44 kg were selected from Robinson Kale Family Piggery, based at Kindeng in Jiwaka Province (5°47'31"S 144°25'18"E), transported to Labu Station, and maintained on standard commercial pellet feed for 14 d (Trial 1) and 19 d (Trial 2), after which four pigs with mean BW's of 22.9 ± 1.14 kg (Trial 1) and 27.1 ± 1.3 kg (Trial 2) were placed into metabolic crates for the experiment feeding. Metabolic crates were two twin-room, all-steel units with dimensions 1.0 m × 1.0 m × 1.5 m on stands 0.7 m above floor level placed in the centre of an open sided shed with the crates positioned face-to-face for visual contact. Eight pigs remained in the cages for the entire 32 d experimental periods. The additional four pigs were kept in pens.

Experiment diets

Two protein concentrates, Pig Conc.1 and Universal Conc., were prepared as a dry meal (Associated Mills Ltd., Lae (PNG)). Soybean, wheat and minerals and other micronutrients were imported products. All other ingredients were available from local producers. Flame Stockfeeds Pig Grower (Associated Mills Ltd., Lae (PNG)) pellet (~10 mm) feed was the control standard (STD). A local SP cultivar (Rachel White) was used to produce SP silages. The highlands grown SP roots, harvested at maturity in packed 90 kg bags were bought at the Lae Main Market. Fresh SP vine (four non-specific varieties) was harvested from local gardens around Labu Station. Processing and ensiling was done immediately when roots and vines were received and silage was fermented for at least 14 d before feeding to pigs. SP roots were shredded, SP vine were diced into 0.5 to 1 cm pieces, using a manually operated chopper. The material was mixed before ensiling; using table salt (NaCl) at 0.05% w/w of feed as a preservative and promptly packed and compressed into large 80 L polyethylene bins used as storage silos. Acidity in ensiled sweet potato roots was measured at pH 4.0 (data not shown). Two silage treatments were SP roots ensiled alone (ER) and SP roots ensiled with vines (ERV) on a 1:1 kg DM basis. The SP vines provided approximately 300 and 250 g/kg DM in ERV400 and ERV500 respectively. Four treatment diets were prepared by weighing fresh components calculated to provide 2,000 g DM on each feed offered. Universal Conc. was blended at 380 g/kg DM or Pig Conc.1 at 430 g/kg DM with ensiled SP roots providing 620 and 570 g/kg DM in ER380 and ER430 diets respectively; Pig Conc.1 was blended at 400 and 500 g/kg DM with 600 and 500 g/kg DM of mixed SP root and vine silage in diets ERV400 and ERV500. Blending the daily feed was done by hand in large basins. Nutrient compositions of the component feeds and the treatments diets are shown in Tables 1 and 2 respectively.

Table 1 *Analysed and calculated nutrient composition of feed components used in the blended SP-based diets for growing MG pigs*

Nutrients	**Feed components**			
	ER	**ERV**	**Pig Conc.1**[1]	**Uni. Conc.**[1]
Analysed comosition (g/kg DM)				
DM	435	269	879	903
OM	400	248	791	782
Ash	35	21	88	121
CF	10	30	41	47
EE	2	2	44	92
CP	19	32	329	377
NFE[2]	370	185	377	266
Ca	4.6	9.3	18.0	20.7
Total P	4.3	3.8	9.7	10.6
Total N	3.0	5.1	52.6	60.3
Calculated composition (g/kg DM)				
Leu	1.0	2.2	23.4	25.6
Lys	0.8	1.2	20.3	24.4
Met	0.1	0.3	8.2	10.7
Met+Cys	0.6	0.7	12.6	15.7
Thr	0.9	1.6	11.8	14.3
Try	0.1	0.2	3.5	4.2
DE (MJ/kg)[2]	15.5	15.8	15.6	14.2
Lys:DE (kg/MJ)[2]	0.05	0.08	1.30	1.72
Ca:P[2]	1.07	2.45	1.86	1.96
NDF[3]	49	73	179	184
ADF[3]	23	50	59	63
Lignin[3]	5	13	14	15
Starch[3]	301	186	146	80
Total sugars[3]	40	24	41	44

ER = 100% ensiled sweet potato roots: ERV = ensiled sweet potato roots and vines, mixed on 1:1 DM basis: Pig Conc.1 = Pig concentrate1: Uni. Conc. = Universal concentrate.

[1] Protein concentrates Pig Conc.1 and Universal Conc. were provided by Carey Animal Nutrition Ltd, 3 Walnut Grove, Cherrybrook, NSW, Australia, 2126, prepared by Associated Mills Ltd., Lae (PNG.

Ingredient composition of Pig Conc.1: Wheat grain, 120 g/kg, Meat meal 130 g/kg, Blood meal 50 g/kg, Fish meal (PNG) 100 g/kg, Tallow 40 g/kg, Soybean meal 180 g/kg, Wheat millrun (PNG) 358 g/kg, Salt 3 g/kg, Choline chloride (75%) 1 g/kg, Rhodimet-88 Liquid (Methionine) 4 g/kg, Lysine HCl 1 g/kg, Pig Premix 10 g/kg, Mycostat 1 g/kg, Sorbasafe 2 g/kg.

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.

Ingredients composition of Universal Conc.: Meat meal 140.6 g/kg, Fish meal 105.3 g/kg, Tallow 43.8 g/kg, Soybean meal 219.3 g/kg, Millrun 384 g/kg, Choline chloride 1 g/kg, Rhodimet-88 liquid (Methionine) 6.3 g/kg, Avizyme (1310) 0.7 g/kg, Mycostat 0.87 g/kg, Sorbasafe 1.75 g/kg.

[2] Nitrogen Free Extracts (NFE), Digestible Energy (DE), Lysine: digestible energy ratio (Lys:DE), Calcium: Total Phosphorus diet (Ca:P) were calculated from chemical proximate analysis values in this table.

[3] Neutral detergent fibre (NDF), acid detergent fibre (ADF), Lignin, Starch and Total Sugars calculated for each of the Treatment components using data from Carey Animal Nutrition formulation of Pig Conc.1 and Uni. Conc. and for sweet potato roots and vines using updated data on Feedipedia (Heuze *et al.*, 2015).

Table 2 *Estimated nutrient composition of the experimental diets on DM basis for testing digestibility in growing MG pigs*

Nutrients	**Treatment diets**				
	ER380	**ER430**	**ERV400**	**ERV500**	**STD**[1]
Calculated from analysed composition (g/kg DM)					
DM	613	626	513	574	880
OM	545	582	465	519	816
Ash	68	44	48	55	64
CF	24	23	39	40	56
EE	36	20	19	23	38
CP	155	153	155	184	165
NFE[2]	330	386	252	273	557
Ca	10.7	8.5	7.9	9.6	9.2
Total P	6.7	4.9	7.1	7.5	9.7
Total N	24.8	24.2	24.7	29.4	26.4
Calculated from analysed and formulated compositions g/kg DM)					
Leu	10.3	10.6	11.0	13.0	10.3
Lys	9.7	9.2	9.0	10.9	8.6
Met	4.2	3.6	3.5	4.3	2.4
Met+Cys	6.4	5.8	5.6	6.7	5.3
Thr	6.0	5.6	5.9	6.8	5.1
Try	1.7	1.6	1.6	1.9	1.7
DE (MJ/kg)[2]	15.0	15.5	15.7	15.7	14.8
Lys:DE (kg/MJ)[2]	0.7	0.6	0.6	0.7	0.6
Ca:P[2]	1.41	1.46	0.87	1.03	0.94
NDF[3]	100	105	115	126	315
ADF[3]	37.9	38.3	53.4	54.4	92
Lignin[3]	8.6	8.9	13.3	13.5	26
Starch[3]	217	234	170	166	354
Total sugars[3]	41.1	40.2	31.0	32.7	53.0

Treatments: 620 g/kg or 570 g/kg DM as sweet potato ensiled roots (ER380 and ER430), or ensiled roots and vines (ERV400 and ERV500) blended with Pig Conc.1 at 600 g/kg and 500 g/kg DM respectively.

[1] STD Pig Grower and Treatment diet formulations were provided by Carey Animal Nutrition Ltd, 3 Walnut Grove, Cherrybrook, NSW, Australia, 2126.

Ingredient composition of commercial STD Pig Grower feed (Associated Mills Ltd., Lae (PNG): Wheat grain 312 g/kg, Meat meal 52.5 g/kg, Fish meal (PNG) 20 g/kg, Wheat millrun (PNG) 600 g/kg, Limestone fine 5 g/kg, Salt 1.5 g/kg, Choline chloride (75%) 0.5 g/kg, Lysine HCl 2 g/kg, Pig Premix 5 g/kg, Mycostat 0.5 g/kg, Sorbasafe 1 g/kg.

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] Nitrogen Free Extracts (NFE), Digestible Energy (DE), Lysine: digestible energy ratio (Lys:DE), Calcium: Total Phosphorus diet (Ca:P) were calculated from chemical proximate analysis values in Table 1.

[3] Neutral detergent fibre (NDF), acid detergent fibre (ADF), Lignin, Starch and Total Sugars calculated for each of the Treatment diets using data in Table 1.

Experimental procedures

The experimental design used in both metabolic trials was a 4 × 4 Latin Square with four diets as interchanged treatments fed to growing pigs over four consecutive 8 d feeding periods, with 5 d of adaptation feeding before 3 d feeding for sampling. Test diets were interchanged according to a randomized schedule, offered *ad libitum* and refusals collected every 24 h on each morning. Feed offered and refused was weighed on a digital scale (ASDA 692/240, 5000 ± 0.1 g). Fresh piped water (local reservoir) was readily available from nipple drinkers, and four overhead fans (Air Monster 18” id) were directed at the cage and clear of the feeding trough and operated at full volume throughout the feeding period. Manual mist spraying was applied when temperatures reached 30 °C and was also applied during humid periods when pigs displayed discomfort (e.g. restless in cage, scratching, heavy breathing and unsettled when laying). Body weights were measured on d 1, 6 and 8 of each period using a digital platform balance (Xiangshan® T3811-JE2; 200 ± 0.02 kg). Close daily observations were made of the pigs and cage set-up during sample collection days to ensure clean sepadiet of faeces and urine. Pigs were managed according to prescribed animal welfare guidelines approved by The University of Adelaide Animal Ethics Committee (Approval Number 0000016426). The two metabolic trials were completed without incident to the eight selected MG pigs. There were no indications of diarrhoea or other abnormality of body condition, temperature, or behaviour, and standing in crates did not negatively affect the feeding behaviour.

Sample collections

Dry pellet feed and the protein concentrate meal were sampled as received from commercial producing mill. SP roots as fresh roots and in dry milled form, and SP vines delivered fresh were sampled for chemical testing on the day received for processing, while ensiled SP forage was delivered as wet silage sampled after 14 d of fermentation. Total collection of faeces and urine was achieved through steel floor bars with 5 mm spacing, onto sliding steel trays, angled to allow urine to drain off while solid contaminants were trapped by a wire coil allowing urine to be funnelled through a fine metal-sieve into 2.5 L sealed brown glass bottles (Note: sulphuric acid for ammonia N fixation was not available at the time of testing). Faeces were weighed before drying in a Labec® forced air oven at 105 °C, milled and stored in a cool, dry location in Snap-lock® sealed plastic sampling bags. Urine was stored in 500 mL PET bottles in an upright Westinghouse freezer. Sampling was done over 3 d for each 8 d period and faeces and urine samples from each test diet were pooled for the collection period. All samples were collected in 1 kg or 0.6 L duplicates.

Nutrient analytical testing

Chemical proximate analyses of feed, faeces and nitrogen in urine was conducted at the National Analytical and Testing Services Laboratory Ltd (Lae, PNG) using AOAC (2012) Official Methods for DM (AOAC 930.15), crude protein (AOAC 954.01), and total fat determined as ether extracts (EE) (AOAC 920.39), crude fibre (AOAC 978.10), ash (AOAC 942.06), calcium (AOAC 927.02) and total phosphorus (AOAC 964.06). Organic matter (OM) was calculated as OM%=DM%–Ash%. Digestible Energy (DE) was calculated as DE (kCal) = 4,151 – (122 × Ash%) + (23 × CP%) + (38 × EE%) – (64 × CF%), R2=0.89 (Noblet and Perez, 1993) and converted to MJ/kg. Essential amino acids, leucine, lysine, methionine+cysteine, threonine and tryptophan, and dietary fibre as neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (Lignin) were calculated from combined formulation ingredients of Pig Conc.1 (Carey Animal Nutrition) and published values (Heuze *et al.*, 2015).

Statistical analysis

Suitability of the sample size and power in the 4×4 Latin Square design was determined on G*Power Version 3.1.9.2 (Franz Faul, Universitat Kiel, Germany) for statistical testing conducted at 95% significance level. Pearson correlation coefficients were calculated for Minimum and Maximum temperature influence on daily DMI. All data sets were analysed by ANOVA of the Latin Square design using GenStat 15th Edition (VSN Ltd) and the means were separated by Tukey's Honest Significant Difference (HSD) test.

Results

Treatments

Inclusion of SP vines in the ensiled feed increased the ash, CF, carbohydrates (as NFE), total P, NDF, ADF and lignin content in the blended diets ERV400 and ERV500 compared to ER380 and ER430. Total sugar was higher in the blended SP root diets ER380 and ER430. However, these nutrients were higher in STD diet (Table 2). Five essential amino acid were estimated to be higher in SPERV500 than the other four diets including STD. DE was similar in the blended SP diets and these were higher than in the STD pellet diet. Lysine:DE ratio was superior for ER38 and ERV500. Coefficients of TTAD, growth pig performance and N balance from Trial 1 and 2 are in Tables 3 and 4 respectively.

Trial 1: MG pigs starting at 23 kg BW

Nutrient digestibility to MG pigs in Trial 1

CTTAD for DM was higher (*P*<0.05) in MG pigs fed ERV400 than ERV500, ER430 or STD (Table 3). OM, CF, fats (EE), carbohydrate (NFE) and energy CTTAD were superior in pigs fed the SP-based diets. Protein CTTAD was higher for pigs fed STD, ERV400 and ERV500 diets and the lowest for pigs fed ER430. Ash, Ca and phosphorus CTTAD were lower on the SP-based diets than the wheat-based STD.

Growth performance of MG pigs in Trial 1

The mean BW of MG pigs over the 32 d metabolic trial was lower on ERV400 and ERV500 (*P*<0.05). DMI was higher on ERV400 and ERV500 than ER430 and STD (Table 3). There was no correlation between minimum daily temperatures (*P*=0.456) and DMI. There was correlation (17% of DMI data) to maximum daily temperature (*P*<0.001) observed as lower DMI during hotter days (data not shown). MG pig performance on STD was better than ERV400 and ERV500 but similar to ER430. Daily faecal DM output was higher from pigs fed STD and ERV500. Daily urine output (mL) was higher for the three SP-based diets.

N balance in MG pigs in Trial 1

N intake (g/d) to the growing pigs (Table 3) were different between the diets (*P*<0.05). Faecal N output (g/d) was higher in pigs fed the SP-based diets than wheat-based STD. Digested N was highest on ERV500. Urine N losses (g/d) were almost twice as high on the SP-based diets as STD. N retained (g/d) by MG pigs was better on STD than on SP-based diets. N retention (NR% intake) was better on STD, while ERV400 and ERV500 were similar and ER430 the least. N utilization (NR% digested) was highest on the STD diet.

Trial 2: MG pigs starting at 27 kg BW

Nutrient digestibility to MG pigs in Trial 2

CTTAD of DM and OM were higher in pigs fed ER380 and ER430 (*P*<0.05) (Table 4). Ash CTTAD were very different to pigs on each of the diets, and higher for ER380 compared to the other three diets. CF CTTAD was improved in pigs fed SP-the based diets compared to the wheat-based STD. Fat and CP CTTAD was high for all four diets. Carbohydrate (NFE) CTTAD was much higher in pigs fed on SP-based diets, than pigs fed on wheat-based STD. Ca and Total P CTTAD were much higher to pigs fed ER380 and STD than ER430 or ERV500. SP-based diets provided over higher CTTAD energy to growing pigs compared to the wheat-based STD.

Growth performance of MG pigs in Trial 2

Mean BW’s of the pigs on the four treatment diets were similar (*P*>0.05) throughout Trial 2 (Table 4). DMI were 400-700 g higher for the ER380 and ER430 than ERV500 and STD.

There was no correlation of DMI with minimum (*P*=0.130) or maximum (*P*=0.278) daily temperatures (data not shown). ADG were statistically similar on the four diets however FCR were very different between ER430 and STD (*P*<0.05), with ER430 the least efficient. Pigs fed ERV400 and ERV500 had statistically similar FCR to STD and ER430. Faeces DM output (g/d) was the lowest from pigs fed ER380 while urine output (mL/d) was over three to five times higher for pigs fed the SP-based diets than STD diet.

N balance in MG pigs in Trial 2

N intake (g/d) were similar (*P*>0.05) to pigs fed the SP-based diets despite differences in dietary CP (Table 1) or DMI (Table 4). There were statistical differences in the pigs daily faecal N output from each of the diets (*P*<0.05), but SP-based diets were higher than STD. Digested N (g/d) to pigs was higher for ER380, but similar for ER430, ERV500 and STD. Urine N (g/d) losses were much lower on ER380 followed by STD. Urine N losses from pigs fed ER430 and ERV500 were similar. N retained (g/d) was highest in pigs fed ER380 and lowest in ER430, where the only major difference between the two diets was the methionine and Met+Cys levels. N retention (NR% intake) was similar in MG pigs fed ER380, ER430 and STD and lowest for pigs fed on ERV500. N utilization (NR% digested) was different in MG pigs the four diets and was the highest for pigs fed on ER380.

Table 3 *Coefficients of total tract apparent digestibility, growth performance and N balance in growing MG pigs fed blended SP silage diets without (ER430) or with vines (ERV400 and ERV500) or a wheat-based commercial pellet (STD) diet in Trial 1*

Parameters	**Treatment means**				**SEM**	***P*-value**
	ER430	**ERV400**	**ERV500**	**STD**		
Coefficients of apparent total tract digestibility						
DM	0.75^{a}	0.78^{b}	0.75^{a}	0.76^{a}	0.048	0.011
OM	0.86^{b}	0.86^{b}	0.85^{b}	0.81^{a}	0.027	<.001
Ash	0.33^{a}	0.47^{b}	0.33^{a}	0.63^{c}	0.045	<.001
CF	0.57^{ab}	0.72^{c}	0.65^{bc}	0.49^{a}	0.194	<.001
EE	0.78^{a}	0.82^{a}	0.81^{a}	0.76^{a}	0.263	0.357
CP	0.76^{a}	0.83^{b}	0.82^{b}	0.84^{b}	0.087	0.003
NFE	0.93^{b}	0.91^{b}	0.90^{b}	0.83^{a}	0.074	<.001
Ca	0.13^{a}	0.23^{b}	0.22^{b}	0.57^{c}	0.082	<.001
Total P	0.13^{a}	0.51^{c}	0.21^{b}	0.54^{d}	0.044	0.001
Energy	0.97^{c}	0.95^{b}	0.97^{c}	0.85^{a}	0.007	<.001
Growth performance						
Mean BW (kg)	41.0^{b}	39.2^{a}	39.0^{a}	41.1^{b}	0.18	<.001
DMI (g/d)	2290^{ab}	2607^{b}	2532^{ab}	2211^{a}	68.8	0.018
ADG (g/d)	915^{b}	684^{a}	718^{a}	1000^{b}	39.2	0.003
FCR	2.54^{a}	4.09^{c}	3.54^{bc}	2.20^{a}	0.20	0.005
Faeces DM (g/d)	506^{a}	489^{a}	586^{b}	585^{b}	6.83	<.001
Urine (mL/d)	$2{,}750^{ab}$	$3{,}178^{ab}$	$3{,}199^{b}$	$1{,}072^{a}$	434	0.039
N balance (g/d)						
N intake	55.4^{a}	62.0^{c}	74.4^{d}	59.8^{b}	0.35	<.001
Faeces N	23.7^{b}	22.5^{b}	25.2^{b}	13.4^{a}	0.98	<.001
N digested	32.4^{a}	38.2	50.3^{d}	45.7^{c}	0.83	<.001
Urine N	12.6^{b}	13.0^{b}	17.6^{c}	6.5^{a}	0.37	<.001
N retained	20.8^{a}	27.1^{b}	29.0^{c}	31.2^{d}	0.28	<.001
NR% intake[1]	36.1^{a}	46.2^{b}	45.3^{b}	65.8^{c}	1.65	<.001
NR% digested[2]	65.3^{a}	79.2^{c}	71.7^{b}	85.4^{d}	0.23	<.001

ER430 = 570 g/kg DM ensiled SP roots (ER) blended with 430 g/kg DM Pig Conc.1: ERV400 and ERV500 = 600 and 500 g/kg DM ensiled SP roots and vine (ERV) blended with 400 and 500 g/kg DM Pig Conc.1 respectively.

[1] NR% intake is N retained as a percentage of N Intake.

[2] NR% digested is N retained as a percentage of N Digested.

Values within a row with different superscripts differ significantly at $P<0.05$.

Table 4 *Coefficients of total tract apparent digestibility, growth performance and N balance in growing MG pigs fed three blended SP silage diets without (ER380 and ER430) or with vines (ERV500) or a wheat-based commercial pellet (STD) diet in Trial 2*

Parameters	**Treatment means**				**SEM**	***P*-value**
	ER380*	**ER430**	**ERV500**	**STD**		
Coefficients of apparent total tract digestibility						
DM	0.83^{b}	0.81^{b}	0.74^{a}	0.73^{a}	0.090	<.001
OM	0.87^{b}	0.88^{b}	0.83^{ab}	0.78^{a}	0.121	0.005
Ash	0.80^{d}	0.44^{b}	0.37^{a}	0.53^{c}	0.095	<.001
CF	0.59^{ab}	0.65^{b}	0.64^{b}	0.42^{a}	0.411	0.026
EE	0.89^{c}	0.82^{b}	0.78^{a}	0.79^{a}	0.018	<.001
CP	0.88^{b}	0.83^{a}	0.82^{a}	0.81^{a}	0.059	0.001
NFE	0.92^{c}	0.92^{c}	0.90^{b}	0.80^{a}	0.021	<.001
Ca	0.66^{c}	0.18^{a}	0.42^{b}	0.50^{b}	0.238	<.001
Total P	0.80^{b}	0.42^{a}	0.27^{a}	0.67^{b}	0.311	<.001
Energy	0.90^{b}	0.95^{c}	0.97^{d}	0.86^{a}	0.035	<.001
Growth performance						
Mean BW (kg)	45.8^{a}	45.1^{a}	45.0^{a}	47.2^{a}	0.88	0.328
DMI (g/d)	2717^{c}	2739^{c}	2306^{b}	2077^{a}	32.3	<.001
ADG (g/d)	994^{a}	1072^{a}	944^{a}	1067^{a}	88.0	0.704
FCR	2.71^{b}	3.70^{b}	2.72^{ab}	2.31^{a}	0.21	0.018
Faeces DM (g/d)	458^{a}	547^{b}	628^{b}	585^{b}	17.4	0.002
Urine (mL/d)	2123^{b}	2693^{c}	2881^{c}	594^{a}	74.7	<.001
N balance (g/d)						
N intake	67.2^{b}	66.4^{b}	67.8^{b}	55.1^{a}	0.77	<.001
Faeces N	19.3^{b}	22.1^{c}	25.7^{d}	11.7^{a}	0.14	<.001
N digested	49.7^{b}	41.8^{a}	42.5^{a}	43.9^{a}	1.15	0.010
Urine N	8.74^{a}	24.8^{c}	22.8^{c}	17.2^{b}	1.08	<.001
N retained	33.9^{c}	25.8^{a}	27.7^{ab}	30.8^{bc}	0.84	0.002
NR% intake[1]	60.2^{b}	57.0^{b}	40.8^{a}	63.7^{b}	2.07	<.001
NR% digested[2]	88.1^{d}	75.3^{b}	63.1^{a}	83.4^{c}	0.51	<.001

ER380* = 620 g/kg DM ensiled SP roots (ER) blended with 380 g/kg DM Uni. Conc.*: ERV400 and ERV500 = 600 and 500 g/kg DM ensiled SP roots and vine (ERV) blended with 400 and 500 g/kg DM Pig Conc.1 respectively.

[1] NR% intake is N retained as a percentage of N Intake.

[2] NR% digested is N retained as a percentage of N Digested.

Values within a row with different superscripts differ significantly at $P<0.05$.

Discussion

Nutrient utilization in MG growing pigs

This work demonstrated improvement in the nutrient utilization by growing pigs for blended SP-based diets which was comparable to their performance on a wheat-based commercial pellet diet. OM, CF and energy digestibility in growing pigs fed the mixed ensiled SP root and vine diets was better than the wheat-based STD. Energy digestibility was particularly high in ERV400 and ERV500 diets. Considering that these SP-based diets provided less starch than STD diet the additional DE gained must have been from the higher digestibility of blended SP-wheat starch and dietary fibre. Reduced energy digestibility for the STD diet was probably related to the higher dietary fibre (NDF) and faster passage rate through the gut (Len *et al*., 2007), although the latter effect was not measured. Digestibility coefficients in the MG pigs was similar to that of the PNG indigenous village pigs fed raw SP roots where digestibility was high despite the lower nutrition provided (Rose and White, 1980). The nutrient profile of SP-based diets tested in this work were similar to specifications of Australian standards for growing pigs (e.g. Moore *et al*., 2013). In addition, digestibility coefficients in these MG pigs was superior to Mong Cai × Large White crossbred growing pigs fed similar SP-based diets in Vietnam (An *et al*., 2004; Giang *et al*., 2004b). Mong Cai crossbred pigs have physiological and morphological adaptations for digesting high fibre feeds (Ngoc *et al*., 2013; Lindberg, 2014). Similar adaptations to improved digestion of fibre may be proposed for the MG pigs farmed in PNG, although the current population are believed to have genetic admixture with wild, feral and village populations in PNG (Spencer *et al*., 2006; Ayalew et al., 2011).

Interestingly, nutrient utilization in the MG pigs was also comparable to commercial crossbred genotype pigs fed the same ensiled SP root and vine diets and the growth performance was also better (Dom *et al*., 2017; Chapter 5). Under similar conditions of changeover diets and when comparing the same control diet (STD) the MG pigs growth rates were higher while feed efficiency was similar to CG pigs, based on higher DM intake by MG pigs (Chapter 5). The MG pigs were better able to cope under the experimental procedure where diets of completely different composition (viz. wheat-based pellets and ensiled SP roots and vines) were offered interchangingly. This mode of adaptation to changing feed sources and better growth rate under feeding stress is expected considering the continual admixture of the indigenous pigs with introduced exotic breeds over several generations (Hide, 2001; Spencer *et al*., 2006). In fact, apparent digestibility and growth performance was higher in the heavier MG growing pigs (23 kg vs. 27 kg) fed SP-based diets. However, apparent digestibility of the wheat-based control diet did not differ between the two metabolic trials. It was therefore surmised that a longer exposure to SP feed while under smallholder farmer management and the subsequent trial adaptation period (14 d vs. 19 d) modified the MG pig capacity for digesting dietary fibres in blended SP diets, as found to occur with observations on other crossbred pigs (Len *et al*., 2009; Ngoc *et al*., 2013). This is an important finding considering that the MG pigs are an expanding subset of commercially farmed growing pigs in PNG where SP is a major feed resource. It is likely that consistent feeding on the same diets rather than changeover feeding as in these experiments may present distinct differences in performance of growing pig. Also, the MG pigs in tropical production environments may be economically competitive to imported commercial exotic genotypes when using feeds such as sweet potato or cassava (Loc *et al*., 1997; Dom and Ayalew, 2010). Local pigs are more adapted to the warm climates and to available fibrous feeds (Kyriazakis, 2011; Lindberg, 2014). The findings support the theory that MG pigs may have improved capacity to digest the fibre SP vine and foliage. However, other factors, such as variation in feed ingredients as well as their micronutrient levels, and even small differences in nutrient composition may also have influenced the outcome of nutrient digestion and absorption. Nevertheless, superior DM digesstibility in the SP-based diets resulted in much higher energy digestibility. The higher OM and CF coefficients for SP-based diets indicates increased fermentation in the hindgut and it is probable that increased fibre digestibility added microbial N and volatile fatty acids added to the total energy supply (Dierick *et al*., 1990; Tetens *et al*., 1996). In wheat-based STD the higher dietary fibre (NDF, ADF and lignin) probably lowered the energy digestibility. Insoluble fibre does not affect ileal digestion whereas soluble fibre reduces nutrient absorption but not starch absorption (Bach Knudsen and Hansen, 1991). SP roots and vines provide a mixture of dietary fibre. Although not directly studied in this work, a slower rate of digesta passage through the gut and fermentation of soluble fibre in the large intestine affects nutrient absorption and digestible energy balance (Ngoc et al., 2013). The higher DE supplied by SP roots and vines may have significantly contributed to growth and maintenance in MG pigs.

Growth performance of growing MG pigs

DMI for pigs fed ERV400 and ERV500 diets was not affected by the bulky ensiled SP vine and foliage, contrary to some predictions (Bindelle *et al.*, 2008). The amounts of SP-vine inclusion in the diet were higher than the recommended 100 g/kg DM for growing pigs (Dominguez, 1992). SP-vine in ERV500 (250 g/kg DM) was not detrimental to performance, however when fed ERV400 (300 g/kg DM) growth performance was reduced. It appears that the high DMI in MG pigs when fed ERV400 and ERV500 was not an advantage to growth performance in lower body weight pigs. Feed conversion ratio for SP-based diets improved in heavier body weight pigs (Trial 2) and also reflected the better N retained (g/d). The wheat-based STD produced the best growth performances at lower DMI.

N utilization in growing MG pigs

Crude protein digestibility in pigs fed SP-based diets was comparable to those fed the wheat-based STD. N retention on SP-based diets was lower than the STD. However, compensatory improvement in N utilization occurs in growing pigs when soluble fibre (pectin) is included in the diet (Hansen *et al.*, 2006) and this was observed on the SP-based diets. Utilization if digested N for retention improved by 18-33% for SP-based diets compared to 20% for STD diet. SP leaves provide adequate ileal and total tract digestibility for OM (82-88%), CP (74-

75%) and CF (61%) although lower in DM (An *et al.*, 2004). Higher amounts of SP foliage reduce N retention and growth and this is mainly due to the increase in dietary fibre particularly when offered in dry form (Giang *et al.*, 2004; Regnier *et al.*, 2013).The level and type of dietary fibre may influence ileal N (Schulze *et al.*, 1995; Ngoc *et al.*, 2013) although amino acid digestibility is not affected (Sauer *et al.*, 1991). SP vines in this work did not increase dietary fibre in ERV400 or ERV500 compared to the wheat-based STD. Fresh SP-vines offered at lower levels improve protein digestibility and nitrogen retention due to a relatively rich amino acid profile in SP leaves (An *et al.*, 2004). The same may be expected for the ensiled SP vines which included the foliage.

It is apparent that the amino acid supplementation in the concentrate feeds vastly improved the N absorption. This was evident in the increased faecal and urine N output for pigs fed SP-based diets despite mostly similar faecal DM output to STD. High DM intake leads to sloughing of epithelial cells in the gut which adds to faecal N. A shift in N losses from urine to faeces was found in the SP-based diets and this is an indication of microbial fermentation in the pig gut (Tetens *et al.*, 1996). However, it is more likely that the SP-based diets provided in excess of MG pig requirement for protein and amino acids because the urine N loss was statistically very high. On SP-based diets the improved N utilization was supported by higher digestible energy and was regardless of levels of crude protein and amino acid or the effects of dietary fibre. By comparison the wheat-based diet (STD) provided less digestible energy but greater N retention and utilization to growing MG pigs. The better performance on STD pellet diet was related to better amino acid absorption. It is surmised that more energy was required for protein digestion and maintenance needs in the growing pigs fed the SP-based diets and that this occurred at the expense of growth (Nyachoti *et al.*, 1997; Hodgkinson *et al.*, 2000). Importantly the N retained by growing pigs fed SP-based diets (20.8-29.0 g N/d) reached the level for the wheat-based pellet feed (30.8-31.2 g N/d). Further reduction of the protein levels in blended SP diets with amino acid supplementation is possible for growing MG pigs and may be unlikely to affect their growth performance (Le Bellego *et al.*, 2002). At lower dietary protein adequate amino acid supplementation will provides similar performance to pigs fed 16% protein (Kerr et al., 2003).

In conclusion, nutrient and energy utilization in growing pigs fed blended diets of SP-roots ensiled with or without vines was similar to that in the wheat-based commercial pellet feed however growth performance was reduced. MG pigs demonstrated high capacity for digesting ensiled SP vines at 25% and 30% DM however these diets may be better suited to finisher pigs and sows. The higher OM and CF digestibility and high DE gained from SP-based diets indicated that fermentation in the hindgut contributed to the growing pigs energy balance. Although dietary fibre in SP vines reduced growth performance, and occurred when pigs were fed inconsistently on mixed diets, the heavier pigs had adapted over time. Protein digestibility was high but poorer N retention reflected excess N losses, and possibly contributions from endogenous sources during digestion and from microbial activity. Nevertheless, N utilization was improved and indicates that lower protein or amino acid supplementation may be recommended for MG pigs.

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References

An LV, Hong TTT and Lindberg JE 2004. Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (*Ipomoea batatas* L. (Lam.) leaves. Animal Feed Science and Technology 114, 127-139.

Association of Official Analytical Chemists (AOAC) 2012. Official methods of analysis 19th Edition. AOAC International, Gaithersburg, Maryland, USA.

Ayalew W, Gariba D, Dom M, Amben S, Besari F, Moran C and Nidup K 2011. Genetic and cultural significance of native pigs in PNG and their phenotypic features. Food and Agriculture Organization of the United Nations. Animal Genetic Resources 48**,** 37-46.

Bach Knudsen KE and Hansen I 1991. Gastrointestinal implications in pigs of wheat and oat fractions 1. Digestibility and bulking properties of polysaccharides and other major constituents. British Journal of nutrition 65, 217-232.

Bindelle J, Laterme P and Buldgen A 2008. Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. Biotechnology Agronomy Society and Environment 12, 69-80.

Dierick NA, Vervaeke IJ, Decuypere JA and Hendrickx HK 1990. Bacterial protein synthesis in relation to organic matter digestion in the hindgut of growing pigs; contribution of hindgut fermentation to total energy supply and growth performances. Journal of Animal Physiology and Animal Nutrition 63, 220-235.

Dom M and Ayalew W 2010. Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. Journal of South Pacific Agriculture 14, 78-86.

Dom MT, Ayalew WK, Glatz PC, Kirkwood RN and Hughes PE 2017. Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate. Animal Feed Science and Technology 223, 82-89.

Dominguez PL 1992. Feeding of sweet potato in monogastrics. In Roots, tubers, plantains and bananas in animal feeding (eds. D Machin and S Nyvold), pp. 217-233. Food and Agriculture Organization, Rome Italy. Retrieved on 2 July 2013 from http://www.fao.org/ag/aga/agap/frg/AHPP95/95-217.pdf

Giang HH, Ly LV and Ogle B 2004a. Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. Livestock Research for Rural Development 16(45). Retrieved 2 July 2013 from http://www.lrrd.org/lrrd16/7/gian16045.htm.

Giang HH, Ly LV and Ogle B 2004b. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. Livestock Research for Rural Development 16(50). Retrieved 2 July 2013 from http://www.lrrd.org/lrrd16/7/gian16050.htm.

Hansen JA, Chwalibog A, Tauson AH, Sawosz E 2006. Influence of different fibre sources on digestibility and nitrogen and energy balances in growing pigs. Archives of Animal Nutrition 60, 390-401. doi: 10.1080/17450390600884385

Heuze V, Tran G, Hassoun P, Renaudeau D, Bastianelli D 2015. Feedipedia: Sweet potato (*Ipomoea batatas*) tubers. Retrieved on 5 November 2015 from http://feedipedia.org/node/745.

Hide R 2003. Pig Husbandry in New Guinea. A literature review and bibliography. ACIAR Monograph Seris No.108

Hodgkinson, SM, Moughan PJ, Reynolds GW and James KCA 2000. The effect of dietary peptide concentdiet on endogenous ileal amino acid loss in the growing pig. British Journal of Nutrition 83, 421-430.

Kanengoni AT, Dzama K, Chimonyo M, Kusina J and Maswaure SM 2002. Influence of level of maize cob meal on nutrient digestibility and nitrogen balance in Large White, Mukota and LW × M F1 crossbred Pigs. Animal Science 74, 127-134.

Kerr BJ, Southern LL, Bidner TD, Friesen KG and Easter RA 2003. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. Journal of Animal Science, 81: 3075-3087.

Kerr BJ, Southern LL, Bidner TD, Friesen KG and Easter RA 2003. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. Journal of Animal Science 81, 3075-3087.

Kyriazakis I 2011. Opportunities to improve nutrient efficiency in pigs and poultry through breeding. Animal, 5, 821-832.

Le Bellego L, van Milgen J, and Noblet J 2002. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. Journal of Animal Science, 80, 691-701.

Le Gall M, Warpechowski M, Jaguelin-Peyraud Y, Noblet J 2009. Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. Animal 3, 352-359. doi:10.1017/S1751731108003728

Len NT, Hong TTT, Ogle B and Lindberg JE 2009. Comparison of total tract digestibility, development of visceral organs, and digetive tract of Mong Cai and YorkShire × Landrace piglets fed diets with different fibre sources. Journal of Animal Physiology and Animal Nutrition 93, 181-191. doi: 10.1111/j.1439-0396-2007.00804.x

Len NT, Lindberg JE and Ogle B 2007. Digestibility and nitrogen retention of diets containing different levels of fibre in local (Mong Cai), F_1 (Mong Cai × Yorkshire) and exotic (Landrace × Yorkshire) growing pigs in Vietnam. Journal of Animal Physiology and Animal Nutrition 91, 297-303. doi: 10.1111/j.1439-0396.2006.00653.x

Lindberg JE 2014. Fiber effects in nutrition and gut health in pigs. Journal of Animal Science and Biotechnology 5, 15. doi: 10.1186/2049-1891-5-15

Loc NT, Ogle RB and Preston TR 1997. Cassava root silage for crossbred pigs under village conditions in Central Vietnam. Livestock Research for Rural Development 9(2). Retrieved on 5 November 2015 from http://www.fao.org/ag/aga/agap/frg/lrrd/lrrd9/2/loc922.htm.

Missotten JAM, Michiels J, Degroote J, De Smet, S 2015. Fermented liquid feed for pigs: an ancient technique for the future. Journal of Animal Science and Biotechnology 6:4. doi: 10.1186/2049-1891-6-4

Moore KL, Mullan BP, Campbell RG, Kim JC, 2013. The response of entire male and female pigs from 20 to 100-kg live weight to dietary available lysine. Animal Production Science 53, 52-56.

Ngoc TTB, Len NT and Lindberg JE 2013. Impact of fibre intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. Animal 7, 736-745. doi: 10.1017/S1751731112002169

Noblet J and Perez JM 1993. Prediction of digestibility nutrients and energy values of pig diets from chemical analysis. Journal of Animal Science 71, 3389-3398.

Nyachoti CM, de Lange CFM, McBride BW and Schulze H 1997. Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. Canadian Journal of Animal Science 77, 149-163.

Regnier C, Bocage B, Archimede H, Noblet J and Renaudeau D 2013. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. Animal Feed Science and Technology 180, 44-54.

Rodriguez L and Preston 1997. Local feed resources and indigenous breeds: fundamental issues in integrated farming systems. Paper presented at the symposium-workshop Better Use of Locally Available Feed Resources in Sustainable Livestock-based Agriculture in SE Asia (FAO project GCP/RAS/143/JPN), 10 to14 September 1996, University of Agriculture and Forestry, Ho Chi Minh city, Vietnam. Retrieved on 2 July 2013 from http://www.lrrd.org/lrrd9/1/faojpn91.htm.

Rose CJ and White GA 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. Papua New Guinea Agricultural Journal 31, 69-72.

Sauer WC, Mosenthin R, Ahrens F and den Hartog LA 1991. The effect of source of fibre on ileal and fecal amino acid digestibility and bacterial nitrogen excretion in growing pigs. Journal of Animal Science 69, 4070-4077.

Schulze H, van Leeuwen P, Verstegen MWA and van den Berg JWO 1995. Dietary level and source of neutral detergent fibre and ileal endogenous nitrogen flow in pigs. Journal of Animal Science 73, 441-448.

Scott GJ, Rosegrant MW and Ringler C 2000. Roots and tubers for the 21st century: Trends, projections, and policy options. Food, Agriculture, and the Environment Discussion Paper No. 31. International Food Policy Research Institute (IFPRI) and International Potato Center (CIP), Washington, D.C. USA.

Spencer PBS, Hampton J, Lapidge SJ, Mitchell J, Lee J and Pluske JR 2006. An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea. Journal of Genetics 85, 63-66.

Tetens I, Livesey G and Eggum BO 1996. Effects of the type and level of dietary fibre supplements on nitrogen retention and excretion patterns. British Journal of Nutrition 75, 461-469.

Chapter 8: Effect of restricted feeding of blended sweet potato root silage or cereal-based pellet feeds on the growth performance of Papua New Guinean mixed genotype growing pigs

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i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Effect of restricted feeding of blended sweet potato root silage or cereal-based pellet feeds on the growth performance of Papua New Guinean mixed genotype growing pigs

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Abstract

Sweet potato (SP) is an economical feed resource for small-scale farmers growing local mixed genotype (MG) pigs for income and food security. SP crops are susceptible to climate induced agronomic challenges in tropical countries where ensiling of roots and vines is a useful means of feed preservation. When feed availability is limited pig performance is reduced, however, increased nutrient density may overcome the lower feed intake. Two pig growth trials were conducted at a research station and a small piggery, to test the hypothesis that growth performance of MG pigs would not be different when feed was restricted on diets composed of either ensiled SP roots (ER) blended with two protein concentrates (ER43 and ER38) or on two commercial pig pellet feeds (FPG and TPG). The 40 d station trial used 8 castrate male and 8 female pigs at 30.2±7.0 kg BW, fed four diets in a replicated 4×4 Latin Square design, while the 80-d farm trial used 96 grower pigs, 49 females, 47 castrated males, at 21.4±5.7 kg BW, in a randomized complete block design with two diet treatments. Feed offer was restricted to 1.0 kg DM/d on ER43 and ER38, and 1.5 kg DM/d on FPG and TPG for the station trial as well as ER43 and FPG used on the farm trial. There were no feed refusals collected during either trial. The on-station diet ER38 ADG (588 g/d) and FCR (2.13) was superior to other diets ($p<0.05$). On-farm diet FPG ADG (531 g/d), FCR (2.98) and finished weight (63.7 kg) was superior to ER43 ($p<0.05$). Restricted feeding on ensiled SP roots blended at 57% or 62% DM with complementary protein concentrates provided adequate DE for MG pigs however higher amino acid content improved growth performance.

Key words: Ensiled sweet potato, growing pigs, protein concentrate, restricted feeding

Introduction

Sweet potato (*Ipomoea batatas*, L. (Lam)) is an economical feed resource to smallholder livestock production in tropical climates (Scott et al. 2000). Feed production may be challenged by yield decline or crop failure due to disease pathogens and seasonal variations, which are increasingly influenced by El Nino-driven drought and frost events. This pig feed research was conducted during an extended dry season in Papua New Guinea (PNG) which resulted in sweet potato (SP), also the major food crop, being affected by drought conditions (ABC News, 5 July 2016). Anecdotally, during such periods when food crops fail, PNG village households try to survive on their pigs for food, barter or trade. However, the productive potential of SP especially during lush seasons is not fully utilized for food or feed purposes where there is little postharvest storage or processing of perishable roots and less utilization of the abundant vine yield after harvest. Ensiling techniques were recommended as a viable option for extending the shelf-life of SP forage as a fermented feed and presenting a palatable and highly digestible feed to pigs during lean times (Peters et al. 2001; Dom and Ayalew 2009a). The fermentation parameters of ensiling SP were studied and a technique was adapted for local settings (Giang et al. 2004a; Dom and Ayalew 2009b; NARI 2011).

In the Asia-Pacific region over 50% of harvested SP roots and much of the fresh vines goes toward feeding livestock, particularly the farming of indigenous crossbred pigs and poultry (Scott et al. 2000; Peters et al. 2001). The same is true in PNG where the indigenous pigs (*Sus scrofa papuensis*) have been indiscriminately crossbred with several introduced breeds, including Landrace, Large White, Large Black, Berkshire, Tamworth and Duroc, so that the present stock of domesticated village pigs are indistinguishable from feral or wild pigs (Hide 2001; Spencer et al. 2006; Ayalew et al. 2011). There is evidence that local MG pigs have growth performances suitable for smallholder commercial production although the specific genotype parameters for lean vs. fat accretion may be indeterminable. Nevertheless, these ‘mixed genotype’ (MG) pigs are the mainstay of subsistence and smallholder farming, making significant contributions to household income and food security (Gibson and Rozelle 1998; Quartermain and Kohun 2002) and thrive despite unaffordability or general inadequacy of feed nutrition or veterinary health services (Ayalew et al. 2011). When feed availability is limited pig performance is reduced, however, increased nutrient density may overcome the lower feed intake. Research into the nutrient requirements of local crossbred pigs are of interest because of their ubiquity in smallholder farming and the digestive implications of dietary fibre to nutrition and gut health (Regnier et al. 2013; Lindberg 2014). Farming indigenous crossbred pigs provides an advantage to smallholder pork producers where the pigs are adapted to local environments, resilient to prevalent diseases and thrive on cheaper fibrous feeds. The challenge remains to provide consistent feeding levels with the optimum nutrition for maximizing pig growth performance.

PNG village pigs have a high capacity for digesting raw SP (Rose and White 1980) and are probably adapted to fibrous feeds as other indigenous crossbred pigs (e.g. Kanengoni et al. 2004; Giang et al. 2004b; Barea et al. 2011). Village pigs increase growth rates when allowed to forage for earthworms (Rose and Williams 1983) and the performance of the modern MG pigs was enhanced by modest improvements in management and nutrition (Dom and Ayalew 2010; Dom et al. 2010, 2011). Metabolic testing of ensiled SP roots blended with protein concentrate demonstrated nutrient utilization and growth in commercial genotype pig equivalent to feeding standard cereal-based feed (Dom et al. 2017). This current work assessed the growth performance of MG pigs on the same diets composed of 57% and 62% DM as SP root silage blended with two formulated protein concentrates at 43% and 38% DM. The SP-based diets were compared against two different cereal-based pellet feeds. Two growth trials were conducted at a research station and an intensive small-scale pig farm. The trials each tested the hypothesis that growth performance of MG pigs would not be different when feed was offered in restricted amounts of either blended SP root silage or cereal-based pellet feed to MG growing pigs bred and managed in a warm lowlands or cool highlands environment.

Methods and materials

Trial locations

The station trial was conducted at NARI Labu Livestock Research Station, in Lae, Morobe Province (6°40’27”S 146°54’33”E) having a warm-humid lowlands climate from 9 November to 19 December 2015 when temperatures ranged between 23-37°Cand humidity 40-81% (Lae, Nadzab Airport). The farm trial took place at Robinson Kale Family Piggery at Kindeng, Jiwaka Province (5°47'31"S 144°25'18"E) having a cool-dry highlands climate from 5 November 2015 to 29 January 2016 when temperatures ranged between 9-27°C and humidity 51-99% (Banz Town).

General management of pig stock

Station site

Labu Station has maintained a small pig breeding unit for over 40 years since its establishment under PNG’s pre-independence Department of Primary Industry. The main stock kept were of Large White, Large Black and Landrace origin as well as other breeds kept infrequently, and more recently Duroc boars were introduced. Recent (~10 years) crossbreeding achieved with either ‘improved’ village pig have maintained 25% and 50% local genotype in crossbred sows, and further mated with either a commercial pure line boars or ‘wild’ genotype boar (Ayalew et al. 2011) obtained from a remote location (Madang Province) to produce weaned pigs for distribution or for research trials on grower pigs. Main feeds offered were commercial cereal-based pig pellet feed and millrun, which is occasionally blended with broiler feeds, corn meal, copra meal or fish meal, and boiled cassava roots and fresh leaves, as well as other crop residues (e.g. banana pseudo-stems and sugar cane stalks). Management was the considered ‘best practice’ for smallholder farmers where all housed pigs, including sows during pregnancy and pigs at weaning, received injectable Ivomectin® as required. Weaned piglets also received oral iron tablets. Large breeding stock (>120 kg BW) were regularly treated with Panacur®. Anti-biotics are administered on veterinary advice (National Agricultural Quarantine Inspection Authority) and Screwworm smear (3% Lindane) applied as required. Pig pens were managed in a fully covered well-ventilated open-wall shed, with all-concrete floors and walls and piped rain water available through steel nipple drinkers.

Farm site

The Robinson Kale Piggery trial used mixed genotype pigs that were progeny of multiple crossings of village pigs with various introduced breeds and commercial crossbreeds over a period of at least 40 years, including Berkshire, Large-White, Large Black, Landrace and Duroc (Pers. Comm. Mr. Robinson Kale). As of the date of experimentation a consistent sow line had been maintained with boars sourced externally as required, including an exchange with Labu Station. The feed is consistently wheat millrun supplemented with sweet potato grown on-farm, occasionally blended corn meal, copra meal or fish meal was offered to younger stock, and crop residues including waste pineapples, banana, orange peels, pawpaw and sugar cane stalks were fed to larger animals. The management of pigs was similar to those of Labu Station. The pens were all-concrete walls and floor, open-air with 50% roof-coverage and piped rain water available through steel nipple drinkers.

Experiment pigs and design

The station trial used 16 MG grower pigs from three crossbred Large White × MG boar (3 male, 3 females), Duroc sow × MG boar (5 male, 2 female) and Labu Station MG sow × Kale

Piggery MG boar (3 female). Four pigs, two female and two castrated male of at least two weeks difference in farrowing date, were penned in four adjacent all-concrete pens (2m×3m) fitted with single steel nipple drinkers which provided cool fresh water. The pig shed was an open-walled, high-roofed structure allowing good shade and ventilation. The pigs were maintained on commercial pellet feed for 20 d before start of trial. The starting weights were 30.2±7.0 kg. Four pigs were group-fed one of four diets, by restricted offer twice daily (10 am and 3 pm) in ~1.5 m concrete troughs in a replicated 4×4 Latin Square design lasting 40-ds. The pigs were washed daily in the mornings before new feed was offered. Pigs in these trials were managed according to prescribed Australian animal welfare guidelines (NHMRC 2013) approved by The University of Adelaide Animal Ethics Committee (Approval Number 0000016426).

The farm trial used 96 grower pigs, 49 female and 47 castrated male, which were fed two diets at starting weights of 21.4±5.7 kg in a randomized complete block design with two blocks of six replicated pens (approx. 5m×6m) equipped with a single steel nipple providing cool fresh water. Eight pigs were group-fed once daily (0900-1000 h) in ~2.0 m concrete troughs on the restricted offer of either ER43 or FPG treatment diets for 80 d. The pig shed was all-concrete with one-side-open-air and partial roofing to 75 percent of the pen area. The pigs were washed daily in the mornings before new feed was offered. At the end of the trials the majority of pigs were maintained on the same diets before sale.

Experimental treatments

Treatments consisted of two SP-based blended diets and two commercially available pellet feeds, namely, FPG and TPG. FPG was composed of wheat grain 31.2%, meat meal 5.25%, fish meal (PNG) 2.0%, and wheat millrun (PNG) 60%, according to a formulation provided by the manufacturer’s nutritionist (Table 1). The precise formulation of TPG was not available however the ingredients list consisted of barley, broken rice, rice bran, and pea and canola meal and soybean meal. Two protein concentrates, Pig Conc.1 and Universal Conc. were formulated by Carey Animal Nutrition (Australia) and prepared as a dry meal from Associated Mills Ltd (Lae, Morobe Province). The SP-based diets were ensiled roots blended at 57% or 62% DM with either Pig Conc.1 (43%) or Universal conc. (38%), and were labelled ER43 and ER38, respectively (Table 1). The diet treatments were blended daily by hand before being offered to pigs.

The SP silage was prepared using mature food grade SP roots of a single variety, common name Rachel White, sourced from local markets washed and cleaned of soil, and the unpeeled roots were grated on a mechanical shredder (station trial) or a diesel flake mill (farm trial), retro-fitted with flat cutting knives, before collecting on clean canvass sheets. The modified flake mill resulted in a crumble type material, whereas the grater used on-station produced shredded material. Table salt was added at 0.5% w/w of wet material before it was mixed thoroughly by hand and immediately packed and compressed into polyethylene garbage bags (Gladbag®), which were sealed air-tight inside of large 80 L bins. Fermentation was allowed for 14 d before the silos were opened for feeding.

Restricted feed offer

All four diets were used for the station trial while ER43 and FPG were used for the farm trial. Feed offered was restricted to 1.0 kg DM/pig/d for ER43 and ER38, and 1.5 kg DM/pig/d for FPG and TPG in the station and farm trials. Feed levels were established during adaptation periods and adjusted when SP feed supply was unavailable due to an extended drought period. The restricted feed offer was established in the station trial as the maximum feed intake during the first hour of feeding. The bulk weight of ER43 and ER38 was effectively 1.6 kg and satiety in pigs fed this fresh blended feed was observed to be around the same time as pigs fed the dry feeds FPG and TPG, therefore this level of feed offer was maintained in trial.

Chemical analyses

Chemical analysis data for the feed proximate nutrients were obtained from preceding work. The chemical analyses were all conducted at the National Analytical Testing Services Laboratory Ltd (Lae, PNG) using AOAC methods for moisture (AOAC 930.15), ash (AOAC 942.06), fats (AOAC 920.39), crude protein (AOAC 954.01) crude fibre (AOAC 978.10), calcium (AOAC 927.02) and total phosphorus (AOAC 964.06). Organic matter was calculated as OM% = DM% - Ash%. Carbohydrates estimated as nitrogen-free extracts (NFE) as NFE% = DM% - Ash% - CF% - CP%. Digestible energy (DE) was calculated by DE (kCal) = 4,151 – (122 × Ash%) + (23 × CP%) + (38 × EE%) – (64 × CF%), and converted to MJ/kg (Noblet and Perez 1993). Amino acid contents were provided in the protein concentrate formulation (Carey Nutrition, Australia) and adjusted using updated values for sweet potato roots (Heuzéet al. 2015). Other nutrient levels were as provided by the respective feed manufacturers.

Statistical analysis

The station trial was set-up as a replicated 4×4 Latin Square with four pigs as replicates of similar BW in each pen. At the start of the trial the group mean weights of four pigs across each pen were 30.7±1.11 kg, 24.8±0.68 kg, 21.2±0.61 kg, and 16.1±1.88 kg. The data were aggregated by pen. Individual pig BW data (n=64) over the four feeding periods were used to estimate means for each treatment (diet) block. Data for the pig body weights, feed offer and refusal, average daily gain (ADG) and calculated feed conversion ratio (FCR) from both trials was analysed by one-way ANOVA using pens as replicates (station trial) and as blocking factor (farm trial). Tukey’s Honest Significant Difference (station trial) and Least Significant

Differences (farm trial) were used for the separation of means on GenStat®15th Edition (VSN International).

Table 1

Analysed and calculated nutrient contents of feed components and the treatment diets TPG and FPG pellet feeds, and ensiled sweet potato roots blended with Pig Conc.1 or Universal Concentrate (ER38 and ER43)

Nutrient	**Components**			**Treatments**			
	ER	**Pig Conc.1**	**Uni. Conc.**	**ER43**	**ER38**	**FPG***	**TPG****
Analysed composition (% DM)							
Dry Matter (as fed)	43.5	87.9	90.3	62.6	61.3	88.0	92.0
Organic Matter	41.8	79.1	78.2	57.8	55.6	81.6	90.0
Ash	1.7	8.8	12.1	4.8	5.65	6.4	-
Fibre	1.2	4.1	4.7	2.5	2.5	5.6	5.0
Ether Extract	0.5	4.4	9.2	2.2	3.8	3.8	4.0
Protein	1.3	32.9	37.7	14.9	15.1	16.5	16.0
Calcium	0.12	1.80	2.07	0.84	0.86	0.92	-
Total Phosphorus	0.12	0.97	1.06	0.49	0.48	0.97	-
Total Nitrogen	0.21	5.26	6.03	2.38	2.42	2.64	2.60
Calculated composition (% DM)							
Leucine	0.07	2.34	2.56	1.04	1.01	1.03	-
Lysine	0.05	2.03	2.44	0.90	0.96	0.86	0.95
Methionine	0.01	0.82	1.07	0.36	0.41	0.24	-
Met+Cys	0.04	1.26	1.57	0.57	0.62	0.53	-
Threonine	0.06	1.18	1.43	0.54	0.58	0.51	-
Tryptophan	0.01	0.35	0.42	0.16	0.17	0.17	-
DE (MJ/kg DM)	16.4	15.6	14.2	16.1	15.6	14.8	13.5
Lys:DE (kg/MJ DE)	0.03	1.30	1.72	0.58	0.67	0.58	0.70
Ca:P	1.00	1.86	1.96	1.37	1.37	0.94	-
NDF	4.9	17.9	18.4	10.5	10.0	31.5	-
ADF	2.3	5.9	6.3	3.8	3.8	9.2	-
Lignin	0.5	1.4	1.5	0.9	0.9	2.6	-
Starch	30.1	14.6	8.0	23.4	21.7	35.4	-
Total sugars	4.0	4.1	4.4	4.0	4.1	5.3	-

FPG and TPG were commercial pellet feeds; ER43 and ER38 were blended meals of Ensiled SP roots + 43% DM Pig Conc1 or 38% DM Universal Concentrate. ER: calculated nutrient contents from the protein concentrate formulation (Carey Nutrition, Australia) and adjusted using updated values for sweet potato roots on Feedipedia (Heuzéet al. 2015). 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%, 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. Universal concentrate: Meat meal 14.06%, Blood meal 9.65%, fish meal 10.53%, Tallow 4.38%, Soybean meal 21.93%, Millrun (PNG) 38.4%, Choline chloride (75%) 0.1%, Rhodimet-88 Liquid (Methionine) 0.63%, Avizyme 0.07, Mycostat 0.087%, Sorbasafe 0.175%. FPG: 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%. TPG nutrient values were estimated by moisture testing and from values provided in the feed ingredients and nutrient labelling also included Selenium 0.3 mg/kg. A dash (-) denotes unavailable data.

Results

Treatment diets

FPG and TPG pellet diets and ER43 and ER38 blended diets were of similar DM content, fibre and total N (Table 1). Lysine level was similar between FPG and ER43, and between TPG and ER38. Methionine and Methionine+Cystine were higher in the blended SP diets. Calcium and phosphorus levels were higher on FPG whereas TPG had additional selenium, which was not supplied in the SP blended diets or FPG. Digestible energy was 1.3 to 2.8 MJ/kg higher on the SP-based ER43, ER38 and FPG diet than on TPG. There were no feed refusals collected during either station or farm trial.Restricted feed intake on ER43 and ER38 on fresh weight basis was about 1.6 kg/d on station or 2.4 kg/d on farm.

Growth performance

In the station trial, ER38 provided superior ($p<0.05$) ADG and FCR to MG grower pigs. TPG provided pigs similar growth rate ($p>0.05$) to ER38 but feed conversion was 30% lower ($p<0.05$). Growth rate on ER43 was the lowest but feed conversion was similar to TPG. Growth rate on FPG was similar to ER43 and TPG but feed conversion was the lowest. Measurements of the cooling effect on floor temperature during the day showed a 1-3^0C drop in temperature between wet and dry locations and the water temperature (data not shown). In the farm trial, FPG provided faster ADG, better FCR and higher finish weights than ER43 ($p<0.05$).

Table 2

Mean body weight (BW), average daily gain (ADG) and feed conversion efficiency (FCR) for the station feed trial of 16 MG grower pigs on restricted offer for 40d

Parameter	**Grand mean**	**Treatment means (Reps=4 pens)**				**SEM**	***F* Pr.**	**CV%**
		FPG	ER43	ER38	TPG			
DMI (g/d)*	-	1,500	1,000	1,000	1,500	-	-	-
BW (kg)**	35.5	34.4^{a}	35.4^{ab}	36.3^{b}	35.7^{ab}	0.32	0.016	1.8
ADG (g/d)	491	435^{ab}	417^{a}	588^{c}	526^{bc}	22.1	0.001	9.0
FCR (DM basis)	2.99	3.84^{c}	2.95^{b}	2.13^{a}	3.04^{b}	0.15	<.001	10.0

*DMI: dry matter intake assumed at 100% offer on the restricted feeding regime provided to each pig.
**BW: mean body weight for each replicate group of paired male and female pigs over four separate feeding periods by the Latin Square arrangement for interchanged diets.
Means with different superscript are significant at $p<0.05$.

Table 3

The effects of a commercial type diet (FPG) or s diets based on ensiled sweet potato on-farm growth performance as mean body weight (BW), average daily gain (ADG) and feed conversion ratio (FCR) for 96 mixed genotype grower pigs on restricted offer for 80-days

Parameter	**Grand mean**	**Treatment means (Reps=6 pens)**		**SEM**	**LSD**	***F* pr.**	**CV%**
		FPG	ER43				
Adopt BW (kg)	18.3	18.3	18.3	0.40	1.27	0.900	5.4
Start BW (kg)	21.4	21.2	21.6	0.42	1.32	0.529	4.8
Finish BW (kg)	61.1	63.7^{a}	58.6^{b}	0.87	2.74	0.002	3.5
DMI (g/d)*	-	1,500	1,500	-	-	-	-
ADG (g/d)	497	531^{a}	462^{b}	9.46	29.80	<.001	4.7
FCR (DM basis)	3.17	2.98^{a}	3.35^{b}	0.09	0.30	0.020	7.3

*DMI: dry matter intake assumed at 100% offer on the restricted feeding regime provided to each pig.
Means with different superscript are significant at $p<0.05$.

Discussion

The local MG pigs in these two trials were the result of several crossings of introduced commercial lines; PNG highlands raised village pig crossbred lines from Robinson Kale Family Piggery, and various parent stocks from the lowlands around Labu Station. It was assumed that the pigs were representative of the current nationwide scenarios of smallholder pig farming described elsewhere (Ayalew et al. 2011; Amben et al. 2013). The present growth rates and feed conversion were comparable to growing pig performance on similar SP root diets and restricted feeding of cereal-based feeds (e.g. Daza et al. 2003; Giang et al. 2004b; Dom et al., 2010). The MG pig performance found in this work was reasonable at the restricted feeding level and given the heterogeneous genotype.

In this work a drought related feed shortage during commencement of the trials necessitated reduced feed offer. In the station trial a bulk weight of 1.6 kg/d ER43 and ER38 provided only 1.0 kg DM/d to pigs. Bulkiness of feeds such as the ensiled SP roots may cause early satiety in pigs fed ad libitum, lowering the DE intake for growth (Bindelle et al. 2008). The lower DE was disadvantageous for growth in pigs fed ER43 whereas on ER38 the performance was better. In the farm trial blended ER43 was offered at 1.5 kg DM/d but again resulted in lower performance, whereas pigs fed on pelleted FPG attained growth rates superior to the same diet fed pigs on-station. Furthermore, the growth rate from feeding FPG on-farm matched that of pigs fed TPG and ER38 diets on-station. There was no clear evidence of whether blended SP-based or pelleted wheat-based diet was better for growing pigs under the different levels of restricted feeding. Feed intake and growth rate was similar in growing pigs fed ad libitum on corn-soybean diets as either a wet-mash or a dry-pellet, but feed conversion improved on the pellet feed (Chae et al. 1997). Blended diets of boiled, ensiled or milled roots resulted in similar DMI, ADG and FCR to commercial crossbred pigs fed the same wheat-based pellet feed (Dom et al. 2017). The same may be expected for these tested SP-based or wheat-based diets when growing MG pigs are fed to satisfaction. In the present trials feed conversion on FPG was poorer on-station and better on-farm, and the reverse was found for ER43. FPG pellet feed was expected to provide more consistent performance and it is unclear why it produced very different results at the two locations. Furthermore, ER43 was less efficient for pig performance when fed at a higher level on-farm, while performance of pigs fed FPG was not related to the restricted feed intake per se. The inconsistent results between the trial locations suggest that the form of diet presentation was not a factor influencing pig growth performance when feed offer was restricted and that some other factors were involved. It was not certain if the poorer growth performance for ER43 and FPG in the station trial was due to the procedure of interchanging diets since the small nutrient differences in ER38 and TPG increased pig performance. In either trial there were no feed refusals collected for any diet and the pigs all had equal access to the feed. Environmental factors such as climate, pen size, number of pigs per pen and physical activities, group feeding habits, and subclinical health problems may also have influenced the different pig performances on FPG and ER43 between the two trial locations.

There is evidence that the MG pigs can perform exceptionally well on lower nutrition diets. In trials where station-bred MG pigs were fed to appetite with FPG under the same environmental conditions ADG was 720-743 g/d and FCR was 2.51-2.60 (Dom and Ayalew 2010; Dom et al. 2011). On the other hand when FPG was offered ad libitum to MG pigs bred in the high altitude highlands (Tambul, Western Highlands Province) their growth and FCR was similar to the present results (Dom et al. 2010). However, at that trial location (2,250 m altitude) it was likely that food energy was also used for heat generation since the pigs were kept under much lower ambient temperatures (10-20°C) well below the pig thermoneutral zone (Quiniou et al. 2000). Under the present trial conditions on-station pig growth on FPG was only 4.3% better than when fed ER43 but on-farm there was a 14.9% difference. Moreover the growth when pigs were fed ER38 was 35.2% better than FPG. It is likely that if ER38 had been offered at 1.5 kg DM/d the growth rate may have been as high as 795 kg/d. Furthermore, ER38 feed offer was lower than TPG but still resulted in better performance. At restricted feed intake the Lys:DE ratio for ER38 (0.67 kg lysine/MJ DE) and TPG (0.7 kg lysine/MJ DE) resulted in better growth than ER43 and FPG (0.58 kg lysine/MJ DE). Previous work provided evidence that apparent DM digestibility of ER38 and ER43 was higher than the control diet FPG (referred to as STD) (Dom et al., 2017; Chapter 7). However, this was based on a very high feed intake. While total tract digestibility of energy in growing pigs is not affected by reduced feed intake, amino acid digestibility is reduced (Moter and Stein 2004). Endogenous protein and amino acid contribution increases in pigs on restricted feeding (Stein et al. 1999). There may be an improved efficiency in the reabsorption of the endogenous amino acids in growing pig to make up for the lower dietary supply which may reduce performance since DE will be used for maintenance. The greatest absorption of amino acids occur 2 h after feeding and nutrient digestibility is better at 0.95% dietary lysine (Zeng et al. 2013). This may explain why ER38 (0.95% lysine) and TPG (0.96% lysine) resulted in better growth rates in MG pigs.

A critical result of this work was that consistent feeding of only 1.0 kg DM/d growing MG pigs were able to maintain reasonable growth rates when fed ensiled SP roots blended with a suitable protein concentrate. This is recommended to maintain MG pigs during periods of feed shortage or when holding animals to delay the fattening phase. Growing pigs undergo compensatory growth in the fattening phase after a period of feed restriction when their protein requirements are satisfied (Kyriazakis et al. 1991; Ugwu and Onyimonyi 2009). The same result may be possible with these SP-based diets however the current work did not extend beyond the growing phase. It is necessary for the SP-based diets to be further tested on MG pigs fed to satisfaction in order to determine their full growth potential on the improved nutrition under farm conditions. Genotype assessments may be applied to differentiate the growth potential as lean or fat deposition in the hybridized stock of local pigs. Along with carcass evaluations from feeding trials on root-based diets this will provide valuable information to support further development of the important smallholder pig farming activity in PNG and other Pacific Island Countries and Territories. Moreover, local feeds such as SP may provide an opportunity for smallholder farmers to capitalize upon less costly modes of meat production through ensiling and storage, where increases in unit productivity of the farms are regularly affected by seasonal availability of feed.

In conclusion, restricted feeding of ensiled SP roots blended at 57% or 62% DM with a complementary protein concentrates provides adequate DE for MG pigs, however, a higher amino acid content improved growth performance.

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References

Amben, S., Dom, M. and Ayalew, W., 2013. Pigs, People and PNG Vision 2050: A glimpse of Morobe Province, In: P. Pandey, R. Orake and H. Toni (eds), Proceedings of the 7th Huon Seminar, Lae, 2013, (Papua New Guinea University of Technology, Lae), 121--129

Ayalew, W., Gariba, D., Dom, M., Amben, S., Besari, F., Moran, C. and Nidup, K., 2011. Genetic and cultural significance of native pigs in PNG and their phenotypic features, FAO Animal Genetic Resources, 48, 37--46

Barea, R., Nieto, R., Vitari, F., Domeneghini C. and Aguilera, J.F., 2011. Effects of pig genotype (Iberian v. Landrace×Large White) on nutrient digestibility, relative organ weight and small intestine structure at two stages of growth, Animal, 5, 547--557

Chae, B.J., Han, I.K., Kim, J.H., Ohh, S.J., Rhee, Y.C. and Chung Y.K., 1997. Effects of Feed Processing and Feeding Methods on Growth and Carcass Traits for Growing-Finishing Pigs, Asian-Australasian Journal of Animal Science, 10, 164--169

Daza, A., Rodriguez, I., Ovejero, I. and Lopez-Bote, C.J., 2003. Effect on pig performance of feed restriction during the growth period, Spanish Journal of Agricultural Research, 1, 3--8

Dom, M. and Ayalew, W., 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets, Journal of the Institute of Chemists PNG, 2, 77--88

Dom, M. and Ayalew, W., 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. Papua New Guinea Journal of Research, Science and Technology, 1, 86--96

Dom, M. and Ayalew, W., 2010. Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG, Journal of South Pacific Agriculture, 14, 78--86

Dom, M., Ayalew, W. and Amben S., 2010. Development of Improved Pig Feeding Systems Using Ensiled Material: On-farm testing of feeding Sweet Potato silage to growing pigs at Tambul in Western Highlands Province, Science in New Guinea, 30, 94--104

Dom, M., Ayalew, W. and Tarabu, J., 2011. Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG), Journal of South Pacific Agriculture, 15, 62--70

Dom, M., Ayalew, W., and Tarabu. J., 2011. Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG), Journal of South Pacific Agriculture, 15, 6--70

Dom, M.T., Ayalew, W.K., Glatz, P.C., Kirkwood, R.N. and Hughes, P.E., 2017. Nutrient utilization in grower pigs fed boiled, ensiled or milled sweet potato roots blended with a wheat-based protein concentrate, Animal Feed Science and Technology, 223, 82--89

Giang, H.H., Ly L.V. and Ogle, B., 2004a. Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. Livestock Research for Rural Development 16(45). http://www.lrrd.org/lrrd16/7/gian16045.htm. Accessed 2 Jul 2013

Giang, H.H., Ly, L.V. and Ogle, B., 2004b. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs, Livestock Research for Rural Development, 16(7). http://www.lrrd.org/lrrd16/7/gian16050.htm. Accessed 2 Jul 2013

Gibson, J. and Rozelle, S. 1998. Results of the household survey component of the 1996 poverty assessment for Papua New Guinea, (Population and Human Resources Division, The World Bank, Washington)

Gonzalez, C., Diaz, I., Milagro, L., Vecchionacce, H., Alexia, B. and Ly, J., 2002. Growth performance and carcass traits in pigs fed sweet potato (*Ipomoea batatas* L. (Lam.)) root meal, Livestock Research for Rural Development, (14)6. http://www.lrrd.org/lrrd14/6/gonz146.htm. Accessed 2 Jun 2013

Heuzé, V., Tran, G., Hassoun, P., Renaudeau, D. and Bastianelli, D., 2015. Sweet potato (*Ipomoea batatas*) tubers. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://feedipedia.org/node/745/. Accessed 15 December 2015

Hide, R., 2003. Pig husbandry in New Guinea: a literature review and bibliography, (Australian Centre for International Agricultural Research, Canberra; ACIAR Monograph No. 108)

Kanengoni, A.T., Dzama, K., Chimonyo, M., Kusina, J. and Maswaure, S.M. 2004. Growth performance and carcass traits of Large White, Mukota and Large White × Mukota F_1 crosses given graded levels of maize cob meal, Animal Science, 78, 61--66

Kyriazakis, I.C., Stamataris, G.C., Emmans, C. and Whittemore, T., 1991. The effects of food protein content on the performance of pigs previously given foods with low or moderate protein content, Animal Production, 52, 165--172

Le Gall, M., Warpechowski, M., Jaguelin-Peyraud, Y. and Noblet, J., 2009. Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows, Animal 3, 352--359

Lindberg, J.E., 2014. Fiber effects in nutrition and gut health in pigs, Journal of Animal Science and Biotechnology, 5, 15

Moter, V. and Stein, H.H., 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs, Journal of Animal Science, 82, 3518--3525

NARI, 2011. Annual Implementation Plan, NARI Corporate Document No. 4.5, (National Agricultural Research Institute (NARI), Lae)

NHMRC, 2013. Australian code for the care and use of animals for scientific purposes, 8th Edition, (National Health and Medical Research Council, Canberra, Australia)

Noblet. J.,and Perez, J.M., 1993. Prediction of digestibility nutrients and energy values of pig diets from chemical analysis, Journal of Animal Science, 71, 3389--3398.

NRC, 1998. Nutrient Requirements of Swine 10th Edition, National Research Council, (National Academy Press, Washington, USA)

Ochetim, S., 1993. Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity, Asian-Australasian Journal of Animal Science, 6, 347--360

Peters, D., Tinh, N.T., Minh, T.T., Ton, P.H., Yen, N.T. and Hoanh, M.T., 2001. Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam, (International Potato Center (CIP), Hanoi)

Quartermain, A.R. and Kohun, P. J., 2002. Pig production in Papua New Guinea. In: by R.M. Jones (ed), Priorities for Pig Research in Southeast Asia and the Pacific to 2010, (Australian Centre for International Agricultural Research, Canberra; ACIAR Working Paper No. 53), 40--47

Quiniou, N., Dubois, S. and Noblet, J., 2000. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and bodyweight, Livestock Production Science, 63.245--253

Regnier, C., Bocage, B., Archimede, H., Noblet, J. and Renaudeau, D., 2013. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs, Animal Feed Science and Technology, 180, 44--54

Rose, C. J., White, G. A., 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (Ipomoea batatas) by village pigs, Papua New Guinea Agriculture Journal, 31, 69--72

Rose, C.J. and Williams, W.T., 1983. Ingestion of Earthworms, *Pontoscolex corethrurus*, by Village Pigs, *Sus Scrofa papuensis*, in the Highlands of Papua New Guinea, Applied Animal Ethology, 11, 131--139

Scott, G., Best, G., Rosegrant, M.W. and Bokanga, M., 2000. Roots and tubers in the global food system, (International Food Policy Research Institute, Washington)

Spencer, P.B.S., Hampton, J., Lapidge, S.J., Mitchell, J., Lee, J., Pluske, J.R., 2006. An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea, Journal of Genetics, 85, 63--66

Stein, H.H., Trottier, N.L., Bellaver, C. and Easter, R.A., 1999. The effect of feeding level and physiological status on total flow and amino acid composition of endogenous protein at the distal ileum in swine, Journal of Animal Science, 77, 1180--1187

Ugwu, S.O.C. and Onyimonyi, A.E., 2009. The growth performance of growing pigs during feed restriction and re-alimentation in a humid tropical environment, African Journal of Biotechnology, 8, 343--347

Zeng, P.L., Yana, H.C., Wang, X.Q., Zhang, C.M., Zhu, C., Shu, G. and Jiang, Q.Y., 2013. Effects of Dietary Lysine Levels on Apparent Nutrient Digestibility and Serum Amino Acid Absorption Mode in Growing Pigs, Asian-Australasian Journal of Animal Science, 26, 1003—1011

Chapter 9: General discussion and conclusions

1. Introduction

This thesis examines the feeding value of sweet potato (SP) roots and vines and cassava roots as sources of starch, dietary fibre and plant proteins when used at over 50% DM contribution in diets formulated for growing pigs in tropical environments. Three root processing methods and two crossbred pig genotypes were assessed in typical local production systems in Pacific Island Countries (PIC). Six experiments studied the nutrient utilization and growth performance of growing pigs fed blended diets based on SP and cassava root in cooked, ensiled and milled forms, or as mixed SP root and vine silages, blended with complementary protein concentrates. Three of the experiments looked at nutrient utilization in commercial genotype (CG) growing pigs fed SP or cassava roots (Chapters 3, 4 and 5). Two more experiments examined nutrient utilization in local mixed genotype (MG) growing pigs fed blended SP diets (Chapters 6 and 7). One simultaneously run station-based and a farm-based feeding trial tested the growth performances of MG pigs under penned management conditions in lowlands and highlands climates (Chapter 8). The experiments were designed to test the overall hypothesis that there would be no differences in nutrient utilization, as total tract apparent digestibility (TTAD) and N balance, or growth performances (DMI, ADG and FCR), between blended diets of either SP or cassava presented in boiled, ensiled or milled forms, when fed to CG or MG growing pigs. The treatment diets were formulated to provide the optimum nutrition for growing pigs of commercial genotype (CG) and compared in each experiment to a wheat-based pellet feed as a standard reference diet (STD). This established a benchmark for assessing the performance of mixed genotype (MG) pigs in subsequent experiments and in other diets formulated for weanlings, sows and finishers, using such blended diets. SP and cassava based diets were formulated to match the nutrient composition of the control diet (STD) as closely as possible by balancing DE and crude protein levels, and amino acid compositions. Table 1 provides the complete set of nutrient compositions for all of the experimental diets.

Table 1: Analysed and calculated nutrient composition of the SP and cassava blended diets and the control wheat-based standard diet (STD) used in metabolic testing with growing pigs

Feed components	**SP roots + Pig Conc.1**			**SP roots +Uni.Conc.***	**SP roots + SP vines + Pig Conc.1**		**Cassava roots + Pig Conc.1**			**Ref. diet**
Nutrients	**SPMR43**	**SPBR43**	**SPER43**	**SPER38***	**SPERV40**	**SPERV50**	**CAMR45**	**CABR45**	**CAER45**	**STD**
Analysed composition (% DM)										
DM	85.4	59.3	55.8	61.3	51.3	57.4	88.4	60.9	59.0	88.0
OM	80.6	55.0	51.3	54.5	46.5	51.9	83.2	56.4	54.5	81.6
Ash	4.8	4.3	4.5	6.8	4.8	5.5	5.2	4.5	4.5	6.4
CF	2.7	2.3	2.3	2.4	3.9	4.0	2.6	2.2	2.2	5.6
Fats	2.3	2.2	2.1	3.6	1.9	2.3	2.3	2.1	2.1	3.8
CP	15.5	14.7	14.7	15.5	15.5	18.4	15.7	15.2	15.2	16.5
NFE	60.1	35.8	32.3	33.0	25.2	27.3	62.6	36.9	35.0	55.7
Calcium	0.83	0.83	0.83	1.07	0.79	0.96	1.47	1.10	1.07	0.92
Total P	0.51	0.48	0.47	0.67	0.71	0.75	0.59	0.50	0.50	0.97
Total N	2.48	2.35	2.35	2.48	2.47	2.94	2.52	2.43	2.43	2.64
DE (MJ/kg)	16.1	16.3	16.2	15.0	15.7	15.7	15.9	16.3	16.3	14.8
Lys:DE (kg/MJ)	0.60	0.58	0.57	0.70	0.60	0.70	0.60	0.58	0.57	0.58
Ca:P	1.62	1.72	1.76	1.41	0.87	1.03	2.51	2.18	2.16	0.95
Calculated composition (% DM)										
Leucine	1.12	1.08	1.08	1.03	1.10	1.30	1.10	1.07	1.07	1.03
Lysine	0.96	0.94	0.93	0.97	0.90	1.09	0.95	0.94	0.94	0.86
Methionine	0.38	0.37	0.37	0.42	0.35	0.43	0.38	0.37	0.37	0.24
Met+Cys	0.60	0.59	0.59	0.64	0.56	0.67	0.60	0.57	0.57	0.53
Threonine	0.60	0.56	0.56	0.60	0.59	0.68	0.56	0.55	0.54	0.51
Tryptophan	0.17	0.16	0.16	0.17	0.16	0.19	0.16	0.16	0.16	0.17
NDF	13.1	10.1	9.7	10.0	11.5	12.6	11.9	8.8	8.8	27.7
ADF	5.0	3.7	3.5	3.79	5.34	5.44	5.3	3.0	3.0	8.1
Lignin	1.1	0.9	0.8	0.86	1.33	1.35	1.5	0.6	0.6	2.3
Starch	39.2	21.2	18.7	21.7	17.0	16.6	45.8	23.8	22.3	31.2
Total sugars	6.1	3.7	3.4	4.11	3.10	3.27	3.0	1.8	1.8	4.7

SP = sweet potato, CA = cassava roots, MR = milled roots, BR = boiled roots, ER = ensiled roots, STD = standard pig grower feed, 38, 40, 43, 45 and 50 refer to DM% of protein concentrate in the blended diets.

The reference STD diet contained higher levels of dietary fibre (NDF, ADF and lignin) and DE was 1.5 MJ/kg DM lower. In Chapter 3 and 4 metabolic trials the STD pellets were roller-milled to provide a similar consistency of feed as the blended SP and cassava root diets. In the subsequent experiments (Chapters 5-8) the STD pellets were not milled. The test diets followed this treatment design:

a) Milled SP and cassava roots (SPMR43 and CAMR45) were high in DM matching the control diet (STD) and raising the available carbohydrates as starch as well as dietary fibre components.

b) Boiled SP and cassava roots (SPBR43 and CABR45) provided soluble carbohydrates, including dietary fibre, at lower DM.

c) Ensiled SP and cassava roots (SPER43, SPER38 and CAER45) provided fermented carbohydrates with potentially increased solubility, at lower DM.

d) Ensiled SP vine inclusion at 25% and 30% of DMfeed (SPERV50 and SPER40) provided an alternative source of dietary fibre and protein, potentially modifying the digestibility of other nutrients.

e) Wheat-based commercial diet used as the standard reference (STD) in all experiments consisted mainly of wheat (31.2%) and millrun (60.0%) and was produced as a pellet feed.

2. Effect of the form of presentation as milled, boiled or ensiled roots in blended diets

A fundamental need for livestock feeding systems in tropical countries involves replacement, substitution or complementary feeding of root-crops, legumes and other crop residues to animals, in addition to commercial feeds or available protein concentrate supplements (e.g. fish meal, copra meal, palm kernel meal). Processing (milling, boiling, ensiling) of raw feed materials is necessary to improve the storage of bulky feed stuff like sweet potato and cassava, improve their palatability, reduce anti-nutrient properties and allow better digestion of the valuable nutrients. Assessing the effects of large DM quantity of carbohydrates, as starch and dietary fibre from SP and cassava in blended diets, was critical for evaluating the level of voluntary feed intake and benefit to nutrient utilization and growth in growing pigs.

The TTAD of dry matter in SP compared to cassava root-based diets as milled (88% vs 84%) or boiled (92% vs 84%) or ensiled (91% vs 87%) forms were clearly higher than the wheat-based STD (69-76%) when fed to CG pigs. The same was found in MG pigs where DM digestibility was lower on STD (77-81%) or CAMR45 (86%) compared to SPBR43 (88-90%) and CABR45 (89-90%). Digestibility of OM was similarly higher for these root-based diets fed to both genotype pigs thereby demonstrating the suitability of either boiling or ensiling or milling methods for processing the starchy roots. More importantly for the SP and cassava root-based diets the CP digestibility was similar to the wheat-based STD diet across all the experiments. Boiled or ensiled root carbohydrates supported protein digestibility equally well in growing pigs compared to root meals or the STD diet in either milled or pellet form but there was otherwise little effect. Furthermore, there was less than 10% difference between the CP digestibility in either CG or MG growing pigs, indicating that dietary protein of 15-16% CP was well digested by both genotypes on any of the root-based diets or the wheat-based STD.

In the current experiments there appeared to be little advantage to nutrient digestibility when SP or cassava roots were blended with protein concentrate as a dry meal (SPMR43 and CAMR45) compared to boiling (SPBR43 and CABR45) or ensiling the roots (SPER43 and CAER45). The DM content of milled roots was over 80% but the physicochemical properties of the root starches, apart from particle size and moisture content, were probably not modified as much as when boiled or ensiled. SP roots contain more soluble fibre (Dhingra et al., 2012) and the starch is slowly digested allowing energy to be absorbed over a longer period (Odenigbo et al., 2012). Cassava roots are lower in soluble fibre than SP roots (Dhingra et al., 2012) and the starch is highly digestible across the entire pig digestive tract (Ospina et al., 1995). Boiling and ensiling increase the solubility of dietary fibre and starches (Teka et al., 2013; Giang et al., 2004; Barampama and Simard, 1995) which in dietary excess may be expected to undergo microbial fermentation in the hindgut (Choct et al, 2010). Increased microbial activity may explain the elevated crude fibre digestibility and disappearance of the minerals (Metzler and Mosenthin, 2008) particularly in pigs fed the SP-based diets. The TTAD of calcium and phosphorus appeared to be affected by feeding pigs with different root sources, higher for SP and lower for cassava based-diets fed to CG pigs, but consistently high in the MG pigs. The lower ash, fibre, calcium, phosphorus and energy digestibility on cassava root-based diets may suggest that there was less active hindgut fermentation when CG pigs were fed the diets, but this was not assessed directly.

In line with the improved DM and OM digestibility another characteristic of the root-based diets was the enhanced energy digestibility. In both CG and MG growing pigs fed the root-based diets energy digestibility was over 90%, but was consistently lower, at around 80%, for the STD diet. This not only reflected the very high digestibility of starch in SP and cassava roots, but supports the possibility of increased hindgut fermentation of dietary fibre and undigested starch, which was provided in excess on the root-based diets. It is likely that microbial fermentation of some fraction of the root carbohydrates in the pig gut provided volatile fatty acids which added to the metabolic energy gain (Johansen et al., 1994; Degen et al., 2009; Sauer et al., 1991) and this energy contribution requires further study. The N balance in growing pigs also indicated an increased microbial growth when fed the root-based diets, particularly for SP roots in boiled form, where starch and dietary fibre were solubilized.

Interestingly there were some characteristic differences in the fibre digestibility for the diets when tested on the two pig genotypes. In CG growing pigs fed milled, boiled and ensiled SP root-based diets (Chapter 3) TTAD of crude fibre were much higher than the similar cassava root-based diets (Chapter 4). This probably indicated an increased utilization of dietary fibre in SP-blended diets without lowering energy digestibility, whereas cassava starch provided much less digestible energy for growth in similar blended diets. In MG pigs fed the same SP and cassava diets fibre digestibility was over 60% to 80% of DM and was superior to the STD diet (Chapter 6). However, when growing pigs were placed under the mixed experimental treatments including SPERV40 diet (Exp 3 and 5) the DM digestibility of SPER43 was higher (83% vs. 75%) in CG pigs than MG pigs, but CF (28% vs. 57%) and CP (71% vs. 76%) digestibility was reduced in the CG pigs. In Exp 3 CG pigs appeared to be less adaptable than MG pigs (Exp 5) to a rapid change in the fibre component when fed mixed SP root and vine silage (SPERV40). TTAD of fibre in MG pigs was also elevated when fed SPERV50 diet in a mixed treatment structure. In addition, when fed the STD diet MG pigs exhibited higher fibre digestibility than CG pigs (49-89% vs. 27-39%). That represents an improvement in fibre digestibility of 50% based on the best performing MG pigs. This is the first indication that the current hybrid pool of pigs may have an improved capacity for crude fibre digestion and supports much earlier work with PNG village pigs revealing high nutrient digestibility when fed fresh (unprocessed) SP roots (Rose and White, 1980). SP and other garden forages provide the bulk source of fibrous feed to village crossbred pigs. It is likely that hindgut fermentation of the fibrous feed has provided some nutritional benefits, potentially through adaptations in the digestive tract, sustained gut health in the sow, and particularly for animals breeding in small groups where healthy piglets may survive through the weaning stage.

N balance in milled, boiled or ensiled roots in blended diets

N retention (or digestibility) and utilization (%) in CG pigs was consistently better across all diets, 50-78% and 59-89% respectively, compared to MG pigs, 34-63% and 39-72% respectively. Primarily the better N balance in CG pigs reflects their higher lean growth potential, with higher N requirements leading to greater ileal digestion and absorption. Then again MG growing pigs demonstrated much lower N retention and utilization when fed CAMR45, SPBR43, CABR45 and SPER43 than when fed the STD diet. The result suggests that the higher dietary fibre content in the wheat-based STD was an advantage to N retention and utilization in MG pigs. The dynamics of N digestibility and faecal N loss versus N absorption and urine N loss in MG pigs may require further investigation.

a. N retention in CG and MG growing pigs

In CG pigs fed SP root-based diets (Chapter 3) faeces N loss was clearly higher (14 g/d) than in pig faeces from STD diet (7 g N/d). Since the root sources increased the starch and dietary fibre available in the blended diets it was presumed that additional microbial N was included, apart from sloughed cells or undigested proteins and from increased digestive juices. There was no clear difference in faecal N loss between the SP and cassava root-sources, for example, the faeces N losses for CG pigs fed cassava root-based diets (Chapter 4) were numerically the same as the SP-based diets(12-15 g N/d). By comparison, faeces N losses in MG pigs was statistically higher for the SPBR43 diet (10-11 g N/d) than for STD (6-7 g N/d), CABR45 (7-8 g N/d) and CAMR45 (5-6 g N/d) diets (Chapter 6). Moreover, when mixed SP vine diets (Chapters 5 and 7) were fed to pigs, the SPER43 yielded much higher faecal N losses when fed to MG pigs (24 g N/d) than CG pigs (14 g N/d) and was higher than when pigs were fed the STD diet (14 vs, 12 g N/d). Different faecal N losses may indicate a difference in digestive processes and gut microbial populations within the CG and MG growing pigs. This suggests an interaction between the feeding form of the root-source and the genotype of pig. Wheat, the other major feed component in these blended diets, contains more insoluble dietary fibre which is also unaffected by microbial fermentation. Root-based diets provided more soluble fibre and undigested starch. There was probably greater microbial N input from gut bacteria in the MG pigs and this requires further study for taking advantage of potential nutrition and health benefits of hind gut fermentation to locally farmed MG pigs (Noblet et al., 2013; Lindberg, 2014).

b. N utilization in CG and MG growing pigs

In CG pigs fed SP root-based diets the urine N losses (7 g N/d) were much lower than the STD (12 g N/d) or the cassava root-based diets (16-17 g N/d), and lower for the SPER43 than the SPBR43 (8 vs 18 g N/d). High N absorption may be expected in the CG pigs due to their higher lean growth potential. Whereas, in MG pigs the urine N loss from all root-based diets (13-30 g N/d) was consistently much higher than from the STD diet (6-17 g N/d). This was also indicative of the lower growth potential of MG pigs, where there is lower N requirement.Boiling roots increases the solubility of starch and dietary fibre. In both pig genotypesa shift in N loss from urine to faeces in the root-based diets reflected increased microbial activity (Tetens et al., 1995) and did not affect the N retained. N retained (g/d) by CG pigs fed root-based diets was 25-26 g N/d and for STD was 28-30 g N/d. N retained by MG pigs fed root-based diets was 20-30 g N/d and for STD was 30-34 g N/d). It is very likely that driven by a high DM, OM and fibre digestibility, as well as fermentation in the hindgut the MG pigs improved their N utilization to achieve competitive growth rates on the root-based diets compared to the CG pigs and with the wheat-based STD diet. It was concluded that the amino acid or protein component of the root-based diets may be further reduced to provide for the lower nutrient requirement of MG growing pigs.

Growth performances in CG and MG pigs fed root-based diets

The use of milled root diets have been well studied and in this work served as a secondary standard reference to the STD pellet diet for determining the value of ensiled feeds compared to boiled feeds for MG growing pigs. In growing pigs fed milled root blended diets (SPMR43 and CAMR45) the DM intakes were at a similar level to the wheat-based STD (1,962-2,163 vs. 1,910-2,222 g/d) and this was not unexpected given their similar DM content. However, the CG pigs demonstrated clearly superior growth rates when fed on SPMR43 (1,158 g/d) and CAMR45 (1,138 g/d) compared to MG pigs fed CAMR45 (639-795 g/d). The FCR for CG pigs fed SPMR43 (1.84) and CAMR45 (1.81) were also more efficient than for MG pigs fed CAMR45 (2.63-3.08). Factors such as particle size and dryness of the feed may also have affected MG pigs more than CG pigs, and may be worth further considediet in practical pig feeding trials.

a. Growing pig performance on boiled root diets

The DM intake in growing pigs fed boiled root-based diets was much higher compared to milled or ensiled root-based diets or the wheat-based STD diet. Despite the large intake of digestible DM nutrients and energy the FCR was poorer for pigs fed on CABR45 (3.12-3.47) than SPBR43 (1.99-3.38). Nevertheless boiled root-based diets yielded higher ADG for CG pigs (919-1,255 g/d) than MG pigs (709-984 g/d). High DMI on boiled root-based diets was also observed for pigs fed similar diets in metabolic trial (Dom and Ayalew, 2009) and in grow-out trials of similar SP based diets (Dom et al., 2010). The current experiments were conducted under similar warm-humid conditions and opedietal set-up as Dom and Ayalew (2009). Voluntary feed intake in pigs is depressed at higher temperatures (Kyriazakis et al., 1995) but this was clearly not the case in this work. Therefore, it is surmised that the increased DM intake by growing pigs fed boiled root diets was required to overcome the lower energy value of the bulky (40% moisture) boiled roots (Wenk, 2001; Bindelle et al., 2008). In MG growing pigs the higher DM intake for boiled root-based diets may have been required for maintenance needs (e.g. replacement of digestive juices, enzymes and sloughed cells in the gut) rather than growth since ADG did not improve significantly against the STD or ensiled root-based diets.

b. Growing pig performance on ensiled root diets

Despite the higher moisture content of the ensiled root-based diets the DM intake was at about the same level for CG pigs fed CAER45 (2,194 vs. 2,030 g/d) as well as between CG and MG pigs fed SPER43 (1,971 vs. 2,290 g/d) compared to STD diet offered across all the experiments (1,910-2,222 g/d). At this DM intake level the FCR for ensiled root-based diets, CAER45 (2.59) and SPER43 (1.67 vs. 2.54) for CG or MG pigs was also on par with STD (1.84 vs. 2.20). However, there were two instances where the growth performance on SPER43 (Chapter 7) and STD (Chapter 6) were much reduced and this was related to the changeover of experimental diets of higher and lower DM and crude fibre contents. Nevertheless, the ensiled blended diets provided competitive growth rates to the STD diet fed to CG and MG pigs at similar feed intake. Furthermore, the improved FCR indicated that ensiled feeds may provide a more efficient use of the bulky root feeds in addition to the long term storability of the fermented feed. Storing and efficient feeding value of ensiled feeds have practical and economic implications at smallholder level, particularly for the MG growing pigs (Hang et al., 1998; Peters et al., 2001; Dom et al., 2010, 2011). Better growth performance may be expected for the higher pedigree CG (Landrace × Large White × Duroc) pigs than local MG pigs. The FCR were more efficient for milled and ensiled root-based diets, although based on a very high DMI for boiled root-based diets growing pigs also had growth rates similar to when fed the wheat-based STD diet. The performance results provide an indication of the differences in the energy partitioning between growth and maintenance in CG or MG pigs which may have implications for practical farm conditions where the environment is less controlled than in these metabolic experiments.

The DM, OM, CF, CP and energy digestibility of the different forms of blended diets were in agreement with results of SP and cassava root-based diets fed to crossbred pigs in studies by several other authors where the DM proportion of roots were either lower or similar (Tomita et al., 1985; Ospina et al., 1995; Phuc et al., 2001; Giang et al., 2004; Dom and Ayalew, 2009). The N balance from root-based diets were comparable to grain based diets fed to purebred pigs of higher pedigree. Moreover, the superior growth rates provided by these diets, albeit while isolated in metabolic crates, indicated a better outcome from nutrient utilization and potentially an improvement in the local MG pigs compared to evidence in the literature (Malynicz, 1972; Rose and White, 1980; Dom and Ayalew, 2009; Dom et al., 2010, 2011).The use of ensiled SP forage diets may be an advantage for nutrition and gut health to breeding, growing and finishing pigs, particularly for smallholder extensive and intensive pig farming in PNG and elsewhere in PIC. Further grow-out pig trial application of the root and forage-based diets is recommended.

3. Effect of increased dietary fibre by SP vine inclusion in ensiled feed offered to growing pigs

SP vines constitute a major portion of feed offered to pigs daily in many smallholder piggeries in the PIC. The feeding value of SP vine was studied in CG pigs (Chapter 5) and MG pigs (Chapter 7) as a source of additional protein and dietary fibre in blended diets.In particular, the effects of a mixture of fermented SP roots and vines were of interest in livestock research and development for smallholder farmers in tropical countries, with potential benefits through maximum utilization of available crop, longer term storage and the impact on feed efficiency and growth in young pigs. In these experiments fresh SP vines with foliage intact, were chopped and ensiled in 1:1 DM weight mixture with SP roots, to provide 30% and 25% DM respectively in SPERV40 and SPERV50 diets. This level of SP vine inclusion was above the recommended 10%DM (Dominguez, 1990) or similarly mixed SP silage diets (Giang et al., 2004; Dom and Ayalew, 2009). SPERV40 was tested in CG and MG pigs (Chapter 5 and 7), but SPERV50 was tested only in MG pigs (Chapter 7).

Effect of SP vines included at 30% DM to CG and MG growing pigs

DM intake in CG growing pigs fed SPERV40 was reduced by 30% compared to either the blended diet of SP roots without vines (SPER43) or to the STD diet. However, contrary to expectations when fed to MG pigs the bulkiness of SPERV40 did not reduce voluntary feed intake (Wenk, 2001; Bindelle et al., 2008). In fact, voluntary feed intake in CG pigs was 48%

lower thanin MG pigs. Nevertheless the better FCR in CG pigs (2.68) than MG pigs (4.09) suggested more efficiency in the use of digestible nutrients for growth. The very high energy digestibility (95%) in MG pigs fed SPERV40 provided marginally better growth rates than CG pigs (684 vs. 555 g/d) where energy digestibility wasmuch lower (82%). In contrast, FCR in CG and MG pigs were similar for STD diet (2.44 vs 1.90-2.59), as was energy digestibility (81% vs. 85%). In fact, the TTAD of OM, CP and CF were higher in MG pigs than in CG pigs fed SPERV40 diet. It is very likely that hindgut fermentation of dietary fibre provided digestible energy but was a less efficient metabolic pathway in growing pigs. Although at 30%DM the SP vine carbohydrates and protein contributed to the nutrient and energy value of the blended diet the increased fibre digestibility in MG pigs apparently reduced metabolic energy utilization for growth and probably diverted this to maintenance requirements, particularly the replenishment of digestive juices atmuch the higher DMI (Degen et al., 2009).

Additionally, N retention and utilization (%) were reduced in CG pigs fed SPERV40 compared to MG pigs. This was because in CG pigs the N intake was much lower on the bulky feed, and also inferred less utilization of any additional protein N supplied by the SP vines, apart from the protein concentrate. Consequently the N retained by CG pigs was only 9 g N/d compared to 27 g N/d of MG pigs when fed SPERV40. By comparison, CG and MG pigs retained as much as 28-31 g N/d when fed the wheat-based STD diet where surprisingly the MG pig growth was much improved against CG pigs (1067 vs. 817 g/d). The improved MG pig growth rate was most likely a result of diet 8 d changeover effects between different experiments with different genotypes fed blended SP vine diets, in which the CG pigs (Chapter 5) did not recover as well as the MG pigs (Chapter 7). Lower feed intake and nutrient utilization in CG pigs fed SP vines at 30%DM resulted in lower growth rates. Higher nutrient utilization, particularly of crude fibre, in MG pigs fed SP vines at 30%DM resulted in marginally better growth rates at the expense of energy utilization. It may be surmised that

MG pigs perform better than CG pigs when fed high fibre diets more consistently over a longer period. The results also suggest that MG pigs have gained physiological or microbiological adaptation which enhances the digestion of SP vines. Nevertheless, while N retention (%) was better in MG pigs the higher N retained (g/d) did not contribute to increased growth. Digestible energy and protein provided to growing pigs in SPERV40 was utilized more for maintenance functions, although additional energy was gained from hindgut fermentation. Blended diets containing SP vines providing 30%DM may not be recommended for growing pigs, but may be perfectly suitable for adult MG pigs and for sows. It is likely that when this level of SP vines is provided to MG growing pigs at 25-30 kg BW the feeding regime should be consistent to maintain the impact of beneficial adaptations. Adaptations in the digestive tract of PNG's MG pigs are yet to be investigated, particularly since these pigs have been survived in the wild on tropical forages (Hide, 2001) and the crossbred progeny are known to thrive on the same feedstuff with minimal nutritional inputs (e.g. Spencer et al., 2006; Dom and Ayalew, 2009; Dom et al., 2010, 2011).

Effect of SP vine inclusion at 25% or 30% DMto MG growing pigs

The experiments in Chapter 7 provided an opportunity for more consistent feeding of SP vine diets at two levels. SP vine inclusion at 30% (SPERV40) and 25% DM (SPERV50) was tested in MG growing pigs at 23 kg and 27 kg BW for a period of 32 days. At 5% more Pig Conc.1 SPERV50 (18.4%CP) provided more crude protein than SPERV40 (15.5% CP) and the amino acid content was also slightly higher (Table 1). The DMI in either 23 or 27 kg BW pigs was not reduced by the bulkiness of these diets, and in fact was higher than when MG pigs were fed STD diet. The DM nutrient digestibility of SPERV40 and SPERV50 were at very similar levels and resulted in very high energy digestibility (95-97%) compared to the STD diet (85%). The FCR for SPERV40 and SPERV50 diet were still higher than STD diet; however, nutrient utilization was improved. Importantly, the OM (83-86%) and CP (82-84) digestibility were equally high for MG pigs fed SPERV40 or SPERV50. Moreover, the fibre digestibility increased up to 80% in MG pigs. These digestibility results were superior to SP based diets fed to other indigenous crossbred pigs (Giang et al., 2004;Regnier et al., 2013). In fact, in MG pigs fibre digestibility was over 70% higher than for CG pigs fed SPERV40 and over 65% higher than when fed the wheat-based STD diet. This finding was in agreement with reports of several authors that indigenous crossbred pigs demonstrated a greater digestive capacity for high fibre diets than exotic crossbred pigs (Kanengoni et al., 2002; Len et al., 2007; Ngoc et al., 2013). As a result of the improved nutrient and energy utilization and the growth rates of MG pigs were increased, with 27 kg BW pigs (944 g/d) performing better than 23 kg BW pigs (718 g/d). The growth rate in MG pigs fed SPERV50 was improved by 5-28% over SPERV40 diet, but was still 12-33% lower than when fed STD diet. The main difference in these diets was the carbohydrate and dietary fibre composition, which was higher in wheat-based STD than in the root-based test diets (Table 1). The improved MG pig performance was probably the result of solubilized dietary fibre in the fermented SP silage (increased energy digestibility), consistent feeding and maintenance of microbial environment and an improved nutrient absorption (e.g. higher N utilization). Fermented liquid feeds provide beneficial changes to the pig gut microflora by encouraging the growth of lactic acid bacteria and reducing gut pH, and result in improved performances (Canibe and Jensen, 2003; Missotten et al., 2015). There may be a similar benefit to feeding the fermented SP and cassava silages to growing pigs, encompassing nutrient utilisation, growth performance and gut health. Age and breed effects on the utilisation of dietary fibre have been identified (Lindberg, 2014). In farming environments where crossbred pigs have been managed extensively, fed a variety of tropical forages, particularly SP and cassava, and survive without the benefit of veterinary interventions, it seems likely that gut microflora may play a significant role in maintaining health and performance of growing pigs.

A key influence on the similar MG pig growth rates for the very different diets (SPERV40, SPERV50 and STD) was that N utilization (%) was improved despite the lower N retention (%) for SP-based diets. This resulted in N retained of about 30 g/d for both SP-based diets and the wheat-based STD, which is comparable to grain based diets fed at increased dietary fibre content. Two factors influencing N utilization could be the partitioning of protein N into maintenance requirements and increased microbial fermentation. Crossbred pigs from indigenous varieties (e.g. Zimbabwean Mukota or Chinese Mong Cai × Large White) tended to have a lower N retention (Kanengoni et al., 2002; Giang et al., 2004) but not CG pigs fed similar SP-based diets (Dom and Ayalew, 2009). However, in this work the MG pigs fed the SP vine blended diets had an improved N utilization above CG pigs fed the same diets. In fact, very high urine N losses for MG pigs fed SP-based diets indicated that the N requirement had been exceeded. The high level of N utilization in MG pigs was maintained with 25% and 30%DM as SP vines, and was regardless of a 3% difference between protein content in SPERV40 and SPERV50 diets and the higher amino acid content of the latter diet. It was surmised that improved N utilization must also have been due to increased replacement of endogenous N loss. At increased VFI of dietary fibre more digestive juices were produced and thereby affected nutrient utilization. On the other hand, higher N losses in the faeces of MG pigs fed SPERV40 and SPERV50 diet (Tetens et al., 1991), and lowered calcium and phosphorus utilization also suggested that increased microbial fermentation in the MG pigs was an advantage over the CG pigs. Microbial fermentation and calcium and phosphorus digestibility would also be influenced by the excess availability of different carbohydrates and dietary fibre from SP and wheat sources in the diets (Metzler and Mosenthin, 2008). Fermentation provided additional metabolic energy gain to MG pigs but this was less efficient for growth and probably utilized for maintenance needs in the MG pigs. Nevertheless, nutrient and energy utilization where SP vines composed 25% DM provided improved performance in growing pigs and demonstrated the suitability of this type of blended diet.

4. Growth performances of MG pigs in typical commercial production environments

The blended diet of ensiled SP roots with Pig Conc.1 (SPER43) and Uni. Conc. (SPER38) were further used in two growth trials (Chapter 8) with MG pigs bred at a research station (lowlands environment) and at a local smallholder piggery (highlands environment). The wheat-based standard diet (FPG) was maintained as the reference diet and an additional grain based pellet feed (TPG) was included in the station trial. The feeding was restricted to 1.0 kg DM/d and 1.5 kg DM/d for pigs fed blended SP root diets or grain based feed respectively for the station based trial (4 pigs/pen), and 1.5 kg DM/d for both diets in the farm based trial (8 pigs/pen).

Station-based trial

Despite the higher DMI for station bred MG pigs fed FPG and TPG diets the FCR were poor (3.84 and 3.04) and the ADG (435 and 526 g/d) comparable to either SPER43 (417 g/d) or SPER38 diets (588 g/d). A slightly higher lysine content balanced by digestible energy in the larger proportion of ensiled SP roots (62% DM) in SPER38 was the best feed option for MG pigs under restricted offer. Moreover, much better FCR on SPER38 (2.13) than SPER43 (2.95) suggest that this diet may well reduce costs of feeding growing pigs provided that SP roots are available for processing, ensiling and storing. In the warm environment (~30°C) where pigs were maintained cooling was achieved by regularly wetting the concrete floors. Two lysine levels in SPER38 and TPG were higher than in SPER43 and FPG and resulted in better growth perfromances in MG pigs under restricted feeding.

Farm based trial

Restricted feed intake was 1.5 kg DM/d for FPG and SPER43 diets. The ADG and FCR of farm bred MG pigs fed FPG (531 g/d; 2.98) were better than those of pigs fed SPER43 diet (462 g/d; 3.35). The growth performances were comparable to MG pigs in the station-based trial. Growth performance was not directly related to DMI and DE level. Neither were the growth performance influenced by the form of feed as blended meal or pellets. However, the improved growth performance of MG pigs fed the FPG diet indicated that in cooler environmental conditions (~25°C) the additional dietary fibre in the wheat-based diet may have been beneficial for maintaining body temperature where the pigs were partially exposed to cooler ambient temperatures (18°C). In the highlands environment it may be possible to improve the growth performance of growing pigs by including SP vine in the silage mixture to increased dietary fibre since the MG pigs have displayed a better nutrient and energy utilization of this mixed feed (SPERV40 and SPERV50).

Comparison of MG pig growth trials

Under the restricted feeding regime the growth performance of MG pigs in these two trials werelower than for similar genotype pigs when fed to satisfaction where the growth rate was 743.4 g/d and FCR 2.51 (Dom et al., 2011).Comparing againstFPG, also the reference diet (STD),the MG pig growth rate was reduced by up to 28-42% under the restricted feeding in this work and this was based on a 24% reduction in DM feed intake. MG pig performance was also better when fed to satisfaction on a blended diet of STD with mixed SP root and vine silage providing 50% DM. For example, in a small-scale station trial MG pig growth rate was 634.1 g/d and FCR was 2.84 for the mixed SP diet (Dom et al., 2011). However, even when fed to satisfaction MG pigs kept in cooler environments did not perform as well when fed either FPG (585.7±144.5 g/d, FCR 3.16) or the same mixed SP root and vine silage (400.0±251.7 kg/d, FCR 3.23) (Dom et al., 2010).

Given the high nutrient and energy digestibility in MG pigs for SPER43, SPER38 test diets compared toFPG it was expected that the growth performance would be more susceptible to environmental temperatures under the restricted feeding regime. Thermal fluctuations may affect VFI and growth performance, particularly where starch would be more readily digested to cater to pig thermal requirements (Quiniou et al., 2000) and where warmer environments reduce VFI. In the farm trial it appeared that despite its lower DE content the additional fibre in the FPG diet was a benefit to growth over and above maintenance requirements at cooler temperatures. The effects of environmental temperature on growth performance should be investigated for blended root-based diets with a higher nutrient density and the inclusion of SP vines as a source of fermentable carbohydrates and protein N. There may be a benefit to feeding the mixed SP vine silage at cooler temperatures, where additional energy for thermal maintenance may be obtained by hindgut fermentation in the pig. Moreover, it was found that regardless of the DMI and DE available in restricted offer of SP-based diets the growth rate in MG pigs was increased by higher lysine content. There may be strategic advantages to smallholder farming for using SP-based diets to provide growing MG pigs with low feed offer containing appropriate lysine and other amino acid supplementation which supports growth performance when feed is restricted and increases pig performance when fed to satisfaction.

Conclusions

- SP and cassava roots in milled, boiled or ensiled form in blended diets provided similar DM nutrient TTAD to CG and MG growing pigs but much higher energy digestibility than a wheat-based reference diet.
- Fibre TTAD in MG pigs was superior for blended diets with SP vine inclusion indicating much better digestive capacity for the different soluble dietary fibres.
- N retained (g/d) by MG pigs matched CG pigs, but growth and feed efficiency were numerically lower.
- Ensiled SP based diets provided sufficient nutrient utilization and growth to pigs, demonstrating an additional feeding value to storing the fermented forage.
- Improvements in N utilization by MG pigs fed mixed SP root and vine silage were related to increased OM, fibre and energy digestibility, and supported increased growth rates, although feed conversion was less efficient.

- Increased amino acids in blended SP root-based diets improved growth performance but in MG pigs the N utilization was enhanced at greater SP root content.
- Under restricted feeding blended SP root diets provide competitive growth performance to the commercial pellet feeds.

Implications

Sweet potatoroot with or without vines and cassava roots in blended diets relied on 38% to 50% wheat-based protein concentrate to provide feeding value suitable to both commercial (CG) and local mixed genotype (MG) growing pigs. This is the first indication that the current hybrid pool of pigs may have an improved capacity for crude fibre digestion. Moreover, there is good indication that in MG pigs improved digestibility of dietary fibre advantages N utilization, energy retention and growth performance. Primarily the better N balance in CG pigs reflects their higher lean growth potential, with higher N requirements leading to greater ileal digestion and absorption. MG growing pigs may not require the higher levels of protein as CG pigs. This means that nutrition gained from root crop feeds may be further adjusted to MG pig requirements. Root-based diets provided more soluble fibre and undigested starch. There was probably greater microbial N input from gut bacteria in the MG pigs and this requires further study for taking advantage of potential nutrition and health benefits of hind gut fermentation to locally farmed MG pigs. In the highlands environment it may be possible to improve the growth performance of growing pigs by including SP vine in the silage mixture to increase dietary fibre since the MG pigs have displayed a better nutrient and energy utilization of this mixed feed. Similar blend feeding may be recommended for smallholder pig production in the Pacific Island Countries where wheat-based concentrate diets are used. Furthermore, utilizing locally grown root crops as ensiled (fermented) feed produced on-farm may contribute to reducing the costs of feeding growing pigs, whereas sourcing protein concentrate feeds in bulk may ease the transportation and storage needs of smallholder farming in tropical environments.

Further research

- Investigate the comparative digestion of dietary fibre in commercial crossbred and mixed genotype pigs in PNG.
- Determine the responses to and requirement for amino acids of commercial crossbred and mixed genotype pigs fed root-based diets.
- Study into the calcium and phosphorus balance in growing pigs fed ensiled feeds.
- Microflora differences in hind gut fermentation in CG and MG pigs

References

Barampama, Z., Simard, R. E., 1995. Effects of soaking, cooking and fermentation on composition, in-vitro starch digestibility and nutritive value of common beans. Plant Foods Hum. Nutr. 48, 349–365.

Bindelle, J., Laterme, P., Buldgen, A., 2008. Nutritional and environmental consequences of dietary fiber in pig nutrition: a review. Biotechnol. Agron. Soc. Environ. 12, 69–80.

Canibe, N., Jensen, B.B., 2003. Fermented and non-fermented liquid feed to growing pigs: effect on aspects of gastrointestinal ecology and growth performance. J. Anim. Sci. 81, 2019–2031.

Choct, M., Dersjant-Li, Y., McLeish, J., Peisker, M., 2010. Soy Oligosaccharides and Soluble Non-starch Polysaccharides: A Review of Digestion, Nutritive and Anti-nutritive Effects in Pigs and Poultry. Asian-Austral J. Anim. Sci. 23(10), 1386–1398.

Degen, L., Halas, V., Tossenberger, J., Szabo, C. S., Babinszky, L., 2009. The impact of dietary fibre and fat levels on total tract digestibility of energy and nutrients in growing pigs and its consequence for diet formulation. Acta Agr. Scand. 59, 150–160.

Dhingra, D., Michael, M., Rajput, H., Patil, R. T., 2012. Dietary fibre in foods: a review. J Food Sci. Technol. doi: 10.1007/s13197-011-0365-5.

Dierick, N. A., Vervaeke, I. J., Demeyer, D. I., Decuypere, J. A., 1989. Approach to the energetic importance of fibre digestion in pigs. I. Importance of fermentation in the overall energy supply. Anim. Feed Sci. Tech. 23, 141–167.

Dom, M., Ayalew, W., 2009a. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: Digestibility and nitrogen retention of mixed silage diets. J. Inst. Chem. PNG 2, 77–88.

Dom, M., Ayalew, W., 2009b. Adaptation and testing of ensiling sweet potato tuber and vine for feeding pigs: On-station growth performance on mixed silage diets. PNG J. Res. Sci. Tech. 1, 86–96.

Dom, M., Ayalew, W., 2010. Effect of replacing 50% of a commercial grower feed with sweet potato silage on the performance of crossbred pigs in PNG. J. S. Pac. Agr. 14, 78–86.

Dom, M., Ayalew, W., Amben, S., 2010. Development of Improved Pig Feeding Systems Using Ensiled Material: On-farm testing of feeding Sweet Potato silage to growing pigs at Tambul in Western Highlands Province. Sci. in New Guinea J. 30, 94–104.

Dom. M., Ayalew, W., Tarabu, J., 2011. Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG). J. S. Pac. Agr. 15, 62–70.

Dominguez, P. L., 1992. Feeding of sweet potato in monogastrics, in: Machin, D., Nyvold, S., (Eds.), Roots, tubers, plantain and bananas in animal feeding. FAO Animal Production and Health Paper No. 95. Rome, pp. 217–233.

Dominguez, P. L., Ly, J., 1997. An approach to the nutritional value for pigs of sweet potato (*Ipomoea batatas* (L.) Lam.). LLRD 9, 2. http://www.lrrd.org/lrrd9/2/ly92.htm (accessed 02.06.2013)

Giang, H. H., Ly, L. V., Ogle, B., 2004a. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. LRRD 16, 50. http://www.lrrd.org/lrrd16/7/gian16050.htm (accessed 02.06.2013)

Giang, H. H., Ly, L. V., Ogle, B., 2004b. Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. LRRD 16, 45.http://www.lrrd.org/lrrd16/7/gian16045.htm (accessed 02.06.2013)

Hang, D. T., 1998. Digestibility and nitrogen retention in fattening pigs fed different levels of ensiled cassava leaves as a protein source and ensiled cassava root as energy source. LRRD 10, 3. http://www.lrrd.org/lrrd10/3/hang1.htm (accessed 02.06.2013)

Hide, R., 2003. Pig Husbandry in New Guinea. A literature review and bibliography. ACIAR MG. S. 108.

Johansen, H. N., Bach Knudsen, K. E. B., Sandstrom, B., Skjoth, F., 1996. Effects of varying content of soluble dietary fibre from wheat flour and oat milling fractions on gastric emptying in pigs. Brit. J. Nutr. 75, 339–351.

Kanengoni, A. T., Chimonyo M., Erlwanger, K. H., Ndimba, B. K., Dzama, K., 2014. Growth performance, blood metabolic responses, and carcass characteristics of grower and finisher South African Windsnyer-type indigenous and Large White × Landrace crossbred pigs fed diets containing ensiled corncobs. J. Anim. Sci. 92, 5739–5748.

Kanengoni, A. T., Dzama, K., Chimonyo, M., Kusina, J., Maswaure, S. M., 2002. Influence of level of maize cob meal on nutrient digestibility and nitrogen balance in Large White, Mukota and LW × M F_1 crossbred pigs. Anim. Sci. 74, 127–134.

Kerr, B. J., Southern, L. L., Bidner, T. D., Friesen, K. G., Easter, R. A., 2003. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. J Anim. Sci. 81, 3075–3087.

Kyriazakis, I., 2011. Opportunities to improve nutrient efficiency in pigs and poultry through breeding. Animal. doi:10.1017/S1751731110002545

Kyriazakis, I., Emmans, G.C., 1995. Do breeds of pig differ in the efficiency with which they use a limiting protein supply? Brit. J. Nutr. 74, 183–195.

Kyriazakis, I., Whittemore, C. T., (eds.) 2006. Whittemore’s Science and Practice of Pig Production, 3rd edn. Blackwell Publishing, India.

Le Gall, M., Warpechowski, M., Jaguelin-Peyraud, Y., Noblet, J., 2009. Influence of dietary fiber level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. Animal. 3, 352–359.

Len, N. T., Hong, T. T. T., Ogle, B., Lindberg, J. E., 2009. Comparison of total tract digestibility, development of visceral organs, and digetive tract of Mong Cai and YorkShire × Landrace piglets fed diets with different fibre sources. J. Anim. Physiol. Anim. Nutr. 93**,** 181–191. doi: 10.1111/j.1439-0396-2007.00804.x

Len, N. T., Lindberg, J. E., Ogle, B., 2007. Digestibility and nitrogen retention of diets containing different levels of fibre in local (Mong Cai), F1 (Mong Cai × Yorkshire) and exotic (Landrace × Yorkshire) growing pigs in Vietnam. J. Anim. Physiol. Anim. Nutr. 91, 297–303. doi: 10.1111/j.1439-0396.2006.00653.x

Lindberg, J. E., 2014. Fibre effects in nutrition and gut health in pigs. J. Anim. Sci. Biotechnol. 5, 15. doi: 10.1186/2049-1891-5-15

Malynicz, G., Nad, H., 1973. The effect of level of feeding and supplementation with sweet potato foliage on the growth performance of pigs. PNG Agr. J. 24, 139–144.

Metzler, B. U., Mosenthin, R., 2008. A Review of Interactions between Dietary Fibre and the Gastrointestinal Microbiota and Their Consequences on Intestinal Phosphorus and Metabolism in Growing Pigs. Asian-Australas. J. Anim. Sci. 21, 603–615.

Missotten, J. A. M., Michiels, J., Degroote, J., De Smet, S., 2015 Fermented liquid feed for pigs: an ancient technique for the future. J. Anim. Sci. Biotechnol. 6, 4. doi: 10.1186/2049-1891-6-4

Ngoc, T. T. B., Len, N. T., Lindberg, J. E., 2013. Impact of fibre intake and source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. Animal7, 736–745. doi: 10.1017/S1751731112002169

Noblet, J., Gilbert, H., Jaguelin-Peyraud, Y., Lebrun, T., 2013. Evidence of genetic variability for digestive efficiency in the growing pig fed a fibrous diet. Animal. 7, 1259–1264.

Ochetim, S., 1993. Traditional pig farming on the South Pacific: Problems and opportunities for increasing productivity. Asian-Australas. J. Anim. Sci. 6, 347–360.

Odenigbo, A., Rahimi, J., Ngadi, M., Amer, S., Mustafa, A., 2012. Starch digestibility and predicted glycemic index of fried sweet potato cultivars. Funct. Foods Health and Dis. 2, 280–289.

Ospina, L., Preston, T. R., and Ogle, B. 1995. Effect of protein supply in cassava root meal based diets on the performance of growing-finishing pigs. LRRD **7**, 2. http://www.lrrd.org/lrrd7/2/6.htm (accessed 02.06.2013)

Peters, D., Tinh, N. N., Thuy, T. T., Thach, P. N., 2001a. Fermented sweet potato vines for more efficient pig raising in Vietnam. AGGRIPPA. FAO, Rome, Italy. www.fao.org.docrep/article/agrippa/x9500e10.htm./ (accessed 21.05.2015)

Peters, D., Tinh, N. T., Minh, T. T., Ton, P. H., Yen, N. T., Hoanh, M. T., 2001b. Pig feed improvement through enhanced use of sweet potato roots and vines in Northern and Central Vietnam. International Potato Center (CIP), Hanoi, Vietnam.

Phuc, B. H. N., Lindberg, J. E., Ogle, B., Thomke, S., 2001. Determination of the Nutritive Value of Tropical Biomass Products for Monogastrics Using Rats: Effects of Drying Temperature, Ensiling and Level of Inclusion of Cassava Leaves and Sweet potato Vines. Asian-Aust. J. Anim. Sci. 14, 994–1002.

Quiniou, N., Dubois, S., Noblet, J., 2000. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and bodyweight. Livest. Prod. Sci. 63, 245–253.

Regnier, C., Bocage, B., Archimède, H., Noblet, J., Renaudeau, D., 2013. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and erythrina in Creole growing pigs. Anim. Feed Sci. Tech. 180, 44–54.

Rose, C. J., White, G. A., 1980. Apparent digestibilities of DM, OM, CP, energy and ADF of chopped raw sweet potato (*Ipomoea batatas*) by village pigs. PNG Agr. J. 31, 69–72.

Sauer, W. C., Mosenthin, R., Ahrens, F., Den Hartog, L. A., 1991. The effect of source of fibre on ileal and fecal amino acid digestibility and bacterial nitrogen excretion in growing pigs. J. Anim. Sci. 69, 4070–4077.

Schulze, H., van Leeuwen, P., Verstegen, M. W. A., Huisman, J., Souffrant, W. B., Ahrens, F., 1994. Effect of level of dietary neutral detergent fibre on ileal apparent digestibility and ileal nitrogen losses in pigs. J. Anim. Sci. 72, 2362–2368.

Schulze, H., van Leeuwen, P., Verstegen, M. W. A., van den Berg, J. W. O., 1995. Dietary Level and Source of Neutral Detergent Fibre and Ileal Endogenous Nitrogen Flow in Pigs. J. Anim. Sci. 73, 441–448.

Scott, G. J. H., 1992. Sweet potatoes as animal feed in developing countries: present pattern and future perspectives, in: Machin, D., Nyvold, S., (Eds.), Roots, tubers, plantain and bananas in animal feeding. FAO Animal Production and Health Paper No. 95. Rome, pp. 183–202.

Scott, G., Best, G., Rosegrant, M. W., Bokanga, M., 2000. Roots and tubers in the global food system. International Food Policy Research Institute, Washington, USA.

Spencer, P. B. S., Hampton, J., Lapidge, S. J., Mitchell, J., Lee, J., Pluske, J. R., 2006. An assessment of the genetic diversity and structure within and among populations of wild pigs (*Sus scrofa*) from Australia and Papua New Guinea. J. Genet. 85, 63–66.

Teka, A., Emire, A. A., Haki, G. D., Gezmu, T. B., 2013. Effects of processing on physicochemical and anti-nutritional factors of cassava (*Manihot Esculenta* Crantz) grown in Ethiopia. Int. J. Sci. Innovations Discoveries. 3, 212–222.

Tetens, I., Livesey, G., Eggum, B. O., 1996. Effects of the type and level of dietary fiber supplements on nitrogen retention and excretion patterns. Br. J. Nutr. 75, 461–469.

Tomita, Y., Hayashi, K., Hashizume, T., 1985. Palatability of pigs to sweet potato-silage and digestion trial by them. Bull. Fac. Agr. Kagoshima Univ. No. 35, 75–80.

Wenk, C., 2001. The role of dietary fibre in the digestive physiology of the pig. Anim. Feed Sci. Tech. 90, 21–23.