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In the search for low-cost year-round feeds: Pen-level growth performance of local and crossbred Ugandan pigs fed forage- or silage-based diets versus commercial diet

Natalie Ann Carter [a,*], Catherine Elizabeth Dewey [a], Delia Grace [b], Ben Lukuyu [c], Eliza Smith [d], Cornelis de Lange [e,**]

[a] *Population Medicine, University of Guelph, Guelph, Ontario, Canada*
[b] *Food Safety and Zoonoses, International Livestock Research Institute, Nairobi, Kenya*
[c] *Integrated Sciences, International Livestock Research Institute, Kampala, Uganda*
[d] *KYEEMA Foundation, Brisbane, Australia*
[e] *Animal Biosciences, University of Guelph, Guelph, Ontario, Canada*

Abstract

Smallholder pig farmers in East Africa report that lack of feed, seasonal feed shortages, quality and cost are key constraints to pig rearing. Commercially prepared pig diets are too expensive and people and pigs compete for food. Smallholder farmers typically feed nutritionally unbalanced diets, resulting in low average daily gain (ADG) and poor farmer profits. Our objective was to compare the ADG of Ugandan pigs fed forage- or silage-based or commercial diets. Ugandan weaner-grower pigs were randomly assigned to forage- or silage-based diets or commercial diet. Pigs were weighed every 3 weeks from 9 to 32 weeks of age. Pen-level ADG and feed conversion were compared across diets using multiple linear regression. The ADG of pigs fed forage- or silage-based diets was lower than those fed commercial diets between 9 and 24 weeks of age ($p < 0.05$). Between 28 and 32 weeks, pigs fed forage-based diets had lower ADG than those on other diets ($p < 0.05$). Least squares mean ADG (g/pig/day) for pigs fed forage- or silage-based diets or commercial diet were 36, and 52, and 294 respectively at 9–15 weeks; 163, 212, 329 at 15–19 weeks; 112, 362, 574 at 20–24 weeks and 694, 994, and 1233 at 28 to 32 weeks of age. It was concluded that forage- and silage-based diets are unsuitable for small, newly weaned pigs. Feeding forage- or silage-based diets to finishing pigs is more suitable. Forage- and silage based diets are year-round low-cost pig-feeding strategies that will improve the growth performance of East African pigs, thereby increasing pig farmer income and food security.

Keywords: average daily gain, East Africa, feed conversion, smallholder, swine

1 Introduction

Lack of feed, poor quality feed and cost of feedstuffs are key constraints to pig rearing for smallholder pig farmers in East Africa (Mutua *et al.*, 2012; Ouma *et al.*, 2015). Pig farmers have limited access to feedstuffs, inadequate storage, restricted processing ability and cannot afford commercially prepared pig diets (ibid.). Feedstuffs availability fluctuates seasonally, exacerbating existing food/feed shortages (Kagira *et al.*, 2012; Mutua *et al.*, 2012). Pig farmers consume many of the same products typically fed to pigs (e.g. maize, fruit, sun-dried fish) resulting in food competition (ibid.). A variety of feedstuffs, including kitchen waste, are fed to pigs and pigs typically eat carbohydrate-rich low-or-no-protein nutritionally unbalanced diets (ibid.). Smallholder pig-keeping practices, i.e., free-range management and inadequate and imbalanced feeding contributes to poor

* Corresponding author – natalieacarter001@gmail.com
60 University Private, Ottawa, Ontario, Canada, K1N 6N5
Phone: +613-562-5800; Fax: +613-562-5154

** Deceased

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growth performance of pigs on East African smallholder farms (130 g/day) (Kagira *et al.*, 2010; Mutua *et al.*, 2012; Carter *et al.*, 2013), and elsewhere in the tropics (Phengsavanh *et al.*, 2010; Kambashi *et al.*, 2014) resulting in decreased farmer profit (Levy *et al.*, 2009). During the dry season, some pigs (33 %) are permitted to scavenge but during the cropping season, most pigs (65 %) are kept tethered (Kagira *et al.*, 2010). In many cases (31 %) pigs feed mainly on grass while tethered under a tree (Mutua *et al.*, 2012; Mbuthia *et al.*, 2015).

Pig performance in East Africa would be improved through the use of well-balanced cost-effective diets. Ideally, locally available feedstuffs fed either fresh or ensiled would be used to meet the nutrient requirements of pigs (Ly *et al.*, 2012; Kaensombath *et al.*, 2013). Efficient use of these feedstuffs is required for sustainable and profitable pig production thereby improving rural livelihoods. Low-cost forage- and silage-based diets containing some zero-cost feedstuffs are needed to improve pig performance and empirical evidence of their efficacy is required. Our hypotheses were threefold: (1) average daily gain (ADG) of pigs fed forage- or silage-based diets is higher than reported ADG of pigs raised under typical East African smallholder management conditions but lower than pigs fed a commercial diet; (2) feed conversion of pigs fed forage- or silage-based diets is less efficient than pigs fed a commercial diet; and (3) ADG is positively correlated with body weight (BW). The objectives of the study were to determine the ADG and feed efficiency (gain to feed [G : F] ratio) of local (LB) and crossbred (exotic × local; CB) pigs in Uganda fed 1 of 3 diets (forage-based, silage-based, or commercial). This study demonstrated that forage- and silage- based diets are low-cost year-round pig-feeding strategies that can improve the growth performance of pigs in East Africa.

2 Materials and methods

2.1 Diet formulation

Feedstuffs included in this study were selected based on nutrient content, cost, relative importance, farmer ease of access, seasonal availability, known safe levels of inclusion due to absence of anti-nutritional factors, and likelihood of securing sufficient volume throughout the trial period. Sweet potato vine and tuber silage was included in response to seasonal feedstuff shortages because silage can be made when vines and tubers are plentiful, and fed when feedstuffs are scarce (Peters, 1997). The 70 % vines, 30 % tubers, 0.05 % salt (as fed basis) ratio reflected optimal pH and nutrient results reported for silage in East Africa (Manoa, 2012).

The nutritional requirements of 8 to 65 kg bodyweight (BW) CB pigs in Uganda were determined using the methods outlined in Carter *et al.* (2017). Briefly, a static model, based on the dynamic National Research Council of the National Academies (NRC, 2012) nutrient requirement model for growing-finishing pigs was developed to represent the use of daily intake of digestible energy (DE in kcal/kg of dry matter; DM) for maintenance, body lipid deposition (Ld, gram/day) and body protein deposition (Pd, gram/day), for pigs between 8 to 65 kg BW. Mean ADG (kg/day) was predicted from Ld and Pd using the static model. Nutrient requirements for Ugandan CB pigs (8 to 65 kg BW) were predicted. All other calculations, including nutrient requirement predictions, were taken directly from NRC (2012). Balanced low-cost diets (forage- and silage-based) were formulated for two phases of feeding (newly weaned and finishing pigs (8 to 20 and 20 to 65 kg BW, respectively) using a least-cost diet formulation program based on Skinner *et al.* (2012) and 26 available feedstuffs (Carter *et al.*, 2015). The composition of diets is presented in Table 1 and the calculated nutrient composition is presented in Table 2.

2.2 Newly weaned and finishing growth study

Animal use was approved by University of Guelph, Guelph, Canada and the International Livestock Research Institute (ILRI), Nairobi, Kenya. In 2014, 45 LB and 45 CB (local × Landrace and/or Large White and/or Camborough) pigs from 16 farms were enrolled in the study. The sample size was calculated based on a 20 gram difference in pen-level ADG using 80 % power and 5 % confidence level. Variance of gain per day was estimated to be 240 grams. Ten pens per diet were required and each pen contained three pigs as replicates. Pig breed was determined by farmer recall. All pigs were born within 3 days of each other. Pigs were individually weighed after the first feeding of the day at the trial start and every 21 days. Pigs were fed one of three diets *ad libitum*: (1) forage-based or (2) silage-based or (3) a commercial sow and weaner feed (Ugachick Poultry Breeders, Namulonge Rd, Gayaza, P.O. Box 12337 Kampala, Uganda), the only pig ration available for purchase from that company. For each pen, feed of the appropriate diet type was weighed, and the weight (kg) was recorded before feeding.

For the newly weaned growth study – 8-week old pigs ($n = 90$), blocked by breed, sex, and litter were randomly assigned to 1 of 3 diets (forage-, or silage-based, or commercial) and 1 of 2 rooms (5 pens per breed type per diet). Each pen contained 3 pigs of the same sex and breed. Mean BW (kg) across diets and the standard deviation did not dif-

Table 1: *Compositions of diets (g/kg of dry matter) used in a growth study of newly weaned and finishing pigs in Uganda.*

	Forage-based diet *			*Silage-based diet* *		
	Age (weeks)			*Age (weeks)*		
	9–15	*16–24*	*28–32*	*9–15*	*16–20*	*21–32*
Ingredient (g/kg of dry matter)						
Avocado (*Persea americana*); ripe, with peel, seed removed	155.1	200.0	200.0	0.0	0.0	0.0
Banana leaf (*Musa sapientum*); centre vein removed	7.3	10.0	10.0	0.0	0.0	0.0
Cassava leaf, blade, and axil (*Manihot esculenta*); wilted	0.0	0.0	0.0	50.0	50.0	0.0
Cottonseed meal	0.0	50.0	50.0	50.0	50.0	50.0
Jackfruit (*Artocarpus heterophyllus*); ripe, with peel and seeds	400.0	200.0	200.0	259.6	256.6	254.7
Maize bran	0.0	133.5	239.2	0.0	220.1	266.1
Papaya leaf (*Carica papaya*); wilted	0.0	0.0	0.0	69.2	43.4	45.3
Ground sun-dried fish (*Rastrineobola argentea*)	226.3†	77.9‡	83.0‡	166.3†	74.5‡	78.1‡
Sweet potato vine (*Ipomoea batatas*); wilted	200.0	316.2	204.6	0.0	0.0	0.0
Sweet potato vine and tuber silage (*Ipomoea batatas*)	0.0	0.0	0.0	400.0	300.0	300.0
Limestone	6.0	6.9	7.2	0.0	0.0	0.0
Common table salt	3.8	3.9	4.0	3.5	3.9	3.9
Vitamin and mineral premix§	1.5	1.6	2.0	1.4	1.5	1.9

* Non-compliance in diet formulation occurred from 24 through 27 weeks of age. Data not presented.
† Pre-ground livestock-grade.
‡ Whole human-consumption grade ground at study site.
§ The premix provided the following per kg of complete feed (dry matter): vitamin A 15,000,000 IU; vitamin D_3 2,000,000 IU; vitamin E 20,000 IU; vitamin K_3 6000 mg; vitamin B_1 1000 mg; vitamin B_2 5000 mg; nicotinic acid 20,000 mg; pantothenic acid 16,000 mg; choline chloride 200,000 mg; biotin 110 mg; folic acid 1500 mg; manganese 40,000 mg; iron 150,000 mg; zinc 110,000 mg; copper 40,000 mg; cobalt 280 mg; iodine 1500 mg; selenium 120 mg

Table 2: *Calculated nutrient composition (% of dry matter [DM]) of forage- and silage-based diets used in a growth study of newly-weaned and finishing pigs in Uganda.*

	Forage-based diet *			*Silage-based diet* *		
	Age (weeks) †			*Age (weeks)* †		
	9–15	*16–24*	*28–32*	*9–15*	*16–20*	*21–32*
Calculated nutrient composition						
DE ‡ (kcal/kg of DM)	2775	2886	2960	2590	2849	2849
Crude protein	14.0	17.4	16.9	15.9	16.8	16.6
Neutral detergent fibre	24.9	29.5	28.4	23.4	24.0	24.3
Ether extract	5.6	7.5	7.5	2.6	2.5	2.0
Total calcium	0.56	0.56	0.56	0.62	0.60	0.52
Total phosphorous	0.64	0.64	0.65	0.52	0.60	0.59
STTD § phosphorous	0.37	0.35	0.35	0.27	0.32	0.30
Total sodium	0.19	0.19	0.20	0.15	0.18	0.18
Total lysine	0.99	1.06	1.06	0.96	1.01	1.00
SID ¶ lysine	0.71	0.74	0.76	0.67	0.73	0.73

* Nutrient composition of commercial diet is unknown due to proprietary confidentiality.
† Non-compliance in diet formulation occurred from 24 through 27 weeks of age. Data not presented.
‡ Digestible energy. Estimated from nutrient composition according to NRC (2012) and based on nutrient composition according to pre-trial proximate nutrient analysis (calculated; data not shown) or nutrient composition of the diets (analysed).
§ Standardized total tract digestible phosphorus concentration.
¶ Standardized ileal digestible lysine concentration.

fer by diet at the start of the trial ($p < 0.05$). During a 7-day acclimation period, all pigs were fed commercial diet, after which they were introduced to their trial diet over a 3-day period, then fed only their trial diet for 11 weeks (9–20 weeks of age), at which point the newly-weaned growth study ended.

For the finishing growth study – Phase 3 (21 to 24-week-old pigs) and Phase 4 (28 to 32-week-old pigs), the 21-week old pigs remained in the same pens with the same pen mates, the same diet formulation was used, and all feeding and sampling methods remained the same. Only diet assignment was changed. Total BW (kg) per pen and pen-level BW tertiles were determined. The two heaviest pens from each tertile were kept on the same diet as during the newly-weaned growth study. All other pens within each tertile were randomly assigned to 1 of the 3 diets. Mean BW (kg) across diets and the standard deviation did not differ. During a 7-day acclimation period pigs assigned to a new diet were fed 40 % new diet and 60 % old diet for 3 days, then 60 % new diet and 40 % old diet for 3 days (as-fed) and then 100 % new diet. Pigs remaining on the same diet as in the newly-weaned growth study received the same diet during the acclimation period. Non-compliance in diet formulation occurred from 24 through 27 weeks of age. (Data not presented. It is unknown if this had any effect).

2.3 Statistical analysis

Pen-level ADG for each of four phases (9 to 15, 16 to 20, 21 to 24, and 28 to 32-week-old pigs, respectively) were analysed using PROC MIXED of SAS (v. 9.4; SAS Institute Inc., Cary, NC). Differences among least square means were assessed using the Tukey's multiple comparisons test for pairwise differences. Pigs were grouped according to diet (commercial, forage-based, silage-based). To control for potential confounding, breed (crossbred or local) and sex (female or barrows) were included as fixed effects. Body weight (kg) at the start of each phase was included as a continuous variable. Interactions between breed and diet as well as starting BW and diet were evaluated to explore any potential effect on ADG. Data are presented as the least square means for the three diets ± standard error. Means were considered different when $p < 0.05$. The same methods as used in the ADG statistical analysis were applied to determine factors associated with gain to feed ratio (kg of gain/kg of feed consumed).

3 Results

Least square means of average daily gain and feed conversion efficiency of newly-weaned and finishing pigs are presented in Table 3. In Phase 1 pigs fed forage- or silage-based diet had lower ADG than pigs fed commercial diet ($p < 0.05$). In Phase 2 pigs fed forage-based diet had lower ADG than pigs fed commercial diet ($p < 0.05$). In Phases 1 and 2 pigs fed forage- and silage-based diet had the lowest feed conversion (gain:feed) ($p < 0.05$). In Phase 3, pigs fed forage-based diet had the lowest ADG, followed by silage-based diet, then commercial diet (0.250 and 0.462 kg/day more respectively for silage-based diet and commercial diet, $p < 0.05$). In Phase 4, pigs fed forage-based diet had the lowest ADG, followed by silage-based diet, then commercial diet (0.300 and 0.539 kg/day more respectively for silage-based diet and commercial diet, $p < 0.05$). Similarly, in Phases 3 and 4, pigs fed forage-based diet had the lowest feed conversion, followed by silage-based diet, then commercial diet ($p < 0.05$). Starting BW was not associated with ADG ($p > 0.05$) because pigs were blocked to have similar mean pen-level BW across diets.

4 Discussion

Across diets ADG was low compared to other pigs in the tropics (Codjo, 2003; Anugwa & Okwori, 2008). Low ADG observed in the newly weaned African growth study may be due to low nutrient density and insufficient DE intake. For newly weaned pigs, the most critical factor limiting growth is daily nutrient intake (Patience *et al.*, 1995). It is unlikely that pigs in this study had sufficient feed intake and fibre digestion capacity to reach their performance potential, as evidenced by low ADG across all three diets. Low ADG may also be due to fairly low mean initial BW (6.8 ± 1.6 kg and 12.1 ± 5.7 kg at 9 and 15 weeks of age respectively). Others report low ADG (97 to 176 g/day) in pigs fed fresh and ensiled forages due to low initial BW (16.9 to 31.4 kg) (Ortega *et al.*, 2012). Pigs' ability to digest dietary fibre is dependent on age, BW, and on-going exposure to fibrous feeds (Noblet & Le Goff, 2001; Wenk, 2001). Feeding fibrous feeds is cost-effective for pigs > 50 kg BW because the animals' ability to digest fibre increases as pigs get older (Machin, 1990). As previous research suggests (Noblet & Le Goff, 2001; Wenk, 2001), pigs may have adapted to fibrous feed through on-going exposure, and their ability to digest dietary fibre may have improved with increased age and BW resulting in higher ADG in Phase 2 than in Phase 1. Higher mean BW in Phase 2 than 1 may have enabled increased feed intake capacity.

Across diets ADG was higher in Phase 3 than in Phases 1 and 2 for the reasons discussed previously. It is important to note that, across diets, pigs in Phase 3 had higher ADG than pigs raised under typical smallholder conditions in East Africa (110 to 130 g/day) (Mutua *et al.*, 2012; Carter

Table 3: *Least square means of average daily gain and feed conversion efficiency of newly-weaned and finishing pigs in Uganda (pen level).*

Item	*Diet*				*Breed*			Diet	Breed	Breed × Diet	Start weight
	Forage-based	Silage-based	Commercial	SEM	Cross	Local	SEM				
Newly-weaned growth study											
No. of observations (pens)	10	10	10	–	15	15	–	–	–	–	–
Initial bodyweight, kg	7.0	6.4	6.8	–	7.9	5.6	–	–	–	–	–
Average daily gain, g											
Phase 1*	36 ^{a}	52 ^{a}	294 ^{b}	10	125	129	10	< .001	.842	.369	.053
Phase 2	163 ^{a}	212 ^{ab}	329 ^{b}	41.5	253	216	16.5	.017	.175	.148	.099
Gain : Feed (kg body weight gain : kg feed intake)											
Phase 1	.032 ^{a}	.034 ^{a}	.348 ^{b}	.008	.154	.122	.008	< .001	.025	.078	.007
Phase 2	.225 ^{a}	.223 ^{b}	.597 ^{c}	.025	.353	.344	.010	< .001	.577	.265	.059
Finishing growth study											
No. of observations (pens)	12	9	11	–	16	16	–	–	–	–	–
Initial bodyweight, kg	21.4	21.4	24.2	–	25.6	19.1	–	–	–	–	–
Average daily gain, g											
Phase 3	112 ^{a}	362 ^{b}	574 ^{c}	26	402	297	20	.002	.002	.206	.672
Phase 4	694 ^{a}	994 ^{b}	1233 ^{c}	52	1071	876	38	< .001	.002	.136	.241
Gain : Feed (kg body weight gain : kg feed intake)											
Phase 3	.039 ^{a}	.098 ^{b}	.346 ^{c}	.011	.169	.153	.009	< .001	.207	.905	.003
Phase 4	.039 ^{a}	.057 ^{b}	.145 ^{c}	.005	.072	.088	.003	< .001	.003	.081	.007

* Phase 1: Pig age 9–15 weeks; Phase 2: 16–20 weeks; Phase 3: 21–24 weeks; and Phase 4: 28–32 weeks. Non-compliance in diet formulation occurred from 24–27 weeks. Data not presented.

^{a,b,c} Means on the same row with different superscripts differ significantly ($p < 0.05$).

et al., 2013). And, although ADG of pigs fed silage-based diet was lower than pigs fed commercial diet, it was higher than that of pigs on smallholder farms in Soroti, Uganda that consumed 400–500 kg of sweet potato for 30 days (Peters, 1997). Similarly Mongcai × Yorkshire (MY) crossbred pigs fed a 40 % sweet potato tuber silage diet, had higher ADG when the starting BW was > 50 kg than at 15–50 kg BW (524 and 423 g/day, respectively), indicating balanced diets including silage can provide the energy and nutrients required for good growth performance (Giang *et al.*, 2004). Ensiling vines and tubers during the wet season converts surplus, highly perishable materials with low marketability, into a much-needed pig feedstuff improving pig growth and farmers' incomes (Peters, 2008; Cargill *et al.*, 2009).

In all growth phases, pigs fed the commercial diet had higher feed efficiency (kg BW gain/kg of feed intake) than pigs fed the forage- and silage-based diets ($p < 0.05$). In this study feed efficiency was rather low for pigs at the BW range tested relative to studies of exotic, commercially raised pigs (NRC, 2012). However, feed conversion ratio (FCR) in this study was similar to FCR reported for LB pigs and CB pigs elsewhere in the tropics (Codjo, 2003; Kanengoni *et al.*, 2004). In this study ADG is low, implying a large proportion of daily energy and nutrient intake is required for maintenance, contributing to reductions in feed efficiency (NRC, 2012). The better feed efficiency in pigs fed commercial diet reflects higher nutrient density in the commercial diet.

This study demonstrated that forage- and silage-based diets are not suitable for small, newly weaned pigs. Feeding commercial diet to newly weaned pigs, and forage-or silage-based diets to finishing pigs is the most suitable solution. Where silage-making resources are available, silage-based diets should be used for growing pigs and when not, forage-based diets can be used. Although in this manuscript we do not report on the cost effectiveness of these diets, in a related pig-level study we determined that it was most cost effective to feed commercial diet until pigs reached sufficient BW, at which time it became cost effective to feed forage- and silage-based diets (10.9 and 11.9 kg BW for forage- and silage-based diets, respectively) (Carter *et al.*, 2017).

We recognize that these forage- and silage-based diets can be improved upon, but they are a better alternative than current smallholder management practices with resulting low ADG (110 g/day) reported elsewhere in eastern Africa (Mutua *et al.*, 2012). The results of this study indicate forage- and silage-based diets are year-round low-cost pig-feeding strategies that will improve the growth performance of East African pigs.

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