Average daily gain and the impact of starting body weight of individual nursery and finisher Ugandan pigs fed a commercial diet, a forage-based diet, or a silage-based diet

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Summary

Objectives: To compare average daily gain (ADG) of Ugandan nursery and finisher pigs fed a commercial diet, a forage-based diet, or a silage-based diet, and to compare the cost effectiveness of the diets.

Materials and methods: Each pig was randomly assigned to the commercial diet, the forage-based diet, or the silage-based diet. Pigs were weighed every 3 weeks from 65 to 230 days of age. Growth was compared within and across diet on the basis of starting body weight (BW). The cost of feed per kg of BW gain was determined.

Results: As age and BW increased, mean BW variability increased in pigs fed the forage-based or silage-based diets and decreased in pigs fed the commercial diet. Starting BW was positively associated with ADG ($P < .01$). Average daily gain of nursery pigs fed the commercial diet was higher than that of pigs fed the forage-based and silage-based diets. At sufficient BW (≥ 11.9 kg), pigs fed the silage-based diet achieved ADG similar to that in pigs fed the commercial diet.

Implications: At sufficient BW (11 to 12 kg) pigs grow well on forage- or silage-based diets. If some ingredients are in surplus on farms, the forage- and silage-based diets are more cost effective than the commercial diet when pigs reach 8.5 kg BW. Interventions to improve weaning weights and provision of creep feed, and identification of nutrient-dense, digestible, palatable feedstuffs for development of low-cost balanced diets are needed in order to improve pig growth performance in East Africa.

Keywords: swine, average daily gain, forage, silage, East Africa

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Resumen - Ganancia diaria promedio y el impacto del peso corporal inicial de cerdos individuales en destete y engorda de Uganda alimentados con una dieta comercial, una dieta a base de forraje, o una dieta a base de ensilado

Objetivos: Comparar la ganancia diaria promedio (ADG por sus siglas en inglés) de cerdos Ugandeses de destete y crecimiento alimentados con una dieta comercial, una dieta a base de forraje, o una dieta a base de ensilado y comparar el costo efectividad de las dietas.

Materiales y métodos: Cada cerdo fue asignado aleatoriamente a la dieta comercial, la dieta a base de forraje, o la dieta a base de ensilado. Los cerdos se pesaron cada 3 semanas desde los 65 a los 230 días de edad. El crecimiento se comparó dentro y entre la dieta en base al peso corporal (BW por sus siglas en inglés) inicial. Se determinó el costo de alimento por kg de peso ganado.

Resultados: Conforme la edad y el peso, incrementó la variabilidad del peso promedio en cerdos alimentados con las dietas a base de forraje y ensilado y disminuyó en los cerdos alimentados con la dieta comercial. El peso inicial fue asociado positivamente con la ADG ($P < .01$). La ganancia diaria promedio de los cerdos en destete alimentados con dieta comercial fue más alta que la de los cerdos alimentados con las dietas a base de forraje y a base de ensilado. En un peso apto (≥ 11.9 kg), los cerdos alimentados con la dieta a base de ensilado lograron una ADG similar a la de los cerdos alimentados con la dieta comercial.

Implicaciones: En un peso apto (11 a 12 kg) los cerdos crecen bien en dietas en base a forraje o ensilado. Si existen algunos ingredientes extra en las granjas, las dietas basadas en forraje y ensilado son más costo efectivas que la dieta comercial cuando los cerdos alcanzan 8.5 kg de peso. Las intervenciones para mejorar los pesos al destete y el suministro de alimento a los lechones en maternidad, y la identificación de piensos densos en nutrientes, digestibles, apetecibles para el desarrollo de dietas balanceadas de bajo costo son necesarios para mejorar el desempeño del crecimiento del cerdo en África del Este.

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Résumé – Gain moyen quotidien et impact du poids corporel initial de porcs en pouponnière et en finition en Ouganda nourris avec une diète commerciale, une diète à base de fourrage, ou une diète à base d'ensilage

Objectifs: Comparer le gain moyen quotidien (GMQ) de porcs en pouponnière et en finition, en Ouganda, nourris avec une diète commerciale, une diète à base de fourrage, ou une diète à base d'ensilage et comparer l'efficacité des coûts de ces diètes.

Matériels et méthodes: Chaque porc fut assigné de manière aléatoire à l'une des trois diètes (commerciale, à base de fourrage, ou à base d'ensilage). Les porcs ont été pesés à chaque 3 semaines à compter de 65 jours d'âge jusqu'à 230 jours d'âge. La croissance a été comparée parmi et entre les diètes sur la base du poids corporel (PC) initial. Le coût en aliment par kg de gain de PC a été déterminé.

Résultats: À mesure que l'âge et le PC augmentaient, la variabilité du PC moyen augmentait chez les porcs nourris avec une diète à base de fourrage ou d'ensilage et diminuait chez les porcs nourris avec une diète commerciale. Le PC initial était positivement associé avec le GMQ ($P < 0,01$). Le GMQ des porcs en pouponnière nourris avec la diète commerciale était plus élevé que celui des porcs nourris avec les diètes à base de fourrage ou d'ensilage. À un PC adéquat (≥ 11,9 kg), les porcs nourris avec une diète à base d'ensilage avaient un GMQ similaire à celui des porcs nourris avec une diète commerciale.

Implications: À un PC adéquat (11 à 12 kg) les porcs se développent bien lorsque nourris avec un diète à base de fourrage ou d'ensilage. Si certains ingrédients sont en surplus sur les fermes, les diètes à base de fourrage et d'ensilage sont plus rentables que les diètes commerciales lorsque les porcs atteignent un PC de 8,5 kg. Des interventions pour améliorer le poids au sevrage et fournir de la moulée de démarrage, et l'identification d'aliments qui sont riches en nutriments, digestibles, et palatables pour le développement de diètes balancées à faible coût sont requises afin d'améliorer les performances de croissance des porcs en Afrique de l'Est.

Smallholder pig farmers in East Africa report that the high cost, poor quality, and lack of feed are key constraints to pig rearing.[1-5] Commercially prepared pig diets are beyond their financial means.[4,5] Pigs are fed carbohydrate-rich diets with little to no protein, which contributes to slow growth and poor farmer profit.[4-8] Well-balanced, cost-effective diets are needed to improve pig performance in East Africa. Fresh and ensiled locally available feedstuffs can be used to meet the nutrient requirements of pigs.[9-13] The objectives of this study were to compare average daily gain (ADG) of nursery and grower Ugandan pigs each fed one of three diets (commercial, forage-based, or silage-based) and to compare the cost effectiveness of the diets.

Materials and methods

The study was reviewed and approved by the institutional animal care and use committees of the International Livestock Research Institute (ILRI), Nairobi, Kenya, and the University of Guelph, Guelph, Canada. The research site was a commercial pig operation in Masaka District, Central Region, Uganda.

Diet formulation

The nutritional requirements of 8-kg to 65-kg pigs in Uganda were estimated using the methods reported previously.[14] Briefly, the dynamic nutrient requirement model for growing-finishing pigs[15] was converted into a static model to represent the use of daily intake of digestible energy (DE kcal per kg of dry matter [DM]) for body protein deposition (kg per day), body lipid deposition (kg per day), and maintenance for pigs weighing between 8 and 65 kg. The energy density in corn and soybean meal diets was used to establish nutrient requirements.[15] To determine the least-cost diet per unit of energy and other nutrients, diet costs were calculated at each 1% decrease in nutrient density, keeping ratios among the nutrient constraints and energy content constant. Diets were formulated at 80% of the reference nutrient density, since nutrients were optimal to improve pig performance, but still affordable to smallholder farmers. To limit fibrous feedstuffs, diet neutral detergent fibre (NDF) content was limited to 350 g per kg of DM, which is higher than that in conventional diets. However, local and cross-breed pigs may tolerate NDF at higher dietary levels than American or European breeds.[13,16] Salt and mineral-vitamin premix minimum constraints (3.9 and 1.5 g per kg of DM, respectively) were imposed per NRC recommendations.[15] Balanced low-cost diets (forage-based and silage-based) were formulated (Table 1) using methods previously described.[14]

Sweet potato vine and tuber silage production

Sweet potato vines of mixed varieties and tubers of mixed orange and yellow flesh varieties were wilted on tarpaulins for 3 days, then chopped into 5- to 10-cm long pieces. Tubers were chopped into 2.5-cm^3 pieces. Six bunks (4.2 × 1.1 × 1.1 m) built with bricks and cement were lined with polythene and filled one at a time. Vines, tubers, and salt were placed in alternating layers (70%, 30%, 0.05% on an as-fed basis, respectively). The vine:tuber:salt ratio reflected reported optimal nutrient and pH results for silage in East Africa.[17] Each layer was compacted by hand-rolling with a heavy log, then was tightly wrapped with polythene for > 30 days before use. The appropriate amount of each ingredient (post wilting) was weighed and mixed, a 0.30-kg sample was collected for nutrient analysis, and then the diet was stored in uncovered 60-L plastic containers.

Sample size

Sample size was calculated using a two-sample *t* test with 80% power to detect a significant difference in ADG of 0.20 kg at the 5% confidence level. Between-pig standard deviation (SD) of gain per day was estimated to be 0.25 kg. Twenty-five pigs per diet were required; therefore 30 pigs were randomly allocated to each diet group using a random number generator.

Pre-study pig management

One hundred and ten pigs from 14 local smallholder farms, born within 3 days of each other, were enrolled in the study. At 10 days of age, pigs were individually ear-tagged and received 2 mL of a single product containing iron and vitamin B_{12} by intramuscular injection (Bremer Pharma GMBh, Werkstr 42, 34414 Warburg, Germany). Males were castrated and birth dates were recorded. At 36 days of age, pigs received 300 µg per kg BW of ivermectin subcutaneously (V.M.D., Hoge Mauw 900, 2370 Arendonk, Belgium). At 56 days of age, all pigs arrived at the research farm and received 300 mg per kg BW of albendazole orally (Ashish Life Science PVT Ltd 213, Mumbai-53, India) and ivermectin as above.

Pen management

Pens were labelled with a number and diet type, scraped daily, and washed weekly. Uneaten feed was weighed and discarded daily. One handful of chopped straw was put in each pen daily for environmental enrichment.

Diets

Pigs were each fed one of three diets ad libitum three times daily. The three diets included a

Table 1: Compositions of diets (as-fed basis) used in a growth study of nursery and finisher pigs in Uganda

	Forage-based diet*			Silage-based diet*		
Age (days)	**65-107**	**108-167**	**199-230**	**65-107**	**108-140**	**146-230**
Ingredient (%)						
Avocado (*Persea americana*); ripe, with peel, seed removed	18.02	19.6	25.5	0.0	0.0	0.0
Banana leaf (*Musa sapientum*); centre vein removed	1.1	1.3	1.7	0.0	0.0	0.0
Cassava leaf, blade, and axil (*Manihot esculenta*); wilted	0.0	0.0	0.0	2.6	2.0	0.0
Cottonseed meal	0.0	1.4	1.8	1.3	1.3	1.7
Jackfruit (*Artocarpus heterophyllus*); ripe, with peel and seeds	39.9	16.8	21.9	20.8	25.8	22.7
Maize bran	0.0	4.1	9.5	0.0	0.0	12.4
Papaya leaf (*Carica papaya*); wilted	0.0	0.0	0.0	6.4	7.1	0.0
Ground sun-dried fish (*Rastrineobola argentea*)	7.5†	2.2‡	3.1‡	4.4†	2.0‡	2.7‡
Sweet potato vine (*Ipomoea batatas*); wilted	33.3	54.2	36.1	0.0	0.0	0.0
Sweet potato vine and tuber silage (*Ipomoea batatas*)	0.0	0.0	0.0	64.5	61.6	60.8
Limestone	0.19	0.10	0.14	0.0	0.0	0.0
Common table salt	0.12	0.10	0.14	0.09	0.09	0.13
Vitamin and mineral premix§	0.05	0.04	0.07	0.04	0.06	0.06

* Non-compliance in diet formulation occurred when pigs were168 to 198 days of age. Data not presented.
† Pre-ground livestock-grade.
‡ Whole human-consumption grade ground at research 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: Analyzed nutrient compositions of study diets (% of DM) used in the growth study of nursery and finisher pigs in Uganda

	Diet											
	Forage-based				Silage-based				Commercial			
Pig age (days)*	65-107	108-140	146-167	199-230	65-107	108-140	146-167	199-230	65-107	108-140	146-167	199-230
DE (kcal/kg of DM)†	1531	2333	2385	2688	1426	2277	2351	2309	2413	2681	2811	2499
Ash	21.2	11.9	11.9	9.4	19.6	12.0	12.6	12.0	10.1	9.3	8.6	11.4
Crude protein	17.9	18.8	18.4	15.7	18.9	17.9	16.9	14.4	15.9	17.2	17.3	18.4
Neutral detergent fibre	35.6	41.5	39.9	38.3	39.5	37.7	34.0	35.1	37.4	35.1	33.8	34.9
Ether extract	5.9	9.8	9.9	11.7	2.8	5.6	6.0	5.8	5.2	7.6	8.1	7.0
Total calcium	1.84	0.88	0.83	0.69	2.07	0.95	0.87	0.68	1.49	0.96	0.89	1.29
Total phosphorus	0.58	1.09	1.07	0.66	0.53	0.96	0.97	0.68	0.79	1.58	1.51	1.32
Total Ca:total P	3.17	0.81	0.78	1.05	3.91	0.99	0.90	1.00	1.89	0.61	0.59	0.98

* Non-compliance in diet formulation occurred when pigs were 168 to 198 days of age. Data not presented.
† Digestible energy (DE), estimated from analyzed nutrient composition of the diets according to NRC (2012).[15]
Ca = calcium; P = phosphorus; DM = dry matter.

commercially prepared diet labeled "Sow and weaner ration" (Ugachick Poultry Breeders, Kampala, Uganda); a forage-based diet; and a silage-based diet. It is important to note that the "Sow and weaner ration" is the only commercially-prepared ration available in Uganda, ie, grower and finisher rations are not available. Diet ingredient composition and analyzed nutrient composition are presented in Tables 1 and 2, respectively.

Diet sampling

A 0.30-kg subsample of each diet type from a composite of the samples collected daily over a 4-week period was used for feed analysis. Each sample was weighed upon arrival, dried to constant weight at 60°C in a Leader oven model GP180CIA02501110 (Leader Engineering Heat Control, St Helens, Merseyside, United Kingdom), weighed again, then ground to pass through a 1-mm screen (Model CE96, United Kingdom). Samples were analyzed for DM,[18] crude protein,[19] ash and NDF,[20] phosphorus,[21] and calcium[22] at ILRI Laboratories, Addis Ababa, Ethiopia, and were analyzed for ether extract[19] at ILRI Laboratories, Hyderabad, India.

Nursery study (65- to 140-day-old pigs)

Ninety 56-day-old pigs were each randomly assigned to one of three diets (commercial, forage-based, or silage-based) and to pens that were each blocked by one of two rooms, resulting in 10 pens per diet. All pigs were fed the commercial diet for a 7-day acclimation period, then introduced to their study diets over a 3-day period. At 65 days of age, the study began, when the pigs were fed only their study diets until they reached 140 days of age.

Finisher study (146- to 167-day-old pigs and 199- to 230-day-old pigs)

The 140-day-old pigs remained in the same pen as for the nursery study, with the same pen mates. The same diet formulations were used, and all feeding and sampling methods remained the same. However, the diet assignment was changed. The total body weight (BW; kg) per pen and pen-level BW tertiles were determined. The two heaviest pens from each tertile within diet were assigned the same diet as during the nursery study. All other individual pens within each tertile were each randomly assigned to one of the three diets. Pigs assigned a new diet were introduced to it over a 7-day acclimation period. Nine replacement pigs were fed the commercial diet from 56 days of age until they were enrolled in the finisher study. Due to failure to procure required ingredients, non-compliance in diet preparation occurred when pigs were 168 to 198 days of age (data not presented).

Pig weighing

Individual pigs were weighed and weights were recorded at Day 0 (65 days of age) and every 21 days following, using a model DV201 pig-weighing crate (Danvaegt, A/S, 8382 Hinnerup, Denmark) accurate to 1.0 kg.

Statistical analysis

The unit of analysis was the individual pig. Each pig that died or was euthanized was replaced by a pig of approximately the same weight so that there were always three pigs in each pen. For the nursery study, the analyses included only the 81 pigs that began the trial at 65 days of age and lived to 140 days of age. For the finisher growth study, the pigs that were added partway through the nursery study were included in the analyses. Analysis of variance and Tukey's pairwise comparison were performed to determine if mean BW differed between diet treatments at the start of the nursery study (65-day-old pigs) and the start of the finisher study (146-day-old pigs). Individual pig ADG was regressed on diet type (commercial, forage-based, silage-based) and BW (kg) at the start of each weigh period as fixed effects, and on pen as a random variable using mixed multivariable linear regression. Pen was included in each model as a random variable to control for pen-level clustering. Linearity of the relationship between starting BW and ADG was assessed by testing the significance of a quadratic transformation of starting BW. A Wald's chi-square test was used to evaluate interactions between starting BW and diet to explore any potential effect on ADG. The coefficients from the linear regression represent the differences in ADG between the commercial diet and the forage- and silage-based diets after controlling for starting BW. Assumptions for the models were assessed by evaluating standardised residuals and plotting residuals against predicted ADG. Model fit with and without potential outliers was assessed using the Akaike's information criterion and the Bayesian information criterion. Mean starting BW (kg), ADG (kg per day), and SD of nursery and finisher pigs were determined (Table 3). Analysis of variance and Tukey's pairwise comparison were performed to determine if mean BW differed between diet treatments at the start of each weigh period (Table 3). The mean BW (kg), SD, and coefficient of variation (CV) within diet treatment were determined for nursery pigs at each weigh date (Table 4). All statistical analyses were performed using Stata 13.1 (StataCorp, College Station, Texas). Values of $P < .05$ were considered statistically significant.

Comparative cost analysis

Using the price per kg of the commercial diet and of each ingredient from 199 to 230 days, ie, the most recent market price available prior to publication (Table 5), the cost of 1 kg of each diet was determined in two ways: first, assuming all ingredients were purchased, and second, assuming that the ingredients farmers could produce rather than purchase were free (ie, avocado, banana leaf, jackfruit, papaya leaf, sweet potato tubers and vines for use fresh or ensiled). Free ingredients were included in the diets, since others have shown that, in order to earn profits, East African pig farmers must feed diets containing some free ingredients.[8] Those costs of 1 kg of each diet were then used to calculate the cost of feed per kg of BW gain (Table 5).

Results

Diets

Ingredient compositions of the forage-based and silage-based diets are presented in Table 1. Ingredient composition of the commercial diet was unknown protected proprietary information. Diet nutrient compositions (analyzed) of all diets are presented in Table 2. Throughout the study, analyzed nutrient content was numerically different from estimated pig requirements and estimated values for diets. Due to high analyzed ash and NDF content, final DE in diets, determined by nutrient analysis, was numerically lower than the expected calculated DE that was based on the assumed nutrient contents of individual ingredients, especially from 65 to 86 days of age. When pre-ground sun-dried fish and unripe avocado were replaced with higher quality whole dried fish and ripe and over-ripe avocado, respectively, lower ash content and higher ether extract resulted in numerically higher calculated DE content, determined by analyzed diet nutrient contents. None of the diets provided the estimated DE requirement. The DE content of the commercial diet was numerically higher than the DE content of the forage- and silage-based diets from 65 to 167 days of age. From 199 to 230 days of age, the DE content of

Table 3: Mean starting body weight (BW; kg), mean average daily gain (ADG; kg/day), and standard deviation (SD) of nursery pigs (65-140 days old) and finisher pigs (146-230 days old)*

	Commercial diet			Forage-based diet			Silage-based diet		
Pig age (days)	Starting BW (kg)	ADG (kg/day)	SD (kg)	Starting BW (kg)	ADG (kg/day)	SD (kg)	Starting BW (kg)	ADG (kg/day)	SD (kg)
65-86	6.8[a]	0.201	0.0816	7.0 [a]	0.021	0.0372	6.7[a]	0.021	0.0461
87-107	11.1[a]	0.405	0.0969	7.5[b]	0.045	0.0371	7.1[b]	0.077	0.0688
108-127	19.6[a]	0.460	0.1392	8.4[b]	0.118	0.0519	8.7[b]	0.153	0.1050
128-140	29.2[a]	0.264	0.2017	10.9[b]	0.160	0.1364	11.9[b]	0.234	0.1687
146-167	24.1[a]	0.552	0.1710	21.4[a]	0.116	0.0953	20.7[a]	0.318	0.1309
199-209	52.6[a]	0.744	0.1973	31.2[b]	0.494	0.2109	38.7[b]	0.713	0.1623
210-230	60.0[a]	0.604	0.1385	36.2[b]	0.336	0.1411	45.8[c]	0.504	0.1369

* Non-compliance in diet formulation occurred when pigs were 168 to 198 days of age. Data not presented.

[a,b,c] Values within a row with differing superscripts are significantly different ($P < .05$; analysis of variance and Tukey's pairwise comparison).

Table 4: Coefficient of variation (CV), within diet treatment, of bodyweight (BW; kg) of nursery pigs at 65, 86, 107, 127, and 140 days of age

	Commercial diet		Forage-based diet		Silage-based diet	
Pig age (days)	Mean BW (kg) (SD)	CV	Mean BW (kg) (SD)	CV	Mean BW (kg) (SD)	CV
65	6.8 (2.12)	0.31	7.0 (2.21)	0.31	6.7 (1.91)	0.29
86	11.1 (3.43)	0.31	7.5 (2.58)	0.34	7.1 (2.48)	0.35
107	19.6 (4.79)	0.25	8.4 (3.08)	0.37	8.7 (3.69)	0.42
127	29.2 (6.55)	0.22	10.9 (3.85)	0.35	11.9 (5.41)	0.45
140	32.6 (7.48)	0.23	13.0 (5.00)	0.38	15.0 (6.51)	0.43

SD = standard deviation.

Table 5: Cost of feed* per kg of weight gain (US$) for commercial, forage-, and silage-based diets according to age

Age (days)	Commercial diet	FB buy all	FB some free	SB buy all	SB some free
65	0.97	5.17	2.48	4.55	2.11
107	1.29	2.29	1.10	1.98	0.92
127	2.11	1.31	0.63	1.66	0.77
146	2.91	1.30	0.62	1.39	0.65
199	3.04	1.59	0.76	1.51	0.70

* At the following ingredient cost per kg as-fed basis (US$): avocado 0.11; banana leaf 0.12; cottonseed meal 0.42; jackfruit 0.11; maize bran 0.14; human grade whole sun-dried fish 2.04; sweet potato vine 0.12; papaya leaf 0.12; sweet potato vine and tubers for silage 0.12; limestone 0.03; salt 0.27; mineral and vitamin pre-mix 4.50.

FB = forage-based diet; SB = silage-based diet.

the commercial diet was numerically lower than that of the forage-based diet and higher than that of the silage-based diet.

Mean BW in each 3-week growth period

Mean BW did not differ between diet treatments at the start of the nursery study (65 days) ($P > .05$) or the start of the finisher study (146 days) ($P > .05$) (Table 3).

Mean BW of pigs differed between the commercial diet and the forage-based diet, and between the commercial diet and the silage-based diet, at the start of all other growth periods ($P < .05$) (Table 3). Mean BW differed between all diet treatments at 210 days ($P < .05$) (Table 3).

Average daily gain of nursery pigs (65 to 140 days of age)

On the basis of the regression analysis, when controlling for starting BW for the first three 3-week growth periods in the nursery phase (65 to 127 days of age), ADG of pigs fed the forage-based diet was lower by 0.176 (± 0.0172), 0.306 (± 0.0181) and 0.196 (± 0.0181) kg per day than ADG of pigs fed the commercial diet ($P < .001$), respectively, in each 3-week weighing period. Similarly, ADG of pigs fed the silage-based diet was 0.181 (± 0.0165), 0.269 (± 0.0181), and 0.163 (± 0.0399) kg per day lower than ADG of pigs fed the commercial diet ($P < .001$), respectively, in each 3-week weighing period. For every 1-kg increase in starting BW, ADG increased by 0.012 (± 0.003), 0.015 (± 0.002), 0.013 (± 0.003), and 0.009 (± 0.003) kg per day, for the four 3-week growth periods, respectively ($P < .001$).

Average daily gain of finisher pigs (146 to 230 days of age)

From 146 to 167 days of age, when controlling for starting BW, ADG of pigs fed the commercial diet was 0.424 (± 0.0350) and 0.221 (± 0.0372) kg per day higher, respectively, than ADG of pigs fed the forage-based and silage-based diets ($P < .05$). From 209 to 230 days of age, when controlling for starting BW, ADG of pigs fed the commercial diet was 0.186 (± 0.0420) kg per day higher than that of pigs fed the forage-based diet ($P < .001$). For every 1-kg increase in starting BW, ADG increased by 0.004 (± 0.0012), 0.008 (± 0.0012), and 0.004 (± 0.0009) kg per day for the three 3-week growth periods of finisher pigs, ($P = .001$, $P < .001$, and $P < .001$, respectively).

Variability in mean BW of nursery pigs

Variability (coefficient of variation; CV) in mean BW increased with age in pigs fed the forage-based and silage-based diets, but decreased with increasing age in pigs fed the commercial diet (Table 4). The CV of pigs fed the commercial diet was highest in 65- and 86-day-old pigs and lower in heavier, older pigs. The CVs of pigs fed the forage-based and silage-based diets were lowest in 65- and 86-day-old pigs and higher in older pigs.

Comparative cost analysis

The cost of feed per kg of weight gain (US$) for each of the three diets when all ingredients were purchased or some ingredients were free is presented in Table 5. The cost per kg of weight gain of pigs fed the commercial diet was less than the cost per kg of weight gain of pigs fed the forage-based and silage-based diets when pigs weighed < 10.9 and < 11.9 kg BW, respectively. However at BW ≥ 10.9 and ≥ 11.9 kg, the cost per kg of weight gain of pigs fed the commercial diet was more than the cost per kg of weight gain of pigs fed the forage-based and silage-based diets.

When some ingredients were free, the cost per kg of weight gain of pigs fed the commercial diet was less than the cost per kg of weight gain of pigs fed the forage- and silage-based diets when pigs weighed < 8.4 and < 8.7 kg BW, respectively (tables 4 and 5). At BW ≥ 8.4 and ≥ 8.7 kg, the cost per kg of weight gain of pigs fed the commercial diet was more than the cost per kg of weight gain of pigs fed the forage-based and silage-based diets, respectively, when some ingredients were free (tables 4 and 5).

Discussion

The results of this study show that East African farmers can improve pig growth performance by feeding forage- and silage-based diets. Empirical studies characterizing the ADG of pigs raised under smallholder management conditions (wherein pigs are tethered to graze on grass or roam free and scavenge) in Uganda have not been done. Pigs at mean BW ≥ 10.9 and ≥ 8.7 kg, fed the forage- or silage-based diet in this study, respectively, or fed the commercial diet, had higher ADG than pigs raised by smallholder farmers in Kenya (0.130 kg per day) under management practices similar to those observed in Uganda.[4,5,7]

The weaning weights of local breeds of pigs reported elsewhere in the tropics (4.87 ± 0.28 kg at 56 days of age;[23] 5.6 to 7.4 kg at 93 to 117 days of age[24]) were similar to the starting BW of pigs enrolled in this study.

Factors contributing to low ADG include introduction of a novel diet that potentially caused transient gastrointestinal hypersensitivity,[25] genotype, the composition and nutrient content of the diet, and the pigs' limited feed intake and digestive capacity for fibrous feeds due to age and size.

The composition and nutrient content of the diets may have contributed to low ADG. Given that the energy density of the forage- and silage-based diets was 70% to 80% of the energy density in the NRC[15] reference corn and soybean meal diets, and the high ash content, especially during the nursery phase, it is unlikely that pigs fed the forage- and silage-based diets consumed sufficient nutrients to reach their genetic growth potential. Although the energy density was reduced in an effort to increase the likelihood that Ugandan smallholder farmers could afford to adopt the forage- and silage-based diets, it is a limitation of this study. Future research is needed to investigate the growth of Ugandan pigs fed diets containing 100% of the nutrient density of NRC[15] reference corn and soybean meal diets.

In commercial settings, nutrient-dense, highly-digestible diets comprising oils, plasma, milk and fishmeal products, and feed additives are formulated to enable young pigs to maximize nutrient intake and potential growth performance.[15,25] However, these ingredients were not available to East African smallholder farmers and commercial creep feed was not available for purchase. The diets studied here contained more NDF and less estimated DE than the estimated amount required by pigs to achieve maximum growth.[14] Others reported that feeding fibrous feeds is cost-effective for pigs > 50 kg BW because pigs' ability to digest fibre increases with age.[26] However, for young growing pigs, dietary fibre provides little or no energy, and the digestibility of energy and nutrients are reduced as dietary fibre content increases.[27] As previous research[28] suggests, pigs may have adapted to fibrous feed through ongoing exposure to the study diets, and their ability to digest dietary fibre may have improved with increased age and BW. This may have been reflected in the higher ADG of finisher pigs compared to nursery pigs and the relative improvement of ADG in the forage- and silage-based diets compared to the commercial diet. From 65 to 107 days of age the wide calcium:phosphorus ratio across diets may have contributed to low ADG. As previous studies suggest, a wide calcium:phosphorus ratio lowers the absorption of phosphorous which results in slower growth.[15,29]

Low starting BW of pigs enrolled in this study may have resulted in low feed intake and consequently low ADG, as others have discussed.[23] Others estimated that ad libitum feed intake is influenced by BW and diet digestibility as follows: 0.013 × BW in kg ÷ (1 – digestibility).[30] This estimation demonstrates the impact that BW and diet digestibility can have on feed intake and consequently on ADG. Others[31] reported that higher feed intake in the period after weaning increases ADG of nursery pigs and ultimately in the finisher phase.

The higher ADG of heavier (≥ 10.9 and ≥ 11.9 kg) nursery pigs fed the forage- and silage-based diets, respectively, than that of lighter nursery pigs indicates the commercial diet was more suitable than the forage- and silage-based diets for small nursery pigs. Moreover, the high CV of mean BW and increase in CV with increased age and BW in pigs fed the forage- and silage-based diets indicates there were heavier pigs fed the forage- and silage-based diets that grew well and small pigs that did not grow well, and that pigs at 65 days of age can grow when fed the forage- and silage-based diets if the starting BW is sufficiently large.

It was more cost effective to feed the commercial diet while pigs weighed < 10.9 and < 11.9 kg BW (forage- and silage-based diets, respectively). In larger pigs (≥ 10.9 and ≥ 11.9 kg BW, respectively) the less expensive forage- and silage-based diets were cost effective. Similarly others[32] reported that as weaning weight increased, the cost per 100 kg of pig sold decreased, and income over cost increased. Although it is cost effective to feed a forage-based diet when pigs reach 8.4 kg if some ingredients are free, given the low ADG of pigs fed the forage-based diet at that BW, feeding a forage-based diet to such small pigs is not recommended. Feeding a commercial diet to newly weaned pigs, and then feeding forage- or silage-based diets to finisher pigs, is recommended. Commercial diets provide the least cost per kg BW gain in newly weaned pigs, but heavier, older pigs can be fed the more affordable forage- and silage-based diets, and achieve good growth performance.

Forage- and silage-based diets may be more accessible than commercial diets for resource-poor smallholder farmers. Resource-poor smallholder farmers may be able to afford the cost of making forage- and silage-based diets, spent in small increments over time when purchasing small amounts of ingredients, and growing some of the ingredients themselves. Purchasing a 70-kg bag of commercial diet may be prohibitively expensive. Purchasing it collectively as a farmer group and dividing it among group members to feed small, newly weaned pigs is recommended. The results of this study indicate that forage- and silage-based diets are not suitable for the smallest nursery pigs. Nursery pigs should be fed a commercial diet until they reach sufficient BW (10.9 and 11.9 kg for forage- and silage-based diets, respectively), to consume and digest sufficient quantities of high fibre, cost-effective diets. Finisher pigs can have higher ADG than that of similar pigs raised under smallholder management conditions, when fed these balanced forage- and silage-based diets that are less expensive than commercial diets. Moreover, finisher pigs can achieve similar ADG to those fed a commercial diet once they achieve sufficient BW.

Smallholder pig farmers should be encouraged to wean only the heaviest pigs and to provide a commercial diet to lightweight nursery pigs until they reach 10.9 and 11.9 kg, then use forage- or silage-based diets, respectively.

Implications

- Cost-effective balanced forage- and silage-based diets can be made by smallholder farmers in East Africa to enhance growth of finisher pigs.
- It is less expensive to feed small nursery pigs a commercial diet until they achieve sufficient BW (10.9 and 11.9 kg) before feeding forage-based and silage-based diets, respectively.
- If some ingredients are in surplus on East African farms, forage- and silage-based diets are more cost effective than a commercial diet when the pigs reach 8.5 kg BW.
- Nutrient-dense, digestible, palatable feedstuffs to improve growth of newly weaned pigs should be identified and their nutrient content characterized for development of low-cost balanced diets.
- Interventions related to improving weaning weights and provision of creep feed are needed in order to improve pig growth performance.

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Conflict of interest

None reported.

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References

1. Ouma E, Dione M, Lule P, Pezo D, Marshall K, Roesel K, Mayega L, Kiryabwire D, Nadiope G, Jagwe J. Smallholder pig value chain assessment in Uganda: Results from producer focus group discussions and key informant interviews, International Livestock Research Institute Research Report, Nairobi, Kenya. 2014. Available at `https://cgspace.cgiar.org/bitstream/handle/10568/68011/PR_Uganda_vca_web.pdf?sequence=6`. Accessed 22 February 2017.

2. FAO. Pig Sector Kenya. FAO Animal Production and Health Livestock Country Reviews. No. 3. Rome. 2012. Available at `http://www.fao.org/docrep/015/i2566e/i2566e00.pdf`. Accessed 22 February 2017.

3. Muhanguzi D, Lutwama V, Mwiine FN. Factors that influence pig production in Central Uganda - Case study of Nangabo Sub-County, Wakiso district. *Vet World*. 2012;5:346–351.

4. Mutua FK, Dewey C, Arimi S, Ogara W, Levy M, Schelling E. A description of local pig feeding systems in village smallholder farms of Western Kenya. *Trop Animal Health Prod*. 2012;44:1157–1162.

5. Kagira JJ, Kanyari PWN, Maingi N, Githigia SM, Ng'ang'a JC, Karuga J. Characteristics of the smallholder free-range pig production system in western Kenya. *Trop Anim Health Prod*. 2010;42:865–873.

6. Kambashi B, Picron P, Boudry C, Théwis A, Kiatokoa H, Bindelle J. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. *Anim Feed Sci Technol*. 2014;19:47–56.

7. Carter N, Dewey C, Mutua FK, de Lange C, Grace D. Average daily gain of local pigs on rural and peri-urban smallholder farms in two districts of western Kenya. *Trop Anim Health Prod*. 2013;45:1533–1538.

8. Levy MA, Dewey CE, Poljak Z, Weersink A, Mutua FK. Comparing the operations and challenges of pig butchers in rural and peri-urban settings of western Kenya. *Afri J Agric Res*. 2014;91:125-136.

9. Kaensombath L, Neil M, Lindberg JE. Effect of replacing soybean protein with protein from ensiled stylo (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) on growth performance, carcass traits and organ weights of exotic (Landrace × Yorkshire) and native (Moo Lath) Lao pigs. *Trop Anim Health Prod*. 2013:43:865–871.

10. Ly NTH, Ngoa LD, Verstegen MWA, Hendriks WH. Pig performance increases with the addition of DL-methionine and L-lysine to ensiled cassava leaf protein diets. *Trop Anim Health Pro*d. 2012;44:165–172.

11. Adeniji AA. The feeding value of rumen content maggot-meal mixture in the diets of early weaned piglets. *Asian J Anim Vet Adv*. 2008;3:115–119.

12. Giang HH, Ly LV, Ogle B. Digestibility of dried and ensiled sweet potato roots and vines and their effect on the performance and economic efficiency of F1 crossbred fattening pigs. *Livest Res Rural Dev*. 2004;16. Available at http://www.lrrd.org/lrrd16/7/gian16050.htm. Accessed 18 January 2017.

13. Kanengoni AT, Dzama K, Chomonyo M, Kusina J, Maswaure S. Growth performance and carcass traits of Large White, Mukota and Large White × Mukota F1 crosses given graded levels of maize cob meal. *Anim Sci*. 2004;78:61–66.

14. Carter NA, Dewey CE, Thomas LF, Lukuyu B, Grace D, de Lange C. Nutrient requirements and low-cost balanced diets, based on seasonally available local feedstuffs, for local pigs on smallholder farms in Western Kenya. *Trop Anim Health Prod*. 2016;48:337–347.

15. National Research Council. *Nutrient Requirements of Swine*, Washington, DC: The National Academies Press; 2012.

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

17. Manoa LA. Evaluation of dry matter yields and silage quality of six sweet potato varieties. MSc thesis; University of Nairobi; Nairobi, Kenya; 2012.

18. Association of Official Analytical Chemists. *Official methods of analysis Assoc Off Anal Chem*. 16th ed. Washington, District of Columbia; 1995;934.01.

19. AOAC International. *Official methods of analysis of AOAC International*. 15th ed. Arlington, Virginia: Association of Analytical Communities. 1990;988.05;920.39.

20. Van Soest PJ, Robertson JB. Analysis of forage and fibrous feeds. *Laboratory Manual for Animal Science 613*. Ithaca, New York: Cornell University; 1985.

21. AOAC International. *Official methods of analysis of AOAC International*. 17th ed. Gaithersburg, Maryland: Association of Analytical Communities USA; 2002.

22. The Perkin-Elmer Corporation. Analytical methods for atomic absorption spectroscopy. Perkin Elmer manual. USA. 1996.

23. Kumaresan A, Bujarbaruah KM, Pathak KA, Chhetri B, Das SK, Das A, Ahmed SK. Performance of pigs reared under traditional tribal low input production system and chemical composition of non-conventional tropical plants used as pig feed. *Livest Sci*. 2007;107:294–298.

24. Phengsavanh P, Ogle B, Stur W, Frankow-Lindberg BE, Lindberg JE. Feeding and performance of pigs in smallholder production systems in Northern Lao PDR. *Trop Anim Health Prod*. 2010;42:1627–1633.

25. Patience JF, Thacker PA, de Lange CFM. Feeding the weaned pig. In: *Swine Nutrition Guide*. 2nd ed. Saskatoon, Saskatchewan: Prairie Swine Centre Inc; 1995:173–186.

26. Machin D. Alternative Feeds for Outdoor Pigs. In: Stark BA, Machin DH, Wilkinson JM, eds. *Outdoor Pigs Principles and Practices*. Marlow, Great Britain: Chalcombe Publications; 1990:103–114.

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

28. Wenk C. The role of dietary fibre in the digestive physiology of the pig. *Anim Feed Sci Technol*. 2001;90:21–33.

*29. Baltazar J, Balderrama V, Calderon D, Reis de Souza TC, Pettigrew J, Mariscal G, Brana D, Cuaron J. Formulating feed to the standardized total tract digestible phosphorous (STTDP) requirement prevents productive failure, as long as the calcium to phosphorous ratio is correct. *Proc IPVS*. Cancun, Mexico. 2014;278.

30. Whittemore CT, Kyriazakis I, eds. *Whittemore's Science and Practice of Pig Production*. 3rd ed. Ames, Iowa: Blackwell Publishing; 2008:426.

31. DeRouchey JM, Goodband RD, Tokach MD, Nelssen JL, Dritz SS. Nursery Swine Nutrient Recommendations and Feeding Management. In: *Pork Centre of Excellence National Swine Nutrition Guide*. Des Moines, Iowa: Pork Centre of Excellence; 2010;65–79.

32. Main RG, Dritz SS, Tokach MD, Goodband RD, Nelssen JL. Effects of weaning age on growing-pig costs and revenue in a multi-site production system. *J Swine Health Prod*. 2005;13:189–197.

* Non-refereed reference.