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Chemical composition, nutritive value and voluntary intake of tropical tree foliage and cocoyam in pigs†

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Abstract: The composition of the leaves of cocoyam (*Xanthosoma sagittifolium*) and of two trees (*Trichanthera gigantea* and mulberry, *Morus alba*), their nutritive value in pigs and voluntary intake by pigs were determined. The average protein content ranged from 170 to 240 g kg^{-1} dry matter (DM) and that of neutral detergent fibres from 218 to 398 g kg^{-1} DM. The leaves are interesting sources of calcium (up to 69 g kg^{-1} DM), potassium, iron and manganese. The proteins are well balanced in essential amino acids, with lysine ranging from 43 to 57 g kg^{-1} proteins. The apparent faecal digestibility was determined by difference in 35 kg pigs fed a diet containing 35% leaf meal. The digestibility coefficients of DM, N and energy were, respectively, 47–57, 33–36 and 51–53%. The digestible energy value ranged from 1.674 to 2.037 kcal kg^{-1} DM. The voluntary intake of *Trichanthera* and *Xanthosoma* was measured in sows weighing 100 kg on average. The intake reached 3.4 kg fresh leaves day^{-1} (0.51 kg DM) and 1.0–1.1 kg dry leaf meal/day. It is concluded that low energy density is the main limiting factor of tree foliage for pig nutrition but that they are good sources of minerals and well-balanced proteins.

Keywords: tree foliage; pig; digestibility; intake; *Xanthosoma*; *Morus*; *Trichanthera*

INTRODUCTION

Pig production can improve the welfare of small farmers in developing countries, in terms of income and food quality. Pigs are prolific, omnivorous, have a low feed conversion ratio and small space requirements. Numerous tropical crops and by-products not consumed by humans could be used to feed these animals. However, most of them are poor in proteins.

On the sloping land of the foothills of the Colombian Andes as well as in many other parts of the world, the small farmers use browse trees as protein sources to feed their pigs. The trees protect against erosion and their leaves contain from 14 to 28% proteins,[1] sometimes with good essential amino acid content.[2,3]

Tree leaves can be used in pig nutrition as long as they are poor in antinutritional factors, are well digested, have good palatability and good amino acid profile. However, other criteria should be considered, such as fibre degradability or bulking properties.[4,5]

Unfortunately, information on the nutritive value of these forages in pigs is scarce and generally limited.[1–3] A better knowledge of the nutritive potential of these forages and of the voluntary intake by pigs would help to improve sustainable pig production systems.

The present work aimed at determining the chemical composition, nutritive value in pigs and voluntary intake by pigs of the foliage of three species widely used in the tropics to feed these animals: nacedero [*Trichanthera gigantea* (H & B) Nees], mulberry (*Morus alba* L) and cocoyam (*Xanthosoma sagittifolium* Schott), also called giant taro, malanga, yautia or elephant ear.

MATERIAL AND METHODS

Chemical composition

Samples of the three species were collected in three villages, located either in the Cauca river valley of Colombia (Jamundi and Palmira, with different rainfalls—1.800 and 1.000 mm water year^{-1}, respectively) or on the foothills bordering the valley (El Dovio, at 1.800 m above sea level vs. 1.000 m for the two others). At El Dovio, the trees were fertilized

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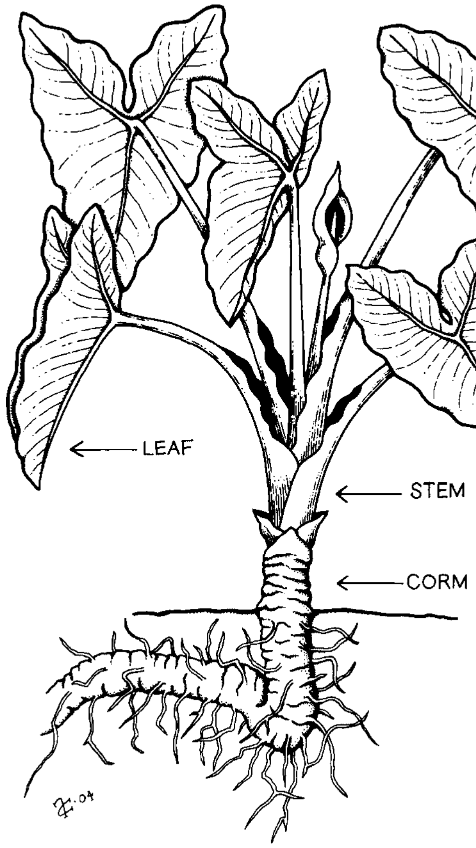

Figure 1. Whole plant of cocoyam (*Xanthosoma sagittifolium*).

with pig manure. In each farm, seven samples of young and mature leaves were collected. The young leaves had a maximum one month of age (after the previous harvest) and the mature ones 3–4 months. The leaves are generally harvested at 3–4 months of age. Since cocoyam is not really a tree but a plant composed of giant leaves (80 cm long), long stems and a starchy corm (Fig 1), and since the whole plant is used to feed the pigs, the chemical composition of the three parts was determined. The samples were kept in cool boxes and immediately brought to the laboratory, where they were frozen, freeze-dried and ground through a 1 mm mesh screen.

The flour was analysed for its content in ash (furnace at 550 °C for 8 h), nitrogen (Kjeldahl method) and oil (ether extract by the Soxhlet system) as described by the AOAC.[6] The neutral and acid detergent fibres (NDF and ADF) and acid detergent lignin were determined by means of an ANKOM fibre analyser (Ankom Technology, Madecon, NY, USA) using nylon bags. The minerals were determined by atomic absorption spectroscopy after mineralization in a furnace and recovery in a HNO_3–$HClO_4$ (2:1) solution, by means of a Perkin Elmer Zeeman AAS 800 spectrophotometer (Wellesley, MA, USA), with the exception of chlorine and phosphorus, which were determined by titrimetry and colorimetry, respectively. The total and reducing sugars were analysed by colorimetry after extraction with ethanol[7] and the amino acids by ion exchange chromatography, using a Biochrome 20 analyser (Pharmacia Biotech Ltd, Cambridge, UK). Methionine and cysteine were determined by the same method after oxidation with performic acid before hydrolysis. Tryptophan was also analysed but after alkaline hydrolysis using 4 M $Ba(OH)_2$. Crude energy was determined using a Parr 1341 calorimeter (Parr Instruments, Moline, MA, USA). The water-holding capacity of the leaf meals was determined after soaking of the meals in water (20 g l^{-1} water) for 6 h and centrifugation for 5 min at 5 × *g*. The supernate was suctioned off with a vacuum pump.

Nutritive value

Animals

Twelve male, castrated pigs (commercial breed × Pietrain), weighing from 29 to 38 kg (34 ± 3 kg, on average), were placed in metabolic cages and adapted to their respective diet for 10 days.

Diets

The tree leaves were hand-collected, immediately sun-dried and ground through a 3 mm mesh screen by means of a hammer-mill. The leaves of cocoyam did not include the stems (Fig 1). Four diets were prepared (Table 1), a basal one and three diets composed of 650 g of the basal diet kg^{-1} dry matter (DM) and 350 g of forage. During a previous experiment (not reported), we established that this amount corresponds to the maximal intake capacity of the pigs of this weight. The intake level ranged from 80 to 90 g DM kg^{-1} weight $(W)^{0.75}$ day^{-1} depending on the pig's appetite.

Methodology

The experimental design was a completely randomized scheme: the 12 pigs were randomly allocated to one of the four diets (three per diet). They were fed three

Table 1. Composition of the experimental diets of the digestibility experiment (g kg^{-1} DM)

	Basal diet	Diets based on *Trichan-thera*	*Morus*	*Xantho-soma*
Ingredients				
Maize	620	400	400	400
Soyabean meal	160	100	100	100
Ground rice hulls	60	40	40	40
Sucrose	100	70	70	70
Premix	60	40	40	40
Trichanthera	—	350	—	—
Morus	—	—	350	—
Xanthosoma	—	—	—	350
Composition				
Ash	73	95	105	129
Crude protein	167	166	160	170
NDF	234	274	259	286
ADF	94	148	129	158
Crude energy (kcal kg^{-1} DM)	4105	3883	3940	4025

times per day (7:00, 12:00 and 17:00) in order to increase DM intake. The diets were mixed with an equal amount of fresh water and the pigs had constant access to fresh water. The temperature varied from 18 °C during the night to a maximum of 32 °C in the afternoon and was quite constant during the experiment. After an adaptation period of 10 days, the faeces were totally collected for 10 days. The refusals were taken after each meal, weighed and immediately dried at 60 °C in order to determine their DM content. The faeces were collected individually once a day, weighed and an aliquot was formed with 5% of the total excreted. The samples were kept at −15 °C. At the end of the collection period, the pigs were randomly allocated to another diet and the faeces collected again for 10 days, after a 10 day adaptation period, so that each diet was tested on six pigs. During the first period, the pigs fed with the control diet gained 4 kg body weight and those fed with the forage-based diet gained 2 kg body weight on average.

Analyses

The ingredients of the diets were analysed for ash, N, fibre and energy. The faeces were analysed for DM, N and energy. The refusals were analysed for N in order to take into account any possible change in the proportion of concentrate and forage, compared with the initial diet.

Voluntary intake

Animals

Eight sows, weighing from 80 to 113 kg (100 ± 6 kg, on average) were kept in large individual crates (2 × 1.5 m) during the whole experiment.

Diets

A basal diet (600 g maize kg^{-1} DM, 180 g soybean meal, 100 g sucrose, 60 g ground rice hulls and 60 g mineral premix) was formulated. Four other diets were prepared. They were composed of the basal diet supplemented with a variable amount (see below) of either *Trichanthera* or cocoyam leaves, offered in either fresh or dry form. The tree foliage was hand-collected, sun-dried and ground with a hammer-mill equipped with a 3 mm mesh screen. In the fresh form, the *Trichanthera* leaves were collected before each meal and immediately provided to the animals. In the case of cocoyam, the leaves were collected before the experiment and kept in a freezer at −10 °C. They were taken out of the freezer at least 2 h before the meal was distributed and passed through a forage chopper.

Methodology

The experimental design was a double 4 × 4 Latin square design, with eight sows receiving four diets during four consecutive periods. The animals were fed five times a day (every 2 h from 08:00 to 16:00). They first received the concentrate, mixed with an equal amount of water. They were then offered either the dry leaf meal or the fresh leaves. The leaf meal was mixed with an equal amount of water. The animals received initially 50 g DM kg^{-1} $W^{0.75}$ day^{-1} of the basal diet and 30 g DM kg^{-1} $W^{0.75}$ day^{-1} of forage. The amount of forage distributed was adjusted every day according to the animal's appetite, in order to reduce the refusals. After an 8 day adaptation period, the total intake was measured for 5 days. The refusals were taken after each meal and their DM content immediately measured using an oven at 60 °C. After the first period, the diets were permuted and the experiment repeated during three other consecutive periods. Each diet was tested on the eight sows.

Calculations and statistical analyses

The digestibilities were calculated as follows:

$$\text{Apparent digestibility coefficients (\%)} = [(X_i - f_X) \times 100]/X_i$$

where X_i is the N, DM or energy intake and f_X the fecal N, DM or energy excretion. The voluntary intake was calculated as follows:

$$\text{Voluntary intake(g day}^{-1}) = \text{DM daily intake (g)} - \text{DM daily refusals (g)}$$

Significant differences in composition were determined by analysis of variance followed, when necessary, by the multiple comparison test of Student–Newman–Keuls, by means of the Instat 3 software (GraphPad, San Diego, CA, USA). The differences in digestibility coefficients were determined by means of the GLM procedure of the SAS statistical software, using the following model:

$$Y_{ijk} = U + P_i + D_j + P_i \times D_j + E_{k(ij)}$$

where Y_{ijk} is the coefficient of digestibility, U the general mean, P_i the effect of the i period, D_j the effect of the j diet, $P_i \times D_j$ the interaction period $i \times$ diet$j$, $E_{k(ij)}$ the effect of pig k within period i and diet j.

The statistical analysis of the voluntary feed intake experiment was also realized by means of the GLM procedure of SAS, using the following model:

$$Y_{ijk} = U + A_i + P_j + D_k + E_{i(j,k)}$$

where Y_{ijk} is the feed intake, U the general mean, A_i the effect of the i animal, P_j the effect of the j period, D_k the effect of the k diet and $E_{i(j,k)}$ the residual error.

RESULTS

Chemical composition

The composition of the foliage is detailed in Table 2. Since forage composition is very variable in the tropics, the users want to know which range of variation can be expected. Therefore, the range, and not only the average content of the components, is presented.

Table 2. Chemical composition of the leaves of *Trichanthera, Xanthosoma* and *Morus* (g kg^{-1} DM)

	Leaves										*Xanthosoma* corm[a]
	Trichanthera		*Morus*		*Xanthosoma*			*Xanthosoma* stems			
	Young ($n = 7$)	Mature ($n = 7$)	Young ($n = 7$)	Mature ($n = 7$)	Young ($n = 7$)	Mature ($n = 7$)	SEM[b]	Young ($n = 6$)	Mature ($n = 6$)	SEM	($n = 6$)
Average value											
DM (g kg^{-1})	137a	161a	242b	303b	99a	139a	14**	56a	65b	5***	72 ± 17
Ash	151ab	161a	108c	128bc	115bc	139ab	4***	120a	147b	6*	68 ± 4
Crude protein	216ab	203ab	194a	170a	240b	231b	6*	91a	68b	4**	75 ± 12
Ether extract	43a	72ab	52a	68ab	80b	97b	5*	47	52	8	53 ± 27
Crude fibre	390a	429a	226b	278b	124c	130c	21**	131a	143b	4**	95±
NDF[c]	398a	397a	218b	278b	246b	298b	15***	231	233	5	170 ± 26
ADF	219a	233a	102b	130b	146b	177ab	10*	170	179	5	99 ± 22
Lignin	75a	80a	15b	29b	32b	46ab	5*	17	7	4	19 ± 10
Total sugars	201	183	188	164	229	197	14	331	383	47	584 ± 53
Reducing sugars	71	64	111	117	140	137	10	210	253	50	298 ± 129
Range											
DM (g kg^{-1})	126–173	131–183	194–304	207–337	84–120	98–171		45–93	46–78		50–99
Ash	136–160	135–177	98–138	92–163	90–131	122–157		116–176	95–137		64–74
Crude protein	193–235	115–219	168–223	113–239	221–258	181–246		66–111	61–78		56–91
Ether extract	34–67	50–90	34–71	61–72	55–118	76–114		26–81	31–99		16–88
Crude fibre	300–434	307–567	183–247	210–388	106–145	115–143		118–137	132–168		81–100
NDF	299–448	307–462	174–247	210–301	186–328	225–371		209–257	209–264		128–197
ADF	166–237	172–337	85–124	82–189	115–186	129–250		152–190	163–211		70–131
Lignin	40–124	51–121	13–21	16–27	11–54	29–75		7–27	3–10		8–32
Total sugars	120–300	88–263	106–273	88–265	146–322	112–257		274–389	292–535		527–606
Reducing sugars	47–98	53–75	42–197	85–215	97–188	95–170		147–360	108–335		76–417

[a] The average starch content of the *Xanthosoma* corms reached 180 g kg^{-1} DM.
[b] SEM, standard error of the mean and results of the comparison of the composition of the leaves of the three species or that of the stems of *Xanthosoma* (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$). (a,b,c) Means in the same row with different letters differ significantly.
[c] The pooled NDF fractions contained, on average, 294, 144 and 181 g crude proteins kg^{-1} NDF crude proteins (CP-NDF), respectively in *Trichanthera, Morus* and *Xanthosoma* leaves.

Differences between species were observed for all the components, with the exception of sugars. For example, *Trichanthera* had the highest fibre content ($p < 0.01$) and mulberry the highest DM content ($p < 0.01$). The total sugar was high in all three species. For *Trichanthera*, the reducing sugars represented roughly one-third of the total sugars whereas, for the mulberry and cocoyam leaves, it represented more than the half. The stems and the corm of cocoyam had also high sugar content. No significant difference ($p = 0.15$) was observed between young and mature leaves. In all cases, there was a broad range of variation of the nutrient contents. The stems, which account for 60–70% of the whole leaves (limb + petiole) of cocoyam, were low in protein and lignin. The corms of cocoyam were also poor in these components and in fibre, due to their high starch content (180 g kg^{-1} DM).

The amino acid profile of the leaves is detailed in Table 3 and compared with the pig amino acid requirements of NRC,[8] expressed as percentage of the total protein. The results correspond to the mean of various samples of either young or mature leaves, coming from different farms. The protein content did not affect the amino acid profile. Therefore, the results were pooled.

The proteins of the leaves of the three species cover the requirements in essential amino acids of growing pigs and lactating sows. The only exception is the lower lysine content in *Trichanthera*. The stems and corms of cocoyam, in contrast, are not well balanced.

Five samples of young and mature leaves collected in two farms (Dovio, Palmira) were analysed for their mineral content. The results are detailed in Table 4. Owing to the wide variation observed and with the objective of making the local users of tree forages aware of this variation, we present the range of variation rather than the average value of mineral content.

The leaves of *Trichanthera* are exceptionally high in minerals, especially in calcium. The leaves of the two other species also contain appreciable amounts of Ca (17–30 g kg^{-1} DM), whereas the stems and corm of cocoyam do not. The leaves of the three species and the corm of cocoyam are also high in potassium. However, all the species are very poor in phosphorus and sodium. The leaves, especially those of *Trichanthera*, are good sources of micronutrients, particularly of iron and manganese. The high variation in iron content is not related to the origin of the leaves or to their growth stage. The stems of the cocoyam leaves are not good mineral sources.

Nutritive value

The results of digestibility of the experimental diets and of the forages alone are given in Table 5. The

Table 3. Amino acid composition of the leaves of *Trichanthera, Xanthosoma* and *Morus* (g kg^{-1} protein)

	Trichanthera leaves ($n = 9$)	*Morus* leaves ($n = 4$)	*Xanthosoma* Leaves ($n = 2$)	*Xanthosoma* Stem ($n = 2$)	*Xanthosoma* Corm	Requirements[a] 50 kg pigs	Requirements[a] Lactating sows
Essential							
Arginine	49 (7)	53 (10)	50 (7)	31 (6)	37	17	27
Histidine	22 (6)	21 (4)	19 (3)	15 (1)	10	15	21
Isoleucine	41 (6)	43 (10)	37 (8)	26 (1)	17	27	29
Leucine	72 (9)	82 (15)	75 (12)	49 (3)	33	46	55
Lysine	43 (5)	57 (8)	56 (9)	40 (2)	28	48	52
Methionine	15 (2)	16 (1)	18 (3)	11 (1)	7	13 (28)[b]	13 (25)[b]
Phenylalanine	46 (6)	52 (10)	47 (6)	29 (0)	24	28 (45)[b]	27 (57)[b]
Threonine	43 (5)	46 (8)	42 (7)	29 (01)	28	33	33
Tryptophan	10 (2)	11 (1)	13 (1)	8 (0)	5	9	9
Valine	50 (7)	54 (13)	48 (8)	38 (01)	35	34	34
Non-essential							
Alanine	49 (5)	58 (6)	57 (6)	51 (7)	41		
Aspartic acid	89 (10)	102 (11)	96 (16)	108 (31)	103		
Cysteine	14 (2)	13 (1)	13 (1)	11 (1)	15		
Glutamic acid	97 (13)	104 (14)	103 (16)	91 (0)	114		
Glycine	50 (6)	51 (9)	49 (5)	34 (0)	26		
Proline	44 (5)	46 (8)	42 (6)	30 (1)	27		
Serine	40 (4)	44 (5)	42 (7)	49 (7)	45		
Tyrosine	33 (6)	34 (9)	29 (2)	13 (3)	5		
Total	779 (83)	869 (115)	834 (123)	663 (36)	600		
N	29 (4)	44 (2)	45 (1)	14 (2)	13		

Means (standard deviation).
[a] Requirements: pigs of 50–80 kg, 15.5% crude protein in the diet.[8]
[b] In brackets: requirements in methionine + cysteine and in phenylalanine + tyrosine.

Table 4. Mineral composition of the leaves of *Trichanthera, Xanthosoma* and *Morus*

	Trichanthera leaves ($n = 5$)	*Morus* leaves ($n = 5$)	*Xanthosoma* Leaves ($n = 5$)	*Xanthosoma* Stem ($n = 1$)	*Xanthosoma* Corm ($n = 2$)
Ash, g kg^{-1} DM	222–308	127–174	123–158	130	198–200
SiO_2, g kg^{-1} DM	5–16	34–62	1–7	0.1	—
Macroelements, g kg^{-1} DM					
Calcium	48.5–69.0	16.8–30.5	19.7–26.2	5.6	6.6–7.1
Phosphorus	1.5–4.0	2.2–4.8	2.5–7.2	1.7	1.9–5.1
Potassium	23.1–35.2	24.7–50.7	34.7–42.0	18.4	52.2–87.6
Sodium	0.3–0.6	0.2–0.5	0.3–0.4	0.3	0.3–0.4
Magnesium	6.9–11.2	2.8–5.1	3.7–7.3	1.1	2.4–2.6
Chlorine	6.9–10.4	0.4–2.1	2.9–5.5	3.1	4.9–5.5
Sulphur	3.7–6.5	0.9–1.9	0.7–0.9	0.3	0.5–0.6
Microelements, mg kg^{-1} DM					
Iron	171–460	101–478	160–522	80	77–116
Zinc	29–46	24–33	30–45	18	31–33
Copper	14–24	4–12	7–23	16	8–18
Manganese	47–232	28–49	37–106	14	27
Selenium	1.4–4.0	0.1–0.2	0.1–0.3	0.2	<0.1
Cobalt	0.1–0.8	0.1	0.1–0.2	<0.1	<0.1

digestibility of the diets containing foliage was lower ($p < 0.001$) than that of the basal diet but no difference ($p > 0.05$) was observed between plant species. The digestibility of the tree foliages alone was calculated by difference. No difference was observed between species either ($p > 0.05$). The digestibility coefficients, especially those of protein, were low. It was calculated that the forages provide between 53 and 60 g digestible proteins per kg DM and from 1.674 to 2.037 kcal digestible energy.

Voluntary feed intake

The results of forage intake by the sows were expressed per 100 kg bodyweight in order to take the bodyweight variation of the animals into account (Table 6). The sows were able to ingest more than 3.3 kg fresh forage

Table 5. Digestibility coefficients (%) of tree leaf-based diets in pigs and the digestibility of the tree leaves alone. Digestible protein and energy content of the diets and the leaves alone

	Diets						Leaves alone				
	Basal	*Trichanthera*	*Morus*	*Xanthosoma*	SEM	p	*Trichanthera*	*Morus*	*Xanthosoma*	SEM	p
Dry matter	85.0a	71.8b	74.7b	75.1b	1.4	<0.001	47.4	55.5	56.9	2.8	0.36
Crude protein	88.0a	71.4b	69.2b	69.7b	2.9	<0.001	36.3	33.0	34.4	3.1	0.90
Energy	86.7a	74.7b	74.1b	75.2b	1.4	<0.001	50.5	50.9	52.8	2.7	0.91
Digestible protein ($g\,kg^{-1}$ DM)	148.1a	117.4b	110.7b	118.5b	3.8	<0.001	60.3	52.8	57.1	5.1	0.87
Digestible energy ($kcal\,kg^{-1}$ DM)	3560a	2900b	2920b	3027b	86	<0.001	1674	1731	2037	89	0.24

(a, b) Means in the same row with different letters differ significantly ($p < 0.001$).

Table 6. Voluntary intake of a basal diet and of forage provided *ad libitum* to sows

	Trichanthera diet		*Xanthosoma* diet		Significance			
Intake	Fresh form	Dry form	Fresh form	Dry form	Forage	Pig	Period	Pig × Forage
Basal diet								
g fresh matter day^{-1}	1874 (137)	1825 (320)	1760 (138)	1703 (244)	NS	NS	NS	NS
g DM day^{-1}	1679 (120)	1635 (281)	1577 (118)	1527 (217)	NS	NS	NS	NS
g DM kg^{-1} $BW^{0.75}$ day^{-1}	52.6 (3.2)	50.8 (9.2)	50.5 (3.1)	48.2 (5.6)	NS	NS	NS	NS
Foliage								
g fresh matter day^{-1}	3393a (826)	1181b (207)	3315a (976)	1116b (159)	**	**	NS	NS
g DM day^{-1}	515a (111)	1080b (191)	510a (232)	1015b (144)	**	**	NS	NS
g DM kg^{-1} $BW^{0.75}$ day^{-1}	16.2a (3.9)	33.6b (6.3)	16.3a (7.3)	32.0b (3.7)	**	**	NS	NS

The results are expressed in g dry matter (DM) or fresh matter (FM) per 100 kg bodyweight (BW) or in g DM per kg metabolic weight ($W^{0.75}$).
(a, b) Means in the same row with different letters differ significantly ($p < 0.01$). Means are presented with their respective standard deviation (in brackets)
NS: not significant.

per day, ie 0.51 kg DM. The DM intake doubled when the forages were presented in dry and ground forms. No difference ($p > 0.05$) was observed between both plant species, neither in fresh nor in dry forms. The maximum daily DM intake (basal diet + forage) did not exceed 69 g DM kg^{-1} $BW^{0.75}$ when the forage was offered in fresh form and 84 g DM in dry form.

DISCUSSION

Nutritive value of proteins

In the tropics, fodder trees are usually used as protein sources for animals. The present study aimed at evaluating the nutritional contribution of tree foliage for pigs.

The leaves contain 170–240 g crude proteins kg^{-1} DM, containing 770–860 g amino acids kg^{-1} crude proteins (Table 3). Other authors have reported recoveries of amino acids ranging from 49 to 92% in tropical plant seeds and leaves.[9,10] The difference is ascribable to inevitable losses during amino acid analysis, to the presence of non-protein N and to the fact that 6.25 is probably not an appropriate N-to-protein conversion factor. Mossé[11] recommend conversion factors ranging from 5.2 to 5.7 for plant seeds and Milton and Dintzis[9] a factor as low as 4.4 for tropical plant leaves.

The crude proteins are also partially bound to fibres (CP-NDF). The NDF residues of the analyses were pooled and their N content determined. The NDF fractions of *Trichanthera*, mulberry and cocoyam contained, respectively, 294, 144 and 181 g crude proteins kg^{-1} NDF (see footnote to Table 2). This represents, respectively, 121, 36 and 49 g CP-NDF kg^{-1} DM and 57.6, 19.8 and 20.9% of the total proteins of the leaves. Shayo and Udén,[1] for their part, measured CP-NDF contents in tropical browse plants ranging from 6 to 72% of the total crude proteins, with high values for *Trichanthera* and cocoyam (59 and 64%, respectively). The current data are similar for *Trichanthera* but lower for cocoyam. The crude proteins bound to fibres are normally not well digested.[1] However, the difference observed here between species did not affect the apparent faecal digestibility results significantly (Table 5).

In the present study, less than 40% of the proteins were digested in the total tract. Other authors report higher values for protein tree leaves: 51% for cassava leaf meal[3] and 46–57% for *Leucaena* leaf meal.[2,12] The leaf meals used here had lower protein content than those of cassava and *Leucaena* leaf meals (<170 vs 225–275 $g\,kg^{-1}$ DM). This could have affected the N digestibility, since the latter rapidly increases with protein content in tree leaves.[1] On the other hand, methodology can also be ascribed. The digestibility coefficients were calculated by difference between pigs fed a control diet and those receiving a diet containing 35% forage. In other studies,[2,12,13] the digestibilities were calculated by regression from pigs fed diets containing 0, 100 or 200 g leaf meals kg^{-1} diet. The decrease was considered linear. However, a thorough study of the data shows that, in all cases, the digestibility decreased more rapidly between pigs receiving 100 and 200 g leaves than between 0 and 100 g. For example, in Laswai *et al*'s work,[12] the N digestibility reached 67, 66 and 59% for diets containing 0, 100 and $200\,g\,kg^{-1}$ leaf meal, respectively. If the decrease in digestibility with increase in incorporation level in the diet was confirmed, this could explain why such low digestibility values were observed in the present case, with high intake levels (350 g leaves kg^{-1} diet).

The protein digestibility was determined at the fecal level although it would have been preferable to measure it at the ileum level in order to avoid the microbial fermentations occurring in the large intestine.[14] The ileal protein digestibilities of the leaf meals were determined in another study.[15] As expected, they were lower than the faecal ones. This can be ascribed to the microbial fermentations in the colon but also to the fact that the apparent ileal digestibility values do not take the loss of endogenous proteins into account. Endogenous losses are high when fibrous diets are ingested.[16] It can be hypothesized that the true digestibility values of the leaf meals are higher than the apparent faecal ones presented here and that the endogenous protein losses were also high. Experiments are currently in progress in our laboratory to determine both the true ileal protein digestibilities and the endogenous nitrogen losses in pigs fed tree leaf meals.

On the other hand, the proteins are of good quality. Many tropical feedstuffs present a deficiency in one or more major amino acids, generally lysine and methionine.[10,17] The comparison with the requirements of pigs weighing 50–80 kg and those of lactating sows demonstrates that lysine is limiting for *Trichanthera* only. In all the other cases, the requirements in the most limiting factors, ie lysine, methionine–cysteine, threonine and tryptophan, were covered. The good amino acid quality was also observed in other tropical plant leaves such as those of *Leucaena*,[2] cassava[3] or batata.[18]

Minerals

Compared with current feedstuffs used in pig nutrition, green leaves are valuable sources of minerals, especially in calcium and iron.[19–21] The leaves of *Trichanthera* deserve special attention due to their extraordinarity high Ca content ($60\,g\,kg^{-1}$ DM on average; Table 4). It is nearly twice as much as the highest concentration observed in Western African foods.[22] Considering the fact that a growing pig (>50 kg) and a gestating sow require 12–14 g Ca day^{-1} and a lactating sow about $40\,g\,day^{-1}$,[8] it can be estimated that 200–250 g dry leaf meal day^{-1} would be sufficient to cover the daily requirements of a pig or gestating sow and $700\,g\,day^{-1}$ to cover those of a lactating sow. The two other plant species provide less Ca, but the requirements of sows reared in extensive pig production systems are also lower than those of improved breeds.

On the other hand, the bioavailability of the minerals was not determined. Aroids such as cocoyam contain high amounts of oxalates in the corms and in the leaves. Ca in this form is not available.[23] Thus, the Ca present in cocoyam probably has a low availability.

Like many plant leaves, those of the three species studied here also contain high amounts of microelements, especially iron and manganese (Table 4). No explanation can be provided for the high variability observed because it was neither related to the stage of development of the leaves nor to the growth conditions of the trees. However, this high amount must be tempered by the fact that only a small portion of these elements is bioavailable in tropical plant leaves: 3–27% of Fe, 11–26% of Zn and 18–47% of Cu.[20,21] Nevertheless, these amounts are still higher than in any starchy feedstuff or fruit used in pig nutrition[24] and it may be considered that tree leaves are appreciable sources of microelements.

Voluntary feed intake (VFI)

The most outstanding observation here is the higher DM intake in sows fed dry leaf meals, compared with fresh leaves (Table 6). Food intake is restricted for high-bulk foods, due to physiological constraints for the animal.[4,25] Bulking is due to the swelling of hydrated fibre and the final volume depends on fibre composition and structure.[26] VFI of bulky foods can be predicted by the amount of water they retain, ie their water-holding capacity (WHC).[4,27] Bulking affects gastric emptying which, in turn, limits VFI.[25,28]

In the present case, the WHC of the leaves reached 8.8 g water g^{-1} DM for the cocoyam leaf meal and 6.2 g for that of *Trichanthera*. However, despite the difference in WHC, no difference was observed between sows fed cocoyam or *Trichanthera* leaves ($p > 0.05$), possibly because the leaves represented less than 40% of the total meal. However, the fresh leaves had a WHC comparable to that of the dry meal (roughly from 6 to 10 g water g^{-1} DM) but VFI was different. These observations suggest that WHC alone is not sufficient to explain the difference in VFI between dry and fresh leaves. The form in which water is retained by dietary fibre is probably different between dry and fresh leaves. The pressure exerted by the stomach might limit the swelling of some fibres and release more or less water. For example, we observed elsewhere that sows can ingest more than 9 kg fresh aquatic plants, corresponding to $\pm 600\,g\,DM\,kg^{-1}$.[15] The higher intake of fresh matter, compared with that observed in the present experiment, could be ascribed to the ability of aquatic plants to release their free water more easily in the stomach. Finally, the sows also spent more time chewing and swallowing the leaves, which could have limited VFI. However, these different assumptions must be verified.

CONCLUSION

It can be concluded that tropical tree leaves offer a variable amount ($170-240\,g\,kg^{-1}$) of proteins that are well balanced in essential amino acids but not well digested by pigs. They also provide large amounts of minerals, especially of calcium, iron and manganese. The low DM intake (0.5 kg DM when leaves are offered in fresh form and 1 kg in dry form) limits energy intake. Despite their nutritional limits, their interest for pig production will depend on the possibility of integrating them in sustainable production systems.

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