

Nutritive value of three tropical forage legumes and their influence on growth performance, carcass traits and organ weights of pigs

Bienvenu Kambashi^{1,2} · Gaetan Kalala¹ · Denis Dochain³ · Jacques Mafwila¹ · Xavier Rollin³ · Christelle Boudry² · Pascale Picron² · Jérôme Bindelle²

Received: 12 October 2015 / Accepted: 27 April 2016 / Published online: 6 May 2016
© Springer Science+Business Media Dordrecht 2016

Abstract The effects of tropical forage legumes on feed intake, growth performance and carcass traits were investigated in 16 groups of two Large White × Duroc pigs. The diets consisted of a commercial corn–soybean meal diet as the basal diet and three forage-supplemented diets. Four groups of control pigs received daily 4 % of body weight of the basal diet, and 12 groups of experimental pigs were fed the basal diet at 3.2 % of body weight completed with fresh leaves of one of the three forage legumes (*Psophocarpus scandens*, *Stylosanthes guianensis* and *Vigna unguiculata*) ad libitum. The study lasted 90 days. The in vitro digestion and fermentation of the forage legumes were also determined. The in vitro digestible energy content of the legumes was between 0.72 and 0.77 that of the basal diet (14.4 MJ/kg dry matter (DM)). *V. unguiculata* was the most digestible forage legume expected for crude protein digestibility. Feeding forage legumes lowered the dry matter intake by 4.5 to 9.6 % ($P<0.05$), final body weight ($P=0.013$), slaughter weight, average daily gain and hot carcass weight ($P<0.05$) without affecting the feed conversion ratio (FCR), dressing percentage and back fat thickness. In conclusion, using forage to feed pig

could be interesting in pig smallholder production with limited access to concentrate, as FCR was not significantly affected.

Keywords Forage legumes · Nutritive value · Pigs · Growth

Introduction

In the western part of the Democratic Republic of the Congo (DRC), as in most developing countries in tropical America, Africa and Asia, pig farming is practiced mainly by smallholders with low input and limited resources (Kagira et al. 2010; Kumaresan et al. 2007; Lapar et al. 2003). Rearing pigs plays a vital role as a source of high-quality proteins, as a source of income and as part of the household insurance system (Kumaresan et al. 2009; Phengsavanh et al. 2011). Pig farming is often integrated with other agricultural activities by providing manure for crops, while crop residues are in turn used as feed (An et al. 2004). In this production scheme, feeding varies according to market opportunities and the availability of the feed ingredients. Commercial concentrates are used by a small number of producers (e.g. <5 % in western DRC; Kambashi et al. 2014c), mostly around and near highly populated cities and in market-oriented production systems. Other producers feed unbalanced diets made of various agro-industrial by-products such as brewer's grains and bran, while in the remote countryside, pigs are fed all sorts of agricultural by-products from local food processing units, such as cassava roots, rice bran or corn. Often, pigs are supplemented with green forage plants that grow naturally in forests, along rivers banks or in fallowed and cropped fields (An et al. 2005; Kumaresan et al. 2007). The use of these resources, especially plant materials, seems to be the most profitable alternative to commercial diets (Lemke et al. 2007) and is often the only option in times of shortages. Some tropical forage species

Parts of this paper were presented at the Digestive Physiology of Pigs symposium in 2015 in Kliczkow (Poland).

✉ Jérôme Bindelle
jerome.bindelle@ulg.ac.be

¹ Université de Kinshasa, Mont-Amba, Lemba, Kinshasa, Democratic Republic of the Congo

² University of Liège, Gembloux Agro-Bio Tech, Precision Livestock and Nutrition Unit, Passage des Déportés, 2, 5030 Gembloux, Belgium

³ University of Louvain, Louvain-la-Neuve, Belgium

known and used by pig smallholders seem to be a good alternative to address protein and mineral deficiencies in unbalanced diets. Earlier studies have shown indeed that some species not only have a high protein content (Bindelle et al. 2007a; Kambashi et al. 2014a, d; Phuc and Lindberg 2000) and high digestibility (An et al. 2004; Leterme et al. 2009), but can also, to some extent, partially replace conventional sources of protein in pig diets without affecting the growth performance as well as the quality of the carcass (Kaensombath and Lindberg 2013; Kaensombath et al. 2013).

Among the tropical forage resources used in pig feeding systems in the Bas-Congo and Kinshasa provinces of DRC, *Psophocarpus* (*Psophocarpus scandens*), *Stylosanthes* (*Stylosanthes guianensis*) and *Vigna* (*Vigna unguiculata*) seem quite promising owing to their high protein value and reasonable energy digestibility as forage in non-ceacotrophic monogastrics (Kambashi et al. 2014b). *Psophocarpus* is a common wild plant that grows in lowlands up to an altitude of 1000 m in areas with an average annual rainfall of 1220–1800 mm and a mean annual temperature of 25 °C. *Psophocarpus* was introduced as a leafy vegetable in several African countries, but it has received limited acceptance (Schippers 2004). *Stylosanthes* grows from an altitude of 0 to 1600 m, between 600 and 3000 mm of annual rainfall and in a temperature range from 23 to 35 °C. It performs exceptionally well in humid tropical climates and those of medium altitude, even with a marked dry season (Husson et al. 2008; Tropical forages, 2014). *Vigna* is drought tolerant and has a short growing period. Dual-purpose varieties, suiting the different cropping systems existing in Africa, have been selected to provide both grain and forage (Gómez 2004; Singh et al. 2003), which allow farmers to diversify their sources of income, improve their livelihood and promote sustainable agriculture.

Most data available on these species is limited to the nutritive value in pigs, namely total tract digestibility in Sarria et al. (2010a, b) for *Vigna* and in Kambashi et al. (2014a) for *Stylosanthes*, *Psophocarpus* and *Vigna*. The present study aimed at assessing how feeding forage legumes to pigs actually affects the in vivo feed intake and growth performance of pigs fed a restricted amount of corn–soybean meal-based diet but supplemented with fresh forage from *Psophocarpus*, *Stylosanthes* and *Vigna*. It also aimed at understanding the relationship between the growth performances, on the one hand, and the chemical composition and the in vitro digestibility of those forage legumes, on the other hand.

Material and methods

Forage legumes were produced on a farm field of the Société des grands élevage de Ndama en Afrique centrale (SOGENAC) in the DRC, which is located at 5° 25' latitude

south and 14° 49' longitude east, about 180 km southwest of Kinshasa. The annual rainfall during the growing season was 1418 mm in 2012 (SOGENAC, personal communication). The average monthly temperature ranged from 21.5 to 25.4 °C. The field had a ferrallitic soil with sand–clay texture (Renard et al. 1995). The first harvest was carried out after 2 months for *Vigna* and *Psophocarpus* and 2.5 months for *Stylosanthes*. Because of its short growing period, to avoid differences in forage composition due to differences in growth stages along the 90-day experiment, *Vigna* was grown three times in three different plots at the same field, each time with an interval of 1 month to yield leaves that were harvested until the initial pod set. *Psophocarpus* and *Stylosanthes* were grown once, and only the leaves and soft stalks were harvested on a regular basis. Since the experiment on pigs lasted for 90 days, forage samples for chemical composition were taken daily and pooled over 10-day periods to make up a total of nine independent samples for each forage species. The chemical composition as well as the amino acid profiles of the forage legumes used in the experiment is displayed in Table 1. Amino acids were determined only on six randomly chosen samples out of the nine that were available as explained previously.

Animals, feeding and management

Thirty-two castrated male growing pigs (Large White × Duroc) with an average body weight ($\pm$ SD) of 25.5 $\pm$ 4.2 kg at the beginning of the experiment and 74.3 $\pm$ 8.0 kg at the end were used. On arrival, the pigs were kept and observed for 1 week. During this period, they were treated against intestinal parasites and fed a commercial corn and soybean-based diet free of antibiotics. The pigs were then divided in 16 groups of two pigs (average weight 50.0 $\pm$ 1.2 kg) randomly while ensuring that piglets of a same litter were split over in each of the four different diets. Each group was randomly assigned to one diet for 90 days, from June 12, 2012, to September 10, 2012. The diets consisted either of a commercial corn and soybean-based diet (MIDEMA, Matadi, Bas-Congo, DRC; basal diet) as control fed at 4 % of body weight on dry matter (DM) basis or of the basal diet fed at 3.2 % of body weight on DM basis (80 % of the allowance of the control groups) supplemented with fresh leaves of one of the three forage legumes fed ad libitum. The pigs were fed twice a day (8 a.m. and 4 p.m.). Forage was harvested every morning and chopped (2–3 cm) to avoid selection. A sample of the distributed control diet and forage was collected daily. A subsample was dried at 105 °C for DM determination, and another subsample was dried at 60 °C and pooled over 10-day periods for further chemical analyses as explained above. The refusals underwent the same treatment. Since the experiment lasted for 90 days, there

Table 1 Proximal composition of tropical forage legumes and essential amino acid contents of a corn–soybean and forage legumes fed to the pigs (g/kg DM) ($N=9$ except for amino acids where $N=6$)

	Control diet	<i>Psophocarpus scandens</i>		<i>Stylosanthes guianensis</i>		<i>Vigna unguiculata</i>	
		Mean $\pm$ SD	Min–max	Mean $\pm$ SD	Min–max	Mean $\pm$ SD	Min–max
Dry matter of fresh forage	885 $\pm$ 8	201 $\pm$ 23		216 $\pm$ 25		156 $\pm$ 16	
Ash	69 $\pm$ 3	95 $\pm$ 9		92 $\pm$ 11		131 $\pm$ 31	
Crude protein ($N \times 6.25$)	192 $\pm$ 7	230 $\pm$ 18	194–252	194 $\pm$ 24	150–226	212 $\pm$ 29	172–263
Neutral detergent fibre	228 $\pm$ 19	473 $\pm$ 28	431–524	507 $\pm$ 64	419–596	359 $\pm$ 61	259–446
Acid detergent fibre	60 $\pm$ 2	316 $\pm$ 27	271–354	347 $\pm$ 59	234–460	252 $\pm$ 58	155–311
Acid detergent lignin	17 $\pm$ 1	70 $\pm$ 10	55–82	64 $\pm$ 13	48–80	51 $\pm$ 14	23–65
Gross energy (kcal/kg DM)	4455 $\pm$ 18	4457 $\pm$ 91	4263–4557	4335 $\pm$ 54	4224–4408	4233 $\pm$ 95	4206–4472
Essential amino acids (g/kg DM)							
Arginine	12.3 $\pm$ 0.9	10.3 $\pm$ 0.7		9.6 $\pm$ 0.8		12.6 $\pm$ 0.7	
Histidine	5.0 $\pm$ 0.3	4.3 $\pm$ 0.1		3.8 $\pm$ 0.4		4.4 $\pm$ 0.4	
Isoleucine	7.3 $\pm$ 0.6	8.8 $\pm$ 0.4		7.8 $\pm$ 0.9		10.0 $\pm$ 0.9	
Leucine	14.1 $\pm$ 0.9	14.2 $\pm$ 0.6		13.0 $\pm$ 0.9		16.5 $\pm$ 0.9	
Lysine	7.7 $\pm$ 0.6	9.4 $\pm$ 0.6		8.1 $\pm$ 0.7		9.7 $\pm$ 0.9	
Methionine	3.4 $\pm$ 0.3	3.5 $\pm$ 0.4		3.2 $\pm$ 0.2		4.2 $\pm$ 0.4	
Phenylalanine	8.7 $\pm$ 0.5	9.4 $\pm$ 0.5		8.8 $\pm$ 0.8		10.9 $\pm$ 0.9	
Threonine	7.8 $\pm$ 0.5	10.1 $\pm$ 0.4		8.5 $\pm$ 0.9		10.5 $\pm$ 0.9	
Tyrosine	4.9 $\pm$ 0.3	5.0 $\pm$ 0.3		4.6 $\pm$ 0.5		5.5 $\pm$ 0.7	

SD standard deviation

were a total of nine samples for the basal diet and for each of the forage species. Those samples were dried (60 °C for 48 h) and ground to pass a 1-mm mesh screen in a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark). The pigs had permanent access to water.

The experiment was conducted in a renovated pigsty in Kolo-Fuma (Bas-Congo, DRC). The pens had concrete floors and were disinfected and repainted with lime 2 weeks before the experiment. They were cleaned daily with water, before feeding, during the experiment. Each box had two areas, one area of about 4 m² under shelter and 6 m² without shelter as exercise area. Animals were weighed at the start of the experiment and every 10 days until the end of the experiment that lasted 90 days. Subsequently, the animals were kept on their respective experimental diets until they reached market weight (>75 kg), for a period which lasted from 1 to 7 days, depending on the animal weight after the 90-day period. All pigs were slaughtered after an overnight fasting and the empty carcasses, and major organs were weighed to compare carcasses quality at market weight. Back fat was measured at the P2 position, 65 mm away from the midline, at the level of the last rib.

In vitro nutrient gastro-intestinal digestion and fermentation

An in vitro nutrient gastro-intestinal digestion and fermentation analysis was done on the control diet and the forages. For this purpose, four randomly chosen samples of each forage legume and the basal diet were assessed for the digestibility of their nutrients using the in vitro model developed by Bindelle et al. (2007a) which simulates the digestion in the pig gastro-intestinal tract by an enzymatic hydrolysis. Briefly, 2-g samples were hydrolysed in 100 ml of a phosphate buffer (0.1 M) with porcine pepsin (100 mg, 2 h, 39 °C, pH 2) and subsequently in 140 ml of a phosphate buffer (0.13 M) with porcine pancreatin (200 mg, 4 h, 39 °C, pH 6.8). The recovered indigestible residue was afterwards fermented with faecal bacteria of sows in a carbonate-based buffer (72 h, 39 °C, pH 6.8) to simulate the fermentation processes occurring in the large intestine with measurement of kinetics of gas production. Fermentation broth collected after 72 h was centrifuged at 13,000g for 15 min, and the supernatants were sampled and frozen at –18 °C until further short-chain fatty acid (SCFA) analysis.

For each of the four samples of each forage species, enzymatic hydrolysis was performed eight times on 2-g samples to yield sufficient amounts of indigestible residues for the subsequent analyses and fermentation. In vitro fermentation was performed in quadruplicate on the pooled residues of each initial sample.

Chemical analyses

Dry forage legumes and the basal diet were analysed for their content in DM by drying at 105 °C for 24 h (method 967.03; AOAC 1990), ash by burning at 550 °C for 8 h (method 923.03; AOAC 1990), nitrogen (N) according to the Kjeldahl method and calculating the crude protein (CP) content ($N \times 6.25$; method 981.10; AOAC 1990), gross energy by means of an adiabatic oxygen bomb calorimeter (1241 Adiabatic Calorimeter, PARR Instrument Co., IL, USA) and neutral detergent fibre (NDF) using thermostable amylase (Termamyl®, Novo Nordisk, Bagsværd, Denmark) and corrected for ash. Feed samples were also analysed for their content in acid detergent fibre (ADF) corrected for ash, acid detergent lignin (ADL) according to Van Soest et al. (1991) using an ANKOM-Fiber Analyzer (ANKOM-Technology, Fairport, NY) and amino acids by HPLC (Alliance 2690, Waters, Milford, MA, USA) after hydrolysis with a mixture of 6 mol HCl/l, containing 1 g phenol/l at 110 °C for 24 h and derivatisation with the AccQ-Fluor Reagent Kit (Waters, USA). Methionine and cystine underwent performic oxidation before hydrolysis. The supernatants of the fermentation broth were analysed for SCFA contents after 72 h of fermentation with the same HPLC instrument fitted with an HPX 87H column (Bio-Rad, Hercules, CA, USA) and an UV detector (210 nm, Waters, Milford, MA, USA).

Calculations and statistical analysis

The in vitro dry matter disappearance (IVDMD), crude protein (IVCPD) and gross energy (IVED) disappearance during the pepsin–pancreatin hydrolysis were calculated as follows:

$$IVDMD = \frac{X - Y}{X},$$

where X is the weight of the sample before hydrolysis and Y is the weight of the residue.

$IVD = 1 - \frac{Y \times (1 - IVDMD)}{X}$, where X is the nutrient content (CP, energy) in the sample before hydrolysis and Y is the nutrient content in the residue after hydrolysis.

The volume of gas produced during fermentation was modelled to calculate four fermentation kinetics parameters: final gas volume (A , ml/g DM), mid-fermentation time (B , h), maximum rate of gas production (R_M , ml/[h $\times$ g DM]) and

time at which the maximum rate of gas production is reached (t_{RM} , h) (Groot et al. 1996).

Potential contribution of fermentation in the large intestine to energy supply through SCFA was calculated as explained in Kambashi et al (2014a) by multiplying the energy value of each SCFA (acetate 14.56 kJ/g, propionate 20.51 kJ/g and butyrate 24.78 kJ/g) by the SCFA production.

In vivo and in vitro data were tested for normality and homoscedasticity. Subsequently, they were subjected to a one-way analysis of variance using the MIXED procedure of the SAS 9.2 software (SAS Inc., Cary, NC) with the group of two pigs as experimental units ($N=4$) for in vivo data and the individual ingredient sample for in vitro data. Growth performance parameters were analysed both per 10-day period independently and over the 90-day duration of the whole trial. In the case of a significant difference ($P < 0.05$), least square means were used as multiple range tests. Correlation between variables was assessed using the CORR procedure in SAS 9.2 software.

Results

Nutritive value

Digestible energy content of the forage legumes, as measured using an in vitro method, was between 0.72 and 0.77 that of the basal diet (Table 2). Differences between forage species were limited to 0.8 MJ/kg DM with *Vigna* being the most digestible forage legume expected for CP disappearance. The IVCPDs of *Vigna* and *Psophocarpus* were lower than those of the basal diet and *Stylosanthes*. However, their high CP content compensated for this lower disappearance, yielding similar estimated digestible protein values for all forage species and the basal diet. Higher values for *Vigna* and *Stylosanthes* were not significant ($P=0.304$). Fermentability of the fibre residue was lower in all forage legumes compared to the basal diet as indicated by lower final gas volume (A) and maximum rate of gas production (R_M), higher times for maximum fermentation (t_{RM}) and lower SCFA productions (Table 2). In terms of SCFA profile, the basal diet produced more butyrate than the forage legumes, and compared to the other forage legumes, *Psophocarpus* produced less acetate and more propionate and butyrate.

Feed intake

Forage legume intake was highest with *Stylosanthes* (321 g/day) as opposed to *Vigna* (232 g/day) and *Psophocarpus* (214 g/day), making up less than the 20 % that of expected from the reduction in basal diet allowance. It resulted in a reduction in dry matter intake (DMI) ($P < 0.001$). However, the *Stylosanthes*-supplemented diets had a higher DMI than

Table 2 In vitro dry matter disappearance (IVDMD), energy (IVED) and crude protein (IVCPD) disappearances during enzymatic hydrolysis and kinetic parameters of the gas production curves modelled according to Groot et al. (1996) and SCFA production for the hydrolysed ingredients incubated with pig faeces ($N=4$)

Ingredients		Control diet	<i>Psophocarpus scandens</i>	<i>Stylosanthes guianensis</i>	<i>Vigna unguiculata</i>	SEM	<i>P</i> value
IVDMD	(–)	0.666 a	0.397 c	0.396 c	0.475 b	0.024	<0.001
IVED	(–)	0.658 a	0.390 d	0.406 c	0.482 b	0.023	<0.001
IVCPD	(–)	0.855 a	0.651 c	0.834 ab	0.742 bc	0.026	<0.001
DP	(g/kg DM)	164	154	182	180	7.880	0.304
Acetate	(mol/mol)	0.467 d	0.480 c	0.524 a	0.507 b	0.004	<0.001
Propionate	(mol/mol)	0.344 b	0.360 a	0.335 b	0.343 b	0.002	<0.001
Butyrate	(mol/mol)	0.116 a	0.086 b	0.065 c	0.071 c	0.006	<0.001
BCFA	(mol/mol)	0.074	0.074	0.076	0.079	0.002	0.740
Total SCFA ^c	(mg/g hydroly-sate)	382.0 a	321.6 b	308.7 b	296.5 b	6.967	<0.001
SCFA energy ^a	MJ/kg DM	2.12 c	3.19 a	2.97 a	2.50 b	0.243	<0.001
Total DE ^b	MJ/kg DM	14.4 a	10.4 c	10.3 c	11.1 b	0.222	<0.001
<i>A</i>	(ml/g DM)	230 a	138 b	169 b	157 c	4.485	<0.001
<i>R_M</i>	(ml/[h × g DM])	14.4 a	7.9 c	11.4 b	10.5 b	0.333	<0.001
<i>t_{RM}</i>	(h)	10.5 c	14.4 a	13.0 b	13.0 b	0.247	<0.001

DP digestible protein, *A* final gas volume, *R_M* maximum rate of gas production, *t_{RM}* time at which the rate of gas production reaches *R_M*, SEM standard error of the means. For one parameter, means followed by different letters in the column differ at a significance level of 0.05

^a Energy supplied to the animal in the form of short-chain fatty acids (SCFAs) produced during intestinal fermentation calculated by multiplying the energy value of each SCFA (acetate 14.56 kJ/g, propionate 20.51 kJ/g, and butyrate 24.78 kJ/g) by the SCFA production of undigested residues

^b Sum of the digestible energy during enzymatic hydrolysis and the contribution of SCFA from intestinal fermentation of undigested residue

^c SCFAs produced during intestinal fermentation of undigested residue

the *Vigna*- and *Psophocarpus*-supplemented diets (Table 3). This difference between *Stylosanthes* and the two other forage-supplemented diets was mainly observed when the pigs were reaching 60 kg of bodyweight (Fig. 1a) after 70 days of experiment (Fig. 1b). Finally, when considering forage intake alone, it was highest with *Stylosanthes* (321 g/day) as opposed to *Vigna* (232 g/day) and *Psophocarpus* (214 g/day).

Growth performance

Over the whole experimental period, the average daily gain (ADG) ranged from 515 to 597 g/day and feed conversion ratio (FCR) from 3.52 to 3.67 (Table 3). The ADG was higher ($P<0.05$) in control pigs than those on the *Psophocarpus*- and *Vigna*-supplemented diets, while no difference was found between control pigs and those supplemented with *Stylosanthes*. These differences in ADG were mainly observed at the end of the experiment, namely after 80 and 90 days (Fig. 1c). Nevertheless, differences in ADG between forage species were not significant throughout the study. However, the FCR remained unaffected during the study (Fig. 1d; $P>0.05$).

Carcass composition and organ weights

The dressing percentage of the hot carcasses was similar in control- and forage-based diets ($P>0.05$), which ranged from 73 to 75 %, and no difference was found between forage species. Among organ weights, the stomach varied from 640 to 756 g and differed ($P<0.05$) between treatments (Table 4). The *Stylosanthes*-supplemented diet had heavier stomach than the control diet ($P>0.05$). The control diet had also heavier kidneys, while *Psophocarpus*-supplemented diets had the lightest. Other organs were unaffected by the treatments.

Discussion

Results from this growth study should be interpreted with caution, owing to the fact that unbalanced diets were used as follows: (1) the control diet was partly replaced by unbalanced forage legumes, and (2) the composition of the control diet was not adjusted to the growth phases of the pigs. Indeed, according to NRC (1998), the CP must

Table 3 Effects of reducing feed allowance in pigs fed either a corn–soybean alone or supplemented with forage legumes on growth performance, average daily feed intake (ADFI) and feed conversion ratio (FCR) in pigs

	Control diet	<i>Psophocarpus scandens</i>	<i>Stylosanthes guianensis</i>	<i>Vigna unguiculata</i>	<i>P</i> values	SEM
Initial BW (kg)	24.4 b	25.1 a	25.5 a	25.0 ab	0.026	0.14
Final BW (kg)	78.7 a	71.3 b	73.8 ab	73.3 b	0.013	0.88
Average daily gain (g/day)	597 a	515 b	543 ab	537 b	0.013	11.0
Total average DMI (g/day)	2077 a	1876 c	1983 b	1894 c	<0.001	19.5
Ingested forage (g/day)	—	214 b	321 a	232 b	0.001	12.4
Total DMI (g/kg ^{0.75} BW)	110 a	105 b	108 a	105 b	0.005	0.84
FCR (kg feed/kg gain)	3.52	3.66	3.67	3.55	0.619	0.04

Values within row with differing letters are significantly different ($P < 0.05$)

SEM standard error of the means

be reduced from 18 to 15.5 % for CP for pigs between 20 and 50 kg and 50–80 kg respectively, while metabolisable energy (ME) remains unchanged to 3265 kcal/kg. This was not the case here because the experiment was intended to reflect the practices of the farmers who use

only one single growth diet and dilute concentrate diets with other fibre-rich ingredients. Moreover, the in vitro model used to investigate the nutritive value did not consider possible antagonist effect when forages are mixed to the control diet.

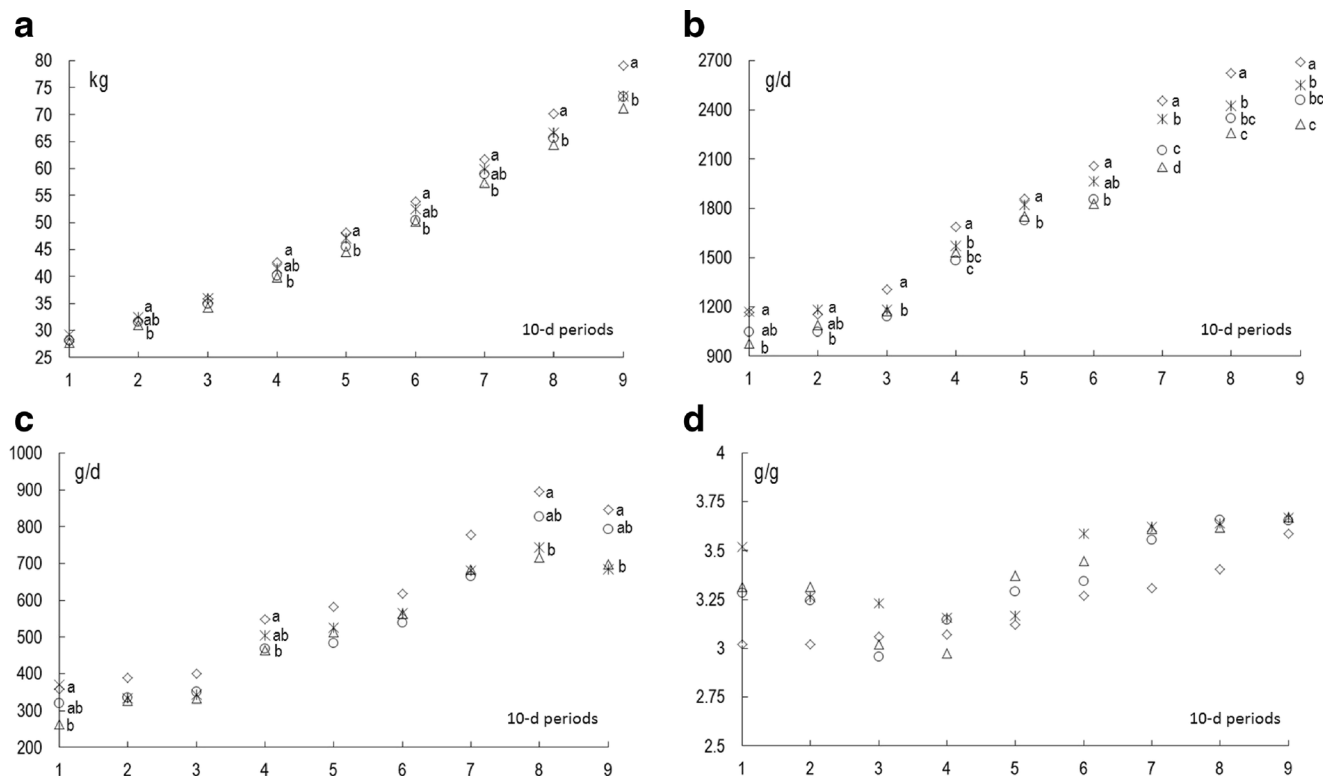


Fig. 1 Evolution of body weights (a), average daily gains (b), total dry matter feed intakes (c) and feed conversion ratios (d) over the course of the experiment for pigs fed: diamond, control diet; triangle, *Psophocarpus scandens*-supplemented diet; asterisk, *Stylosanthes*

guianensis-supplemented diet; and circle, *Vigna unguiculata*-supplemented diet. Each number on the abscissa relates to the 10-day periods between two consecutive weighings of the animals. Values with differing letters differ in the classification of means for $P < 0.05$

Table 4 Effects of reducing feed allowance in pigs fed either a corn–soybean alone or supplemented with forage legumes on carcass composition and organ weight in pigs

	Control diet	<i>Psophocarpus scandens</i>	<i>Stylosanthes guianensis</i>	<i>Vigna unguiculata</i>	<i>P</i> values	SEM
Slaughter weight (kg)	79.5 a	72.2 b	74.6 ab	74.2 b	0.038	0.14
Hot carcass weight (kg)	59.7 a	52.7 b	54.2 b	54.7 b	0.017	0.76
Back fat at P2 (mm)	18	15	15	17	0.197	0.59
Stomach (g)	640 b	691 ab	756 a	679 ab	0.045	14.5
Dressing carcass (%)	75.1	73.0	72.7	73.5	0.190	0.43
Liver (g)	1395	1306	1382	1401	0.650	29.1
Lung (g)	706	752	725	801	0.361	23.6
Kidney (g)	299 a	238 c	251 bc	276 ab	0.001	7.00
Kidney (g/kg carcass weight)	5.0	4.3	4.5	4.9	0.125	0.12

For one row, means followed by different letters differ ($P < 0.05$)

SEM standard error of the means

Pigs were not able to fully compensate the 20 % reduction in basal diet feeding allowance using forage legumes. It resulted in lower DMI and, therefore, in lower growth performance and lower slaughter hot carcass weight. While digestible protein contents appeared to be similar to that of the basal diet, forage legumes had lower digestible energy contents which, on the top of the reduction in intake, induced these lower performances. The reduction in digestible energy content of the forage legumes was mainly caused by their higher NDF content as well as the difference in hemicellulose (i.e. NDF–ADF), cellulose (i.e. ADF–ADL) and lignin (i.e. ADL) fractions, the latter considering that cellulose and lignin are less fermentable than hemicellulose (Noblet and Le Goff 2001). Indeed, with hemicellulose values of 157, 160 and 107 g/kg DM, for *Psophocarpus*, *Stylosanthes* and *Vigna*, respectively, forage legumes did not supply more highly fermentable hemicellulose than the control diet (168 g/kg DM). Moreover, the basal diet probably contained corn. It is known for supplying resistant starch which is not included in the hemicellulose fraction but is also highly fermentable (Sajilata et al. 2006). This explains why the intestinal fermentation of the fibre residues of forage legumes could not compensate through SCFA productions for the lower ileal digestibility (Table 2). The low DMI for forage-supplemented diets, in this study, is related to the high water and high fibre content of the forage-supplemented diets compared to the control diet (Table 1). Moreover, the high water holding capacity of some dietary fibre fractions of forage plants leads to bulkiness and reduced intake as showed by Ndou et al. (2013). Bulky diets give a sensation of a full stomach and, thereby, prevent animals from continuing to eat and fulfil their nutritional requirements (Leterme et al. 2010). The amount of bulky feed that an animal can eat depends on its own capacity to cope with bulk and the bulkiness of the feed itself. A study with pigs fed *Stylosanthes* and *Aeschynomene histrix*-supplemented diets

showed a similar decrease in DMI, when forage was included, as leaf meal, to the diets in levels of 13, 21 and 37 % in the pig diet (Phengsavan and Lindberg 2013). However, Keoboulapheth and Mikled (2003) reported an increase in individual feed intake from 942 to 1309 g DM/day when pigs were fed a protein-deficient corn, and rice bran-based diets, supplemented with fresh *Stylosanthes*. The intake in *Stylosanthes* represented less than 12 % of the total intake, showing that supplemented pigs ate more of both the protein-deficient basal diet and forage. In the present experiment, the average daily forage DMI for *Psophocarpus*, *Stylosanthes* and *Vigna* was 11.5, 16.2 and 12.3 % of the total DMI, respectively. The results of this study show that pigs could not ingest the forage legumes as extensively as the control diet, leading to a lower total intake in forage-supplemented pigs. *Stylosanthes* was more consumed than the other forage species which could be explained by its higher DM content (Table 1). Indeed, the DMI of each individual forage legume was positively related to the DM content of the forage ($R^2 = 0.74$, $P < 0.05$). The DMI of forage resources can be improved by processing methods such as ensiling, drying, chopping or milling, reducing water content and bulk effect, with a subsequent reduction of anti-nutritional compounds such as tannins and trypsin inhibitory activity as well as oxalic acid, which improves digestibility and potential absorbability of protein and minerals for pigs (Martens et al. 2012, 2014).

As the FCR was not different between the diets, the reduction in growth performance observed in this study was probably mainly caused by the lower DMI. These results are consistent with those of Phengsavan and Lindberg (2013) who found a decrease in DMI and growth rate (14 %) with 11 % legume leaf meal incorporation level, but just like in the present study, FCR was unaffected.

In contrast with growth performance, carcass quality and dressing percentage were not influenced by the inclusion of forage. However, pigs fed forage-supplemented diet had heavier stomachs than those on control diets. Pigs fed *Stylosanthes* tended to have a high stomach weight probably due to its high fibre content (Len et al. 2009; Ngoc et al. 2013).

Moreover, the low-growth performance (e.g. ADFI, ADG) of pigs fed forage-supplemented diets originates from the fact that those diets were compared with a commercial balanced diet in pigs with not only a high growth potential but also high nutritional requirements (Kambashi et al. 2014d). However, as mentioned before, the one-phase feeding applied in this experiment is not in line with NRC (1998) recommendations. This drift from recommendations, in combination to the fact that pigs reared in the tropics display lower growth performances due to heat load, lead to the high FCR of 3 to 3.5, while values when 2.5 were expected for animals of that age. Moreover, differences between forage legumes in forage-supplemented diets were higher at the end of the experiment, when pigs were older, possibly because heavier animals have higher digestive capacity when it comes to fibre fermentation (Le Goff and Noblet 2001; Bindelle et al. 2007a, b). Therefore, among the three legume species, the best-performing one was *Stylosanthes* which also displayed the highest fermentability of its fibre fraction. Earlier studies have shown that when pigs are fed an unbalanced and fibre-rich diet, generally made of crop residues and by-products available to the smallholding farmer, the provision of forage legumes to those animals (*A. hystrix* and *S. guianensis*) improves growth (Keoboulapheth and Mikled 2003; Phengsavanh and Lindberg 2013).

In conclusion, feeding forage legumes to pigs in replacement to a reduction of 20 % of feed allowance of a well-balanced basal diet in this study decreases global feed intake by 4.5 to 9.6 % as well as growth performance, depending on the forage species without affecting feed conversion ratio.

Acknowledgments The authors gratefully acknowledge Wallonie-Bruxelles International (WBI), the Development Cooperation Agency (DGD) and the Commission de la Coopération au Développement de l'Académie de Recherche et d'Enseignement supérieur (ARES-CCD; Brussels, Belgium) for funding this study (CAVTK and Systèmes intégrés projects) and the workers in Kolo-Fuma (SEBO, Bas-Congo, DRC) for their support.

Compliance with ethical standards

Statement of animal rights All experimental animals were handled with respect according to the rules and regulations in force in the European Union following similar procedures to those usually accepted by the Ethical Committee of the University of Liège (Belgium) for experiments performed in Gembloux Agro-Bio Tech (Belgium).

Conflict of interest The authors declare that they have no conflicts of interest.

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. *Animal Feed Science and Technology*. 114, 127–139
- An, L.V., Hong, T.T., Ogle, B., Lindberg, J.E., 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
- AOAC, 1990. Official Methods of Analysis, (Association Official Analytical Chemists, Arlington)
- Bindelle, J., Ilunga, Y., Delacollette, M., MulandKayij, M., Umba di M'Balu, J., Kindele, E., Buldgen, A., 2007a. Voluntary intake, chemical composition and in vitro digestibility of fresh forages fed to Guinea pigs in periurban rearing systems of Kinshasa. *Tropical Animal Health and Production*. 39, 419–426
- Bindelle, J., Buldgen, A., Lambotte, D., Wavreille, J., Leterme, P., 2007b. Effect of pig faecal donor and of pig diet composition on in vitro fermentation of sugar beet pulp. *Animal Feed Science and Technology*. 132, 212–226
- Gómez, C., 2004. Cowpea: post-harvest operations. In: Mejía (Ed.), *Post-harvest compendium*, (AGST, FAO) 71
- Groot, J.C.J., Cone, J.W., Williams, B.A., Debersaques, F.M.A., Lantinga, E.A., 1996. Multiphasic analysis of gas production kinetics for in vitro fermentation of ruminant feeds. *Animal Feed Science and Technology*. 64, 77–89
- Husson, O., Charpentier, H., Razanamparany, C., Moussa, N., Michellon, R., Naudin, K., Razafintsalama, H., Rakotoarinivo, C., Rakotondramanana, Séguy, L., 2008. *Stylosanthes guianensis*, Manuel pratique du semis direct à Madagascar, (CIRAD, Montpellier)
- Kaensombath, L., Lindberg, J.E., 2013. Effect of replacing soybean protein by taro leaf (*Colocasia esculenta* (L.) Schott) protein on growth performance of exotic (Landrace × Yorkshire) and native (Moo Lath) Lao pigs. *Tropical Animal Health and Production*. 45, 45–51
- Kaensombath, L., Neil, M., Lindberg, J.E., 2013. 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. *Tropical Animal Health and Production*. 45, 865–871
- Kagira, J., Kanyari, P., Maingi, N., Githigia, S., Ng'ang'a, J., Karuga, J., 2010. Characteristics of the smallholder free-range pig production system in western Kenya. *Tropical Animal Health and Production*. 42, 865–873
- Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H., Bindelle, J., 2014a. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. *Animal Feed Science and Technology*. 191, 47–56
- Kambashi, B., Picron, P., Boudry, C., Kiatoko, H., Bindelle, J., 2014b. Feeding value of hays of four tropical forage legumes in pigs: *Vigna unguiculata*, *Psophocarpus scandens*, *Pueraria phaseoloides* and *Stylosanthes guianensis*. *Tropical Animal Health and Production*. 46, 1497–1502
- Kambashi, B., Picron, P., Boudry, C., Thewis, A., Kiatoko, H., Bindelle, J., 2014c. Smallholder pig production systems along a periurban-rural gradient in the Western provinces of the Democratic Republic of the Congo. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 115, 9–22
- Kambashi, B., Boudry, C., Picron, P., Bindelle, J., 2014d. Forage plants as an alternative feed resource for sustainable pig production in the tropics: a review. *Animal*, 8, 1298–1311

- Keoboulapheth, C., Mikled, C., 2003. Growth Performance of indigenous pigs fed with *Stylosanthes guianensis* CIAT 184 as replacement for rice bran. *Livestock Research for Rural Development*. 15 (9)
- Kumaresan, A., Bujarbaruah, K.M., Pathak, K.A., Chhetri, B., Das, S.K., Das, A., Ahmed, S.K., 2007. Performance of pigs reared under traditional tribal low input production system and chemical composition of non-conventional tropical plants used as pig feed. *Livestock Science*. 107 294–298
- Kumaresan, A., Bujarbaruah, K.M., Pathak, K.A., Das, A., Bardoloi, R.K., 2009. Integrated resource-driven pig production systems in a mountainous area of Northeast India: production practices and pig performance. *Tropical Animal Health and Production*. 41, 1187–1196
- Lapar, L., Binh, V.T., Ehui, S., 2003. Identifying barriers to entry to livestock input and output markets in South-East Asia. The case of Vietnam, (ILRI, Nairobi)
- Le Goff, G., Noblet, J., 2001 Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. *Journal of Animal Science*. 79, 2418–2427
- Lemke, U., Kaufmann, B., Thuy, L.T., Emrich, K., Valle Zárate, A., 2007. Evaluation of biological and economic efficiency of smallholder pig production systems in North Vietnam. *Tropical Animal Health and Production*. 39, 237–254
- Len, N.T., Hong, T.T., Ogle, B., Lindberg, J.E., 2009. Comparison of total tract digestibility, development of visceral organs and digestive tract of Mong cai and Yorkshire × Landrace piglets fed diets with different fibre sources. *Journal of Animal Physiology and Animal Nutrition*. 93, 181–191
- Leterme, P., Londono, A.M., Munoz, J.E., Suarez, J., Bedoya, C.A., Souffrant, W.B., Buldgen, A., 2009. Nutritional value of aquatic ferns (*Azolla filiculoides* Lam. and *Salvinia molesta* Mitchell) in pigs. *Animal Feed Science and Technology*. 149, 135–148
- Leterme, P., Londoño, A.M., Ordoñez, D.C., Rosales, A., Estrada, F., Bindelle, J., Buldgen, A., 2010. Nutritional value and intake of aquatic ferns (*Azolla filiculoides* Lam. and *Salvinia molesta* Mitchell.) in sows. *Animal Feed Science and Technology*. 155, 55–64
- Martens, S.D., Tiemann, T.T., Bindelle, J., Peters, M., Lascano, C.E., 2012. Alternative plant protein sources for pigs and chickens in the tropics—nutritional value and constraints: a review. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. 113, 101–123
- Martens, S.D., Hoedtke, S., Avila, P., Heinritz, S.N., Zeyner, A., 2014. Effect of ensiling treatment on secondary compounds and amino acid profile of tropical forage legumes, and implications for their pig feeding potential. *Journal of the Science of Food and Agriculture*. 94, 1107–1115
- Ndou, S.P., Bakare, A.G., Chimonyo, M., 2013. Prediction of voluntary feed intake from physicochemical properties of bulky feeds in finishing pigs. *Livestock Science*. 155, 277–284
- Ngoc, T.T., Len, N.T., Lindberg, J.E., 2013. Impact of fibre intake and fibre source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. *Animal* 7, 736–745
- Noblet, J., Le Goff, G., 2001. Effect of dietary fibre on the energy value of feeds for pigs. *Animal Feed Science and Technology*. 90, 35–52
- NRC, 1998. Nutrient requirements of swine. National Academy Press, Washington, DC
- Phengsavanh, P., Lindberg, J., 2013. Effect of replacing soybean protein with protein from porcupine joint vetch (*Aeschynomene histrix* BRA 9690) and stylo (*Stylosanthes guianensis* Composite) leaf meal on growth performance of native (Moo Lath) Lao pigs. *Tropical Animal Health and Production*. 45, 1795–1802
- Phengsavanh, P., Ogle, B., Stür, W., Frankow-Lindberg, B.E., Lindberg, J.E., 2011. Smallholder pig rearing systems in Northern Lao PDR. *Asian-Australian Journal of Animal Sciences*. 24, 867–874
- Phuc, B.H.N., Lindberg, J.E., 2000. Ileal and total tract digestibility in growing pigs given cassava root meal diets with inclusion of cassava leaves, leucaena leaves and groundnut foliage. *Animal Science*. 71, 301–308
- Renard, J.F., Frère, P., Lecomte, P., 1995. Evaluation pastorale des savanes du ranch de kolo (Bas-Zaïre). *Tropicultura* 13, 65–70
- Sajilata, M.G., Singhal, R.S., Kulkarni, P.R., 2006. Resistant starch—a review. *Comprehensive Reviews in Food Science and Food Safety* 5, 1–17
- Sarria, P., Rivera, L.F., Araujo, R., Peters, Y.M., 2010a. Follaje de caupí (*Vigna unguiculata*) como fuente de proteína para cerdos en crecimiento. *Revista Computadorizada de Producción Porcina* 17, 228–234
- Sarria, P., Montoya, C., Yusti, L. M., Orejuela, I., Guevara, M., Cruz, A. C., Arredondo, J., Londoño, A., Peters, M., 2010b. Valor nutricional de la harina de hoja de caupí (*Vigna unguiculata* (L) walp.) en cerdos en crecimiento. *Livestock Research for Rural Development*. Volume 22, (110).
- Schippers, R.R., 2004. *Psophocarpus scandens* (Endl.) Verde, In: Grubben, G.J.H., Denton, O.A. (Eds.), *Plant resources of tropical Africa 2. Vegetables*, Fondation PROTA, Wageningen, Pays-Bas/Backhuys Publishers, Leiden, Pays-Bas, CTA, Wageningen, Pays-Bas
- Singh, B.B., Ajeigbe, H.A., Tarawali, S.A., Fernandez-Rivera, S., Abubakar, M., 2003. Improving the production and utilization of cowpea as food and fodder. *Field Crop Research*. 4, 169–177
- Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*. 74, 3583–3597