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ASSESSING TROPICAL FORAGE SPECIES USED AS PIG FEED INGREDIENTS IN THE WESTERN PROVINCES OF THE DEMOCRATIC REPUBLIC OF THE CONGO

Bienvenu KAMBASHI MUTIAKA

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Promoteurs: Jérôme BINDELLE
Honoré KIATOKO MANGEYE

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Summary

The use of forage species to feed pig goes back to immemorial times. If forage is no longer used in industrial farms with genetically-improved breeds, its accounts for an important part of pig diets in smallholder pig production systems in tropical areas including the Western provinces of the Democratic Republic of the Congo (DRC). The aim of this research thesis was to assess the relevancy of the use of local forage resources as a strategy to reduce reliance of pig production systems on concentrate feed ingredients in tropical environment, by identifying plant species available to smallholders with interesting nutritional value that could partly replace concentrates in the diets. First, smallholder pig production systems in two western provinces of the DRC were characterized and the most used forage species in pigs identified. Their nutritional value was determined using an in vitro model of the pig's gastro-intestinal tract. It was concluded that *Manihot esculenta*, *Ipomoea batatas*, *Moringa oleifera*, and legume species exhibit an interesting profile for feeding pigs while grasses, *Eichhornia crassipes*, *Acacia mangium* and *Cajanus cajan* should be discouraged. Feeding values of *Psophocarpus scandens*, *Vigna unguiculata*, *Stylosanthes guianensis*, and *Pueraria. phaseoloides* were measured by assessing the voluntary feed intake of forage hays-based diets and their digestibility. Finally, the economic impact of feeding *Psophocarpus scandens, Vigna unguiculata*, and *Stylosanthes guianensis*, was measured through growth performance, carcass quality, and production costs determination. It is concluded that although forage species reduce the nutritive value and the growth of animals, the investigated legumes do not impact negatively the economical balance of concentrate-fed pigs when forage accounts for approx. 10 % of the diet. The ability of some forage species to improve performances of animals fed ill-balanced diets as usually practiced by smallholder farmers in the DRC should be investigated as it is suspected that under less favourable conditions, conclusions on the usefulness of forage legumes in pigs might be more positive.

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Résumé

L’utilisation d’espèces fourragères dans l’alimentation porcine remonte à la nuit des temps. Si les espèces fourragères ne sont plus utilisées dans les élevages industriels aux races de porc génétiquement améliorées, elles constituent une part importante dans l’alimentation des porcs élevés par les petits exploitants en milieux tropicaux et notamment dans la partie Ouest de la République démocratique du Congo (RDC). L’objectif de cette thèse de recherche était d’évaluer la pertinence de l’utilisation des espèces fourragères locales comme stratégie visant à réduire la dépendance de la production porcine aux ingrédients concentrés en milieu tropical, en identifiant les espèces fourragères disponibles auprès de petites exploitations porcines et ayant une valeur nutritive intéressante pour remplacer partiellement les ingrédients concentrés dans les régimes. Les systèmes d’élevage porcin ont tout d’abord été caractérisés dans deux provinces à l’Ouest de la RDC et les espèces fourragères utilisées par les éleveurs identifiées. Leurs valeurs nutritionnelles ont ensuite été déterminées en utilisant un modèle *in vitro* du tractus gastro-intestinal du porc. Il a été conclu que certaines espèces, les légumineuses en particulier mais également *Manihot esculenta*, *Ipomoea batatas* et *Moringa oleifera* présentent un profil nutritionnel intéressant pour l’alimentation des porcs alors que les graminées, *Eichhornia crassipes*, *Acacia mangium* et *Cajanus cajan* devraient être déconseillées. Les valeurs alimentaires de *Psophocarpus scandens*, *Vigna unguiculata*, *Stylosanthes guianensis* et *Pueraria phaseoloides* ont été mesurées en réalisant un essai d’ingestion volontaire et de digestibilité des aliments dans lesquelles ces espèces ont été incorporées. Enfin, l’impact économique d’une alimentation à base de *Psophocarpus scandens*, *Vigna unguiculata* et *Stylosanthes guianensis* a été calculé en prenant en compte la performance de croissance, la qualité de la carcasse ainsi que le coût de production. En conclusion, bien que les espèces fourragères réduisent la valeur nutritive et la croissance des animaux, les légumineuses étudiées n'ont pas d'impact négatif sur l'équilibre économique de porcs nourris de concentrés lorsqu’elles sont incorporées à environ10% dans la ration. Néanmoins, la capacité de certaines espèces fourragères à améliorer la performance de croissance des porcs nourris avec des régimes mal équilibrés comme souvent observés dans les petites exploitations de porc dans notre zone d’étude doit être étudiée davantage. En effet, dans des conditions moins favorables, il est raisonnablement envisageable que l’incorporation des légumineuses fourragères dans ces régimes donne lieu à un résultat plus positif.

A mes enfants

Ne me prenez pas pour un modèle

Mais considérez moi plutôt comme une référence

Afin de faire mieux que ce que j'ai fait

C'est pour vous que ce travail se doit d'avoir été réalisé

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Abbreviations

AA : amino acid

ADF : acid detergent fibre

ADL : acid detergent lignin

CP : crude protein

DE : digestible energy

DM : dry matter

DP : digestible protein

DRC : Democratic Republic of the Congo

EE : ether extract

IVCPD : *in vitro* crude protein digestibility

IVDMD : *in vitro* dry matter digestibility

IVED : *in vitro* gross energy digestibility

NDF : neutral detergent fibre

OM : organic matter

PSM : plant secondary metabolites

r^2 : simple coefficient of determination

SCFA : short-chain fatty acids

SID : the standardized ileal digestible

R_M : maximum rate of gas production

tR_M : time at which the maximum rate of gas production is reached

GENERAL INTRODUCTION

General introduction

1. Introduction

With an approximate production of 24,000 tons per year, pork has become the most important farmed meat in the Democratic Republic of the Congo (DRC) (FAOSTAT, 2014). In 1998, the nation's pig population topped 1,153,507, with that number slightly dropping shortly afterwards to just below 1 million. Since 2001, the population has been stabilized to around 960,000 pigs. The numbers of animals mentioned in the different available documents are estimates derived from projections, with the projections being based on data from the 1984 census. These official data are probably underestimated, given the popularity of pig farming among the rural and peri-urban populations, coupled with the high consumption of pork by the vast majority of the Congolese.

Pig farming is primarily practiced in to low-scale systems and is done using traditional methods. In 2009, it was estimated that there were about 208,068 small family farms, and each farm had an average of three pigs, accounting for 65% of the national herd. There were also approximately 9,634 commercial family farms, with an average of 30 pigs in each farm, representing 30% of the livestock. Finally, there were approximately 100 industrial commercial farms, totaling 5% of the national herd.

With 41.8% of the national herd, the provinces of Bas-Congo and Bandundu are the main centres for pig production. Thanks to their geographical proximity and the relative high quality of road infrastructures, these two provinces are also the main national providers of pork to Kinshasa (FAO, 2012). The international imports of pork intended to supply major urban centres of the DRC have sharply increased in recent years. Less than 2,000 tons were reported in 2001, while in 2011, this number reached 17,626 tons, with 41.5% of these imports consisting of edible offal (FAOSTAT, 2011). However, as stated previously, during this time, the domestic production had stagnated.

Like all sectors of the Congolese economy, pig production was strongly affected by the socio-political unrests and wars that repeatedly shook the country since the late 1990s. However, over the past decade, there has been a steady increase in the number of pig farms, usually small ones, that are run by a single family or a community, in and around Kinshasa, which is the city with the largest pork-related consumer market (NEPAD & FAO, 2006). The increase in pig smallholders in the western part of the DRC, especially around Kinshasa, can be partly justified by an increasing demand in the urban market, as well as by the lack of unemployment benefits that leads people to practice informal activities, including pig farming, in a search for greater self-sufficiency and better food security for their households. This increase is exacerbated by the high migration rates towards Kinshasa due to (i) the recurrent insecurity in the eastern part of the country, causing residents of rural areas to move to the metropolis of Kinshasa in search of peace and safety and (ii) the increasing school rates among young people, who are more keen to move to the urban areas in search of available skilled jobs matching their skills.

The important role of pig production in the DRC in improving the livelihood and food security of poor farmers in rural and periurban areas is not an exception in the developing world, as similar trends are found in many developing countries across Africa, Asia and the Americas (Keoboualapheth & Mikled, 2003; Kumaresan et al., 2009a; Nguyen Thi Loc et al., 1997). In some countries, such as Laos, smallholders can contribute up to 75% of the national pig production (Le Van et al., 2004).

With 45–75%, feed represents the main component of pig production costs. The rate of feed consumption and the price of pork are major determinants of the economic viability of pig farms and their development worldwide (Tregaro & Djaout, 2012). Corn and soybean meal are the primarily feed ingredients in commercial pig diets, and the high volatility of corn and soybean meal prices on the global market asphyxiates smallholder pig producers in the tropics, due to the fact that in developing countries, agricultural production in general, the production of cereals in particular, is too low to ensure food security. Furthermore, a significant part of the food production is lost, mainly due to the absence of appropriate food-chain infrastructures, in addition to the lack of knowledge about or investment in storage technologies on the farm (Godfray et al., 2010). The problems mentioned above can explain the fact that Sub-Saharan African countries are the second largest net importers of food, after the Middle East countries (Hoering, 2013; Valdés & Foster, 2012).

Smallholders in the tropics generally use two strategies to tackle the above-mentioned high prices and scarcity of concentrated pig feeds: they either use partial or complete free-range pig systems or they keep pig in stalls, providing minimum care while using feeding strategies tailored to valorise the locally available resources (Logtene et al., 2009; Petrus et al., 2011). Free range practices, when conducted in unhealthy environments without biosafety measures, especially in areas with endemic African swine fever or cysticercosis, have more disadvantages than advantages, causing the pig farms to be unprofitable in the long run.

However, in semi-intensive systems, a steady supply of feed ingredients is still a large limitation for pig production (Kagira et al., 2010). Farmers near urban centres or close to food industries, feed pigs using industrial by-products, such as brewers' grains, wheat or rice bran, and oilseed cakes (e.g. palm kernel cake, cottonseed cake, copra cake), as well as with commercial concentrates when available. Those in rural areas typically use local agricultural by-products (e.g. cassava tubers and leaves, potatoes, rice bran, corn residues, etc.). Both groups of farmers also feed pigs with kitchen waste and leftovers, supplementing the pigs' diet with forage. Bad or non-existent road infrastructure and high transportation and feed costs, especially in inaccessible areas where farmers are without resources, are key factors that determine the ingredients used in the preparation of pig diets.

Most of the agricultural by-products used by the farmers in these conditions are rich in fibre, while being low in proteins. Protein has been determined to be the most limiting nutrient in the smallholder pig feeding systems located in tropical areas (Leterme et al., 2005; Martens et al., 2012). Several authors demonstrated that some forage species are rich in protein and can be used as alternative ingredients in order to meet the protein requirement of pigs (Kaensombath & Lindberg, 2013; Kaensombath et al., 2013; Phengsavanh &Lindberg, 2013).

Although forage is used in the western provinces of the DRC, no information on the extent of this practice among pig smallholders can be found. Moreover, if relevant, the lack of information on the nutritive value of the forage species that are locally available is an obstacle to their use. This probably leads to unbalanced diets in the pigs, causing a decrease in animal performance and profitability, as observed elsewhere (Kumaresan et al., 2009b). The inventory of forage species used by farmers to feed pigs and the identification of the ones that present interesting nutritional characteristics are some of the viable ways to select and use forage species efficiently to optimise growth performance under low cost forage-based diets feeding system. In this thesis, we have undertaken this challenge.

2. Objective

The aim of this thesis is to increase knowledge regarding swine feeding practices in the western provinces of Bas-Congo and Kinshasa, and to challenge the relevancy of the use of local forage resources in the development of sustainable pig production systems in DRC. To achieve this goal, we have identified three research questions that we will address as part of our thesis. These questions are:

1. What types of pig production systems do smallholders in the western part of DRC use?

2. What are the types of forage species used for pig nutrition by pig smallholders in the western RDC, and what is the chemical composition of those species?

3. What is the feeding value of interesting plants, as well as their impact on the growth performance of pigs?

3. Strategy

A literature review was conducted in order to give an assessment of the use of forage species in pig feeding (the first publication in this document). A survey was also conducted in the western provinces of Bas-Congo and Kinshasa in order to understand the pig production systems practiced by smallholders and in order to get an objective insight into the forage species used by smallholders. The results obtained from the survey are presented in the second publication in this thesis.

Based on the information collected during this preliminary work, the 20 forage species the most commonly used by smallholder farmers in the western DRC were collected so that the nutritive value could be assessed using chemical analyses and an *in vitro* model of the pig gastrointestinal tract. The results of this work (3rd publication) enabled us to select four forage species with an interesting profile and use them in three successive experiments that were conducted from 2011 to 2012 in order to assess their actuel feeding value.

The first of these experiments focused on the ability of growing pigs to ingest diets containing hay meals in varying proportions, while the second experiment determined the digestibility of diets containing two levels of hay meal (4th publication). Based on their feeding value, three out of the four forage species were then used to assess the feed intake and growth performance of pigs fed a soybean-corn diet that was supplemented with forage (5th publication). Finally, a general discussion is drawn and future prospects are outlined.

Chapter 1. State of knowledge on the use of forage in the tropics

Article 1. Forage Plants as an Alternative Feed Source for Sustainable Pig Production in the Tropics: A Review

Accepted for publication in *Animal*

This review examines the nutritive value of several tropical forage species, the influence of breed and physiological status of the animal on the ability of pigs to be sustained on forage-based diets, and the socio-economical and environmental implications of feeding forages to pigs in low-input farming systems.

Chapter 2. Overview of pig production by small farmers in the western part of the DRC

Article 2. Smallholder Pig Production Systems in the Western Provinces of the Democratic Republic of the Congo

Accepted for publication in the *Journal of Agriculture and Rural Development in the Tropics and Subtropics*

The purpose of this study is to document and to understand smallholder pig production in the western part of the DRC, focusing on feed resources and feeding management, breeding systems, and issues with productivity and sanitation. In addition, the study aims to identify whether or not the resources or constraints driving those systems differ according to the location of the farm.

Chapter 3. Screening of forage species used by pig smallholders in the western provinces of the DRC

Article 3. Nutritive Value of Tropical Forage Plants Fed to Pigs in the Western Provinces of the Democratic Republic of the Congo

Published in 2014 in *Animal Feed Science and Technology*, 191, 47-56

The aim of this work is to assess the nutritive value of the forage species most commonly used by smallholder farmers in western DRC, using an *in vitro* model of the pig gastrointestinal tract. The goal of this study is to provide information that could guide farmers in the choice of forage resources for improved pig performances.

Chapter 4. The effect of forage species and level of incorporation on the digestibility of the diet

Article 4. Feeding Value of Four Tropical Forage Legumes in Large White Pigs:

Vigna unguiculata, Psophocarpus scandens, Pueraria phaseoloides, and *Stylosanthes guianensis*

Submitted to *Tropical Animal Health and Production*, under review after resubmission

This manuscript assesses the voluntary feed intake and determines the *in vivo* digestibility of forage species that displayed a high nutritive value according to the *in vitro* model, in order to establish pratical recommendations for pig farmers.

Chapter 5. The effect of the incorporation of forage species on growth performance of Large White pigs

Article 5. Impact of Feeding Three Tropical Forage Legumes on the Growth Performance, Carcass Traits, Organ Weights, and Production Costs of Pigs

Prepared for submission to *Tropical Animal Health and Production*

The study aims to assess the feed intake and growth performance of pigs that are restricted fed a restrictive soybean-corn diet that is supplemented with fresh forage legumes.

The five chapters are preceded by the general introduction above and are followed by a general discussion. The thesis ends with a conclusion designed to guide the smallholders in the choice and the use of forage species on pig farms.

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CHAPTER I

In the Democratic Republic of the Congo (DRC), pigs are raised almost exclusively by smallholders either in periurban areas of major cities such as Kinshasa or in rural villages. It was found that some farmers feed their pigs with forage plants. Several reasons can justify this situation but the most important are the poverty of farmers and the high cost of conventional ingredients. However, little information regarding the nutritive value of most forage species is available. Thus, to select the plants which the study was to investigate and to understand the contribution of these forage species in the pigs diet in order to improve growth performance and to reduce the cost of pig feed by using fodder in DRC, it was necessary to assess the current state of knowledge on the nutritional value of plants that are being used in pig feeding and the factors that affect them. This review of the literature was published in Paper 1. It examines the nutritive value of several tropical forage species, the influence of breed and the physiological status of the animal on the ability of pigs to sustain on forage-based diets and the socio-economical and environmental implications of feeding forage to pigs in low-input farming systems. Briefly, one can state that forage is widely used by smallholding farmers in low-input and semi-intensive pig production systems of tropical Asia, Africa and America. However, the success of feeding pig with forage depends on several parameters including those related to the animal, the plant species, and the rearing and experimentation conditions. Feeding forage is often used with indigenous pigs which are the preferred breed of smallholders in rural areas. This choice is made on the basis of breed adaptation to the specific environment, the harsh rearing conditions, feeds availability and the feeding systems. Moreover, plant species and its maturity, preservation techniques and processing methods, inclusion rate, possible presence of secondary metabolites, others ingredients in diets and theirs interactions have different effects on the nutritional value of the forage plants.

Article 1:
Forage plants as alternative feed resource for sustainable pig production in the tropics

Review I — Kambashi*et al*. (2014)
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Bienvenu Kambashi[1,2], Christelle Boudry[2], Pascale Picron[2], Jérôme Bindelle[2]

[1]University of Kinshasa, Animal Science Unit, Mont-Amba, Lemba, Kinshasa, Democratic Republic of Congo

[2]University of Liège, Gembloux Agro-Bio Tech, Animal Science Unit, Passage des Déportés, 2, 5030 Gembloux, Belgium

Corresponding author : Jérôme Bindelle. E-mail: jerome.bindelle@ulg.ac.be

Running head : Forage plants as pig feed: a review

1. Abstract

Globally, pressure on concentrate feed resources is increasing, especially in the tropics where many countries are net importers of food. Forage plants are a possible alternative but their use as feed ingredients for pigs raises several issues related to their higher fibre and plant secondary metabolites contents as well as their lower nutritive value. In this paper, the nutritive value of several forage species as well as the parameters that influence this nutritive value in relationship to the plant family, the physiological stage, the plant part and the preservation method (fresh, hay and silage) are reviewed. The influence of the breed and the physiological status of the animal on animal voluntary intake of fibre-rich ingredients, digestibility as related to gastrointestinal volume and transit time and growth performances are also discussed. The final section highlights the assets and drawbacks of forage plants in pig diets and stresses the need for proper economic evaluation to conclude on the benefits of the use of forage plants in pig feed.

Keywords: forage; pigs; tropics; digestibility

2. Implications

This work reviews the possibility of using forage plants for feeding pigs reared in tropical areas. It highlights the constraints of forage as low digestible feed ingredients because of their high content in fibre and anti-nutritive compounds. However, their rich protein and mineral contents can be useful to improve the diets of pigs fed poorly balanced diets. The advantage of forage as pigs feeds however remains controversial as the economical and environmental implications at the farm level in mixed farming systems have seldom been quantified.

3. Introduction

Forage was considered in the past as an essential component of the feed of pigs in all production environments. The development of high growth performance breeds over the past decades and the widespread adoption in developed as well as in developing countries of industrial indoor grain-fed production systems have led to the abandon of forage in the diets of industrially raised pigs and a scarcity in up-to-date knowledge on the nutritional value of forage plants for pigs (Blair, 2007). Forage is nonetheless still widely used by smallholding farmers in low-input and semi-intensive pig production systems of tropical Asia, Africa and America. Forage is only one part of the various ingredients that smallholders usually feed to their pigs which include: agricultural by-products from local food processing units, weeds that grow naturally in the forests and along the banks of rivers, aquatic plants and plant of previous crops on fallow (Kumaresan *et al.* 2009; Phengsavanh *et al.*, 2010). Various reasons explain why smallholders still include significant amounts of forage in the diets of their animals: their low income as compared to the high prices of imported grains or oil-seed cakes (Kagira *et al.*, 2010; Kaensombath *et al.*, 2013), the remoteness and inaccessibility of their farms, increasing the energy and protein concentrate costs at the farm gate (Kumaresan *et al.*, 2007), and the lack of accessible market (Lemke *et al.*, 2007). This maintains most smallholders in low-input agricultural systems with little room for mid- or long-term investments, as an improvement in the genetics and the feeding systems would require. In addition, when the activity is driven by socio-cultural motivations and is more oriented towards auto-consumption than to the market (Lemke *et al.*, 2006; Kumaresan *et al.*, 2009), little effort is made to improve growth performances of animals by seeking feed with high nutritional value. For example, it is reported that in Gambia animals are only managed intensively when they make a significant contribution to production and income, but not if savings is their main function (Bennison *et al.*, 1997). Moreover, feeding forage is often used with indigenous pigs which are the preferred breed of smallholders in rural areas (Lemke *et al.*, 2007; Len *et al.*, 2009a) and investigations in Burkina Faso and Cameroon reveal that under specific conditions the low-input by-products and forage-based sector can even be more profitable than industrial pigsties (Lekule and Kyvsgaard, 2003).

The extent to which forage species can economically contribute to supply pigs in nutrients for growth and reproduction will depend on the voluntary feed intake as well as the digestibility of the forage itself and the relative cost and availability of forage as opposed to concentrate feeds. The present review examines the nutritive value of several tropical forage species as well as how breed and physiological status of the animal influence the animal's ability to sustain on forage-based diets. Finally, the socio-economical and environmental implications of feeding forage to pigs in low-input farming systems are discussed.

4. Chemical composition and feeding value of tropical forage species in pigs

1. Diversity of tropical forage species used in pigs

Forage used in the diets of pigs across the tropics covers a wide range of plant materials as listed in Table 1. It includes grasses, legumes, aquatic plants, and leaves from shrubs and trees. Forage is fed, either in fresh or preserved form as hay or silage (Ogle, 2006). Some tropical forage species such as *Manihot esculenta*, *Ipomoea batatas*, *Leucaena leucocephala*, *Arachis hypogaea*, *Stylosanthes guianensis*, *Colocasia esculenta*, *Azolla filiculoides*, *Salvinia molesta*, *Xanthosoma saggitifolium*, and *Morus alba* have been already assessed *in vivo* in pigs. However, although there are locally used by smallholders, most species have not been assessed further than the determination of their chemical composition and, sometimes for their *in vitro* digestibility for pigs (Feedipedia, 2013). Examples of such plants are numerous and they include, among others, *Moringa oleifera*, *Psophocarpus scandens* (Kambashi *et al.*, in press), *Crassocephalum crepidioides*, and *Amaranthus viridis* (Phengsavanh *et al*. 2010).

Table 1. Range of proximate chemical composition (g/kg DM) and energy (MJ/kg DM) of plant materials used in pig diets

Plant species	*Family*	*Plant part*	*OM*	*CP*	*GE*	*NDF*	*ADF*	*ADL*	*Ca*	*P*	*Ref*[1]
Trichanthera gigantean	*Acanthaceae*	*Leaves*	*823-864*	*115-219*	*15.8*	*299-468*	*166-337*	*40-124*	*nd*	*nd*	*1*
Colocasia esculenta	*Araceae*	*Leaves*	*854*	*90-225*	*10.3**[3]	*316-505*	*nd*	*Nd*	*0.10-1.00*	*0.20-3.20*	*2*
Lemna minor	*Araceae*	*Plant*	*808-830*	*296-370*	*9.1**	*370*	*283*	*Nd*	*3.27*	*1.43*	*3*
Xanthosoma sagittifolium	*Araceae*	*Leaves*	*843-910*	*169-258*	*18.0*	*186-371*	*115-253*	*11-75*	*nd*	*nd*	*1 ; 4; 5*
Azolla filiculoides	*Azollaceae*	*Plant*	*855-902*	*232-237*	*12.8-16.4*	*469-620*	*284-387*	*104-168*	*0.08-0.11*	*0.20-0.40*	*6*
Ipomoea aquatica	*Convolvulaceae*	*Leaves*	*867-871*	*256*	*8.3**	*349*	*283*	*Nd*	*1.03*	*0.59*	*3 ; 7*
Ipomoea batatas	*Convolvulaceae*	*Leaves and Stem*	*855-986*	*187-298*	*16.9-17.7*	*232-449*	*136-327*	*93-125*	*0.07-0.19*	*0.02-0.07*	*5; 8; 9*
Manihot esculenta	*Euphorbiaceae*	*Leaves or Tops*	*894-96.5*	*208-306*	*19.0-21.4*	*320-615*	*202-428*	*237*	*0.62-0.75*	*0.30-0.40*	*10; 11; 12*
Aeschynomene histrix	*Fabaceae*	*Leaves and Stem*	*931*	*237*	*8.7**	*467*	*260*	*Nd*	*nd*	*nd*	*13*
Arachis hypogaea	*Fabaceae*	*Tops*	*906*	*175*	*18.1*	*419*	*219*	*Nd*	*nd*	*nd*	*10*
Erythrina glauca	*Fabaceae*	*Leaves*	*900*	*287*	*19.6*	*477*	*288*	*108*	*nd*	*nd*	*5*
Leucaena leucocephala	*Fabaceae*	*Leaves*	*901-910*	*225-283*	*Nd*	*318-388*	*175-215*	*Nd*	*0.49-2.40*	*0.12-0.25*	*5 ; 14*
Stylosanthes guianensis	*Fabaceae*	*Tops*	*853-917*	*141-188*	*7.8**	*549-602*	*424*	*Nd*	*2.20*	*0.48*	*15 ; 16*
Psophocarpus scandens	*Fabaceae*	*Leaves and Stem*	*852-904*	*231-297*	*Nd*	*326-418*	*228*	*66*	*1.45*	*0.34*	*15 ; 17*
Vigna unguiculata	*Fabaceae*	*Leaves and Stem*	*859*	*243-360*	*12.3-13.0*	*365*	*235*	*Nd*	*0.96-3.70*	*0.34-0.42*	*15; 18*
Morus alba	*Moraceae*	*Leaves*	*908-837*	*113-239*	*17.54*	*174-301*	*82-189*	*13-27*	*nd*	*nd*	*1 ; 2*
Musa paradisiaca	*Musaceae*	*Leaves*	*880*	*74*	*17.3*	*701*	*400*	*108*	*nd*	*nd*	*19*
Brachiaria mulato	*Poaceae*	*Plant*	*Nd*	*58*	*Nd*	*732*	*468*	*200*	*nd*	*nd*	*20*
Talinum triangulare	*Portulacaceae*	*Plant*	*754*	*211*	*Nd*	*347*	*277*	*76*	*nd*	*nd*	*17*
Eichhornia crassipes	*Pontederiaceae*	*Plant*	*853-870*	*110-267*	*8.4**[3]	*nd*	*nd*	*Nd*	*1.08*	*0.14*	*15; 21*
Salvinia molesta	*Salviniaceae*	*Plant*	*768-849*	*92-191*	*14.7-16.4*	*518-629*	*358-414*	*123-168*	*1.00-1.20*	*0.60-0.70*	*6*

[1] Ref, references: (1) Leterme *et al.* (2006b) ; (2) Kaensombath and Lindberg (2013) ; (3) Dung *et al*. (2006); (4) Leterme *et al*. (2005) ; (5) Régnier *et al*. (2013) ; (6) Leterme *et al*. (2009) ; (7) Ty and Preston (2005); (8) An *et al*. (2004) ; (9) An *et al*. (2003) ; (10) Phuc and Lindberg (2000) ; (11) Nguyen *et al*. (2012) ; (12) Khieu *et al*. (2005) ; (13) Phengsavanh and Lindberg (2013) ; (14) Laswai *et al*. (1997) ; (15) Kambashi *et al*. (in press) ; (16) Kaensombath *et al*. (2013) ; (17) Bindelle *et al*. (2007) ; (18) Uusiku *et al*. (2010) ; (19) Ly *et al.* (1998) ; (20) Sarria *et al*. (2012); (21) Men *et al.* (2006) ;

[2]nd, non determined

[3]*, metabolizable energy instead of gross energy

2. Chemical composition and variability

Forage ingredients are by definition rich in fibre as opposed to concentrate feed ingredients (Gillespie and Flanders, 2010). However, the composition of forage ingredients is highly variable, including within a given species, as the stage of harvesting, climatic stresses during the plant growth and variety or cultivars exert an influence on the chemical composition of the forage. This high variability coupled with unpredictability due the factors outlined above limit the possibility of using forage plants for feeding pigs. Forage plants used as pigs feed have NDF content ranging from 174 g/kg DM in *Morus alba* to 732 g/kg DM in *Brachiara mulato*, with lignin fraction ranging from 13 g/kg DM to 200 g/kg DM. Moreover, they are usually low in crude fat and starch. As stated later in this review if one excludes the influence on the intestinal eco-physiology, fibre is not of particular interest for pigs in terms of supply of nutrients to the animal. The benefits of forage feed ingredients for pigs lie in their richness in protein, essential amino acids and minerals. Most forage species used by smallholders in the tropics have high crude protein contents (up to 370 g/kg DM, Table 1) especially *fabaceae*. In semi-intensive or extensive pig rearing systems in tropical countries, many energy sources are locally available: peelings or millings of bananas, tubers, and grains, palm oil by-products or sugarcane juices. Forage as alternative ingredient should therefore supply protein which is the most limiting nutrient in smallholder pig feeding systems in tropical areas (Leterme *et al.*, 2005; Martens *et al.*, 2012). Some forage species such as *Stylosanthes guianensis, Ipomoea batatas, Colocasia esculenta*, and *Leucaena leucocephala* present amino acids (AA) profiles (Table 2) that match quite well that of the ideal protein for pigs while others are deficient in one or more essential AA (Phuc and Lindberg, 2001; An *et al.*, 2004; Kaensombath and Lindberg 2013; Régnier *et al.*, 2012). Cassava (*Manihot esculenta*) and sweet potato (*Ipomoea batatas*) leaves, for example, are rich in protein but have a deficient profile in methionine and lysine, respectively (Nguyen *et al*. 2012). Some forage species suffer from a low bioavailability of their amino acids, and from the presence of plant secondary metabolites that reduce protein digestibility. Using forage species therefore does not allow maximizing growth performance of genetically-improved breeds, but this strategy makes sense for smallholder pig producers or local breeds with lower requirements.

Table 2. Amino acid profiles of some forage (% protein)

	Arg	*His*	*Ile*	*Leu*	*Lys*	*Met*	*Phe*	*Thr*	*Trp*	*Val*	*Ref*[3]
Requirements for growing pigs (20-50 kg)[1]	*3.19*	*2.49*	*3.76*	*7.20*	*7.14*	*2.04*	*4.33*	*4.59*	*1.21*	*4.78*	*1*
Arachis hypogaea	*5.20*	*2.00*	*3.70*	*7.00*	*4.10*	*0.90*	*5.40*	*4.00*	*nd*[2]	*5.10*	*2*
Erythrina glauca	*4.10*	*1.70*	*3.10*	*5.30*	*4.30*	*1.00*	*3.90*	*2.90*	*1.40*	*4.00*	*3*
Colocasia esculenta	*5.20*	*1.20*	*5.00*	*7.60*	*2.90*	*2.20*	*4.20*	*4.10*	*nd*	*5.00*	*3 ; 4*
Ipomoea batatas	*4.50-6.60*	*1.70-3.30*	*3.70-5.20*	*6.40-8.70*	*3.90-4.80*	*1.30-1.50*	*4.10-6.70*	*3.60-5.50*	*1.20-1.50*	*4.70-5.70*	*3 ; 5; 6*
Leucaena leucocephala	*4.00-5.70*	*1.80-2.00*	*4.10-9.50*	*5.80-7.90*	*4.30-5.80*	*1.20-1.60*	*3.90-5.60*	*3.30-4.00*	*nd*	*4.70-5.40*	*2 ; 7*
Manihot esculenta	*4.40-5.93*	*1.70-2.19*	*3.90-5.51*	*6.80-8.30*	*4.21-5.60*	*1.20-1.50*	*4.18-5.70*	*3.30-4.46*	*1.6*	*4.11-5.30*	*2; 3 ; 8*
Morus alba	*5.30*	*2.10*	*4.30*	*8.20*	*5.70*	*1.60*	*5.20*	*4.60*	*1.10*	*5.40*	*9*
Trichanthera gigantea	*4.90*	*2.20*	*4.10*	*7.20*	*4.30*	*1.50*	*4.60*	*4.30*	*1.00*	*5.00*	*9*
Xanthosoma sagittifolium	*3.10-5.00*	*1.50-1.90*	*2.60-3.90*	*4.90-7.50*	*4.00-5.60*	*1.10-1.80*	*2.90-4.70*	*2.90-4.50*	*0.80-1.70*	*3.80-4.80*	*3; 9*
Stylosanthes guianensis	*4.80-5.12*	*1.90-1.97*	*3.30-4.13*	*6.80-7.32*	*4.30-4.51*	*1.10-1.60*	*4.60*	*4.00-4.13*	*1.10-1.78*	*3.90-4.84*	*10, 11*
Vigna unguiculata	*4.70-4.90*	*1.80-4.10*	*6.60*	*13.40*	*9.50*	*2.60-5.0*	*6.10-7.80*	*6.60*	*nd*	*6.10-9.50*	*12 ; 13*

[1]calculated from amino acid estimated requirements in a diet with 2.51 % nitrogen fed ad libitum to growing pigs (90% dry matter)
[2]nd, not determined
[3]Ref, references: (1) NRC (2012) ; (2) Phuc and Lindberg (2001) ; (3) Régnier *et al*. (2012) ; (4) Kaensombath and Lindberg (2013); (5) Nguyen *et al*. (2012) ; (6) An *et al*. (2003) ; (7) Ly *et al.* (1998); (8) Nguyen *et al*. (2012) (9) Leterme *et al*. (2005) ; (10) Kaensombath et al. (2013) ; (11) Phengsavanh and Lindberg, 2013; (12) Nielsen *et al*. (1997) ; (13) Heinritz *et al. (2012)*

Several studies showed the high content of minerals in plants and plant parts (Cook *et al.*, 2000; Kumari *et al.*, 2004; Leterme *et al.*, 2006a). However, the mineral content of plants varies not only between species, but also depends on the maturity stage of the harvested material (Wawire *et al.*, 2012), the season, the number of harvests (Baloyi *et al.*, 2013), the physicochemical properties of the soil and the environmental conditions, including plant stress (Kabata-Pendias, 2004). A rational use of plant materials will allow the farmer to cover a significant portion of micronutrients, essential minerals and vitamins requirements for animal growth (Agte *et al.*, 2000; Ishida *et al.*, 2000).

Besides fibre content, the second major drawback of tropical forage is related to the presence in some species of plant secondary metabolites (PSM) that might at best exert some anti-nutritive properties through a decrease in diet palatability and digestibility (Acamovic and Brooker, 2005; Halimani *et al.*, 2005) and at worst be toxic for the animal as described later in this review. Such compounds fall under different molecular families such as phenolic compounds, cyanogenic glucosides, oxalic acid, lectins, alkaloids, antitrypsic molecules, non-physiological amino acids, *et cetera*. Some PSM are rather specific to some species or botanical families such as hydrogen cyanide (HCN) in cassava, oxalic acid in cocoyam or mimosine in *Leucaena leucocephala*, while others such as tannins are present in plant foliage of many forage species at different concentrations (Acamovic and Brooker, 2005; Makkar, 2007). As for other nutrients such as fibre, protein or minerals, the content in PSM depends of course of botanical families, plant species and variety or cultivar, but in some cases also of the plant part, the stage of maturity and the growing conditions such as soil fertility and season (Ravindran and Ravindran, 1988; Acamovic and Brooker, 2005). Young leaves contain higher concentrations of PSM than senescing tissues and stems (Wink, 2004), similarly to proteins. Conversely, lignin and fibre contents increase with age and stem-to-leaf ratio in the forage (Buxton and Redfearn, 1997).

5. Feeding value of tropical forage species in pigs

1. Energy content

The richness in fibre as well as the degree of lignification of the fibre fraction of forage is probably the major constraint to their use as pig feed (Noblet and Le Goff, 2001; Högberg and Lindberg, 2006). Due to the lack of fore-gut fermentation and caecotrophic behaviour, the ability of pigs to recover nutrients from fibre, in particular energy, is limited to the uptake through the intestinal wall of short-chain fatty acids produced during hindgut intestinal fermentation (reviewed by Bindelle *et al.*, 2008). Therefore, with total tract OM digestibility ranging from 0.30 to 0.63 (Table 3) as well as digestible and metabolizable energy contents ranging from 5.2 to 11.9 MJ/kg DM) and 5.0 to 8.3 MJ/kg DM, respectively (Phuc and Lindberg, 2000; Leterme *et al.*, 2006b; Régnier *et al.*, 2013), the energy value of plant foliages are quite lower than those of concentrate feed ingredients such as cereal grains (Table 3). Cereals have OM digestibility value usually falling between 0.84 and 0.98, and digestible and metabolizable energy contents as high as 12.9 to 15.4 MJ/kg DM and 12.4 to15.0 MJ/kg DM, respectively (Sauvant *et al.*, 2004). As stated previously, the composition of forage is also more variable than concentrate feed ingredients. Owing to this variability, it is more difficult to study the actual nutritive of these high fibre materials from an experimental point of view. The measured nutritive values depend on animal factors such as age or breed, experimental design such as rate of incorporation in the diet, presentation form and factors related to tropical foliage itself as showed previously.

As a consequence of the low digestibility of the fibre fraction, growth performances of pigs fed forage-based diets are often below those of concentrate-fed pigs, depending on forage inclusion rate (Laswai *et al.*, 1997; Halimani *et al.*, 2005; Phengsavanh and Lindberg, 2013; Régnier *et al.*, 2013). Nonetheless, if one goes through the list of plants that have been reported as being used for pigs in the literature, wide differences in total tract OM and energy digestibility between forage species are reported (Table 3). For example, some accessions of *Xanthosoma sagittifolium*, *Morus alba*, *Azolla filiculoides* and *Arachis hypogea* have total tract OM and energy digestibility ranging, respectively, from 0.49 to 0.71 and from 0.60 to 0.69. Conversely, the aquatic fern *Salvinia molesta* used in production systems integrating pig production to pond aquaculture has an OM digestibility as low as 0.29 to 0.33 and an energy digestibility of 0.31. Such differences are to be ascribed not only to the difference in total fibre content which varies with (1) species, with *poaceae* generally containing more fibre than *fabaceae*, (2) plant parts, as stems have higher fibre content than leaves, and (3) maturity at harvest (Buxton and Redfearn, 1997). Other differences are to be ascribed to differences in fermentability between fibre types (Noblet and Le Goff, 2001; Anguita *et al.*, 2006) and the insoluble to soluble fibre ratio, with soluble fibre affecting more negatively voluntary fibre intake and ileal digestibility.

2. Interaction between fibre content and digestibility of nutrients

High fibre content, and especially viscous fibre reduces enzyme contact and traps nutrients and minerals in a voluminous chyme, away from absorption sites in the intestine

(Anguita *et al.*, 2006; Urriola and Stein, 2012). Leterme *et al.* (2009), for example, observed a relatively high faecal digestibility for *Azolla filiculoides* and low for *Salvinia molesta* (Table 3) a species rich in fibre with high water-holding capacity, while both species have similar NDF contents (523 *vs* 539 g/kg DM, Table 1).

The increase in chyme volume especially with foliage or fibre fractions with high water-holding capacity also increases digesta passage rate, decreasing the accessibility and time of action of digestive enzymes, decreasing global digestibility (Partanen *et al.*, 2007; Régnier *et al.*, 2013). However, the influence of fibre on intestinal transit time is controversial as several authors mention increases (Wilfart *et al.*, 2007), decreases (Wenk, 2001) or no influence (Partanen *et al.*, 2007) of fibre on this parameter. As mentioned above, such variability between studies may originate from differences in methodology, i.e. experimental design, rate and form of forage incorporation, analytical methods, etc.

3. Digestibility of protein and bioavailability of amino acids

Crude protein can include non-protein N as the analytical procedure for crude protein yields the N content × 6.25 (method 981.10; AOAC, 1990). It is reported that nitrogen-to-protein conversion factors of some vegetal materials (rice, oat and wheat) are lower than 5.36 (Chang, 2010). For instance, Régnier *et al.* (2012) found that the sum of AA in tropical plant leaves (cassava, sweet potato, cocoyam and erythrina foliages) was 25% lower than the CP content. This gap between crude protein and individual AA analysis is one first factor to consider when determining the actual protein value of a forage species. In addition, the individual AA profile as well as their bioavailability must be considered. Fibre strongly interferes with protein digestibility. Proteins can be bound to the NDF fraction preventing them from being hydrolysed by the digestive enzymes of the pigs. This NDF-bound protein fraction is higher in dicotyledons than grasses (Bindelle *et al*., 2005).

This was observed, for example, by Leterme *et al*. (2006b) with *Trichanthera gigantea*, a tropical tree fed to pigs in Colombia. NDF-bound N in this species reaches 59% of the total N leading to low ileal and fecal protein digestibility of approximately 0.15 and 0.30 respectively. However, low fecal N-digestibility values not always mean low protein value. High fermentable fibre content of some forage species decreases the fecal apparent digestibility of N trough a shift of N excretion from urinary-N (urea) to fecal-N (bacterial protein) without systematically altering the protein value of the diet (Bindelle *et al.*, 2009). Therefore the only actual protein value should mention ileal digestibility or possibly the standardized ileal digestible (SID) amino acids of the forage ingredients as these value might strongly differ from raw AA composition (Table 2 and Table 4). Many authors report a decrease in N and AA digestibility in growing pigs when tropical leaves are included in a basal diet (e.g. Phuc and Lindberg, 2001; An *et al.*, 2004; Régnier *et al.*, 2013). The values for apparent ileal digestibility (AID) are established when total ileal outflow of AA is related to dietary AA intake. Total ileal outflow consists of non-digested dietary AA but also endogenous AA secretions or losses. The latter may be separated into (i) basal losses which are considered in the SID calculations and are not influenced by feed ingredient composition, and (ii) specific losses, which are induced by feed ingredient characteristics such as fibre levels and types, the presence of PSM, or mineral contents (Stein *et al.*, 2007). As some forage plants have both high fibre content and PSM which lead to the increase in specific endogenous AA losses explain the low AID of AA.

4. Minerals digestibility

The bioavailability of minerals in tropical forage species should be investigated, as the little data available in the literature indicates that it strongly varies between plant species and the considered minerals. For example, mineral bioavailability for pigs in tropical forage ranges from 41 to 58% for P (Poulsen *et al.*, 2010), 3 to 27% for Fe (Kumari *et al.*, 2004), 11 to 26% for Zn and 18 to 48% for Cu (Agte *et al.*, 2000). Furthermore, the high dietary mineral content of some forage species is likely to have a negative influence on energy and protein values. Noblet and Perez (1993) reported that the digestibility coefficients of energy and crude protein were highly dependent on dietary fiber and mineral contents. They also suggested that dietary minerals increase protein endogenous losses through intestinal cell debris with subsequent increase of endogenous energy and AA losses.

Table 3. In vivo ileal and total tract digestibility coefficients of nutrients of tropical forage species in pigs

	Ileal digestibility					*Total tract digestibility*					
	OM	*CP*	*NDF*	*ADF*	*Energy*	*OM*	*CP*	*NDF*	*ADF*	*Energy*	*Ref*[1]
Ipomoea batatas	*nd*[2]	*0.74*	*0.23-0.25*[3]	*nd*	*nd*	*nd*	*0.75-0.77*[3]	*0.55-0.57*[3]	*0.32-36*[3]	*nd*	*1*
	nd	*nd*	*nd*	*nd*	*nd*	*nd*	*0.21*	*nd*	*nd*	*0.38*[6] *0.48*[7]	*2*
Manihot esculenta	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.08*[6] *0.15*[7]	*nd*	*nd*	*0.31*	*2*
	0.42	*0.37*	*0.26*	*0.16-0.17*	*0.41*	*0.54-0.59*	*0.45-0.46*	*0.31-0.32*	*0.20-0.21*	*0.52-0.57*	*3*
Arachis hypogaea	*0.55*	*0.43*	*0.49*	*0.34*	*0.52*	*0.64*	*0.47*	*0.58*	*0.46*	*0.60*	*3*
Leucaena leucocephala	*0.44*	*0.39*	*0.24*	*0.12*	*0.40*	*0.53*	*0.42*	*0.27*	*0.18*	*0.51*	*3*
Azolla filiculoides	*nd*	*nd*	*nd*	*nd*	*nd*	*0.33-0.50*[4,5]	*0.31-0.66*[5]	*nd*	*nd*	*0.30-0.63*[5]	*4*
Salvinia molesta	*nd*	*nd*	*nd*	*nd*	*nd*	*0.29-0.33*[4,5]	*0.31-0.56*[5]	*nd*	*nd*	*0.31*	*4*
Morus alba	*nd*	*nd*	*nd*	*nd*	*nd*	*0.56*[4]	*0.33*	*nd*	*nd*	*0.51*	*5*
	nd	*nd*	*nd*	*nd*	*nd*	*0.63*[4]	*0.49*	*nd*	*nd*	*0.65*	*6*
Trichanthera gigantean	*nd*	*nd*	*nd*	*nd*	*nd*	*0.47*[4]	*0.36*	*nd*	*nd*	*0.60*	*5*
	nd	*nd*	*nd*	*nd*	*nd*	*0.49*[4]	*0.30*	*nd*	*nd*	*0.54*	*6*
Xanthosoma sagittifolium							*0.65*			*0.47*	*2*
	nd	*nd*	*nd*	*nd*	*nd*	*0.57*[4]	*0.34*	*nd*	*nd*	*0.57*	*5*
	nd	*nd*	*nd*	*nd*	*nd*	*0.71*	*0.57*	*nd*	*nd*	*0.69*	*6*

[1] Ref, references: (1) An *et al.* (2004); (2) Régnier *et al*. (2013); (3) Phuc and Lindberg (2000); (4) Leterme *et al*. (2009); (5) Leterme et al. (2005); (6) Leterme *et al*. (2006b)
[2]nd, not determined
[3]Range according to preservation method (fresh, dried, ensiled)
[4]DM digestibility instead of OM digestibility
[5]Range according differences in estimates because of varying proportion of forage in the basal diet for the calculation of digestibility of leaves alone with the difference method
[6]Leaves
[7]Leaves and stems

Table 4. Ileal apparent digestibility of amino acid of forage species in pigs

	Arg	*His*	*Ile*	*Leu*	*Lys*	*Met*	*Phe*	*Thr*	*Trp*	*Tyr*	*Val*	*Ref*
Arachis hypogaea	*0.77*	*0.73*	*0.71*	*0.72*	*0.73*	*0.73*	*0.68*	*0.69*		*0.65*	*0.72*	*1*
Erythrina glauca	*0.47*[1]	*0.13*[1]	*0.04*[1]	*0.22*[1]	*0.13*[1]	*0.43*[1]	*0.29*[1]	*-0.07*[1]	*0.00*[1]		*0.08*	*2*
Ipomoea batatas	*0.51*[1]*- 0.80*	*0.25*[1]*- 0.80*	*0.32*[1]*- 0.78*	*0.45*[1]*- 0.80*	*0.43*[1]*- 0.83*	*0.46*[1]*- 0.75*	*0.40*[1]*- 0.78*	*0.22*[1]*- 0.75*	*0.14*[1]		*0.31- 0.78*	*2 ; 3*
Leucaena leucocephala	*0.48*	*0.67*	*0.52*	*0.52*	*0.61*	*0.57*	*0.55*	*0.52*		*0.60*	*0.61*	*1*
Manihot esculenta	*0.41*[1]*- 0.56*	*0.15*[1]*- 0.68*	*0.20*[1]*- 0.48*	*0.30*[1]*- 0.57*	*0.29*[1]*- 0.64*	*-0.36*[1]*- 0.56*	*0.34*[1]*- 0.55*	*0.08*[1]*- 0.54*	*0.13*[1]	*0.64*	*0.18- 0.62*	*1 ; 2*
Xanthosoma sagittifolium	*0.63*[1]	*0.44*[1]	*0.46*[1]	*0.61*[1]	*0.54*[1]	*0.36*[1]	*0.60*[1]	*0.25*[1]	*0.20*[1]	*0.80*	*0.46*	*2*

[1] SID of AA instead of ileal apparent digestibility

(1) Phuc and Lindberg (2001) ; (2) Régnier *et al*. (2012) ; (3) An *et al.* (2004)

5. Plant secondary metabolites

As stated before, plant secondary metabolites can display various effects on the animals including some specifically related to the feeding value of the forage ingredient such as a reduction in digestibility and voluntary intake (reviewed by Martens *et al.*, 2012). Tannins are diverse regarding their chemical structure but share common biochemical properties in their ability to precipitate proteins at neutral pH. As a consequence, some tannin-containing feeds decrease the voluntary intake which may be associated with astringency caused by the formation of tannin–salivary protein complexes in the mouth or signals of gut distension resulting from tannin interactions with proteins of the gut wall (Acamovic and Brooker, 2005). Tannins decrease protein and dry matter digestibility in pigs via an increase in faecal nitrogen excretion, an inhibition of digestive enzymes or intestinal micro-organisms and an effect on gut permeability (Walton *et al.*, 2001). Tannins also increase endogenous losses from animals, including mineral losses by chelation. Nevertheless the effect varies with the binding strength in protein–tannin complexes which can vary over several orders of magnitude between species (Mueller-Harvey, 2006) and the total tannin content. For example condensed tannins from *Leucaena leucocephala* have the ability to precipitate proteins approximately by half than that of *Leucaena pallida or Leucaena trichandra* on g of protein/g of tannins basis, while tannins from *Leucaena collinsi* hardly precipitate any proteins (Osborne and McNeill, 2001). However, the effect of tannins on pigs is controversial as some authors mention improvements (Myrie *et al.*, 2008; Biagi *et al.*, 2010), decreases (Halimani *et al.*, 2005; Kim *et al.*, 2007) or neutral effect on digestive processes (Lizardo *et al.*, 2002; Stukelj *et al.*, 2010). Moreover, the inclusion of 4 g/kg tannin in the diet resulted in improved feed efficiency and reduction of intestinal bacterial proteolytic reactions (Biagi *et al.*, 2010) and 15 g/kg tannin in the diet did not affect growth performance (Myrie *et al.* 2008). Furthermore, when reduced growth performance is reported in monogastric animals fed tannin-rich feedstuffs, the latter are generally characterised by the presence of significant amounts of other PSM that altogether might result in reduced animal growth (Biagi *et al.*, 2010). For example, HCN increases methionine requirements for detoxication (Mansoori and Acamovic, 2007), so in *Manihot esculenta*, protein-binding tannins and HCN act together to worsen the deficiency in methionine in cassava leaves-based diets.

HCN and alkaloids decrease intake because of their bitter taste. Ingestion of non-lethal dose of HCN (<100 ppm in the diet for pigs) also reduces growth rates associated with increased serum and urinary levels of thiocyanate, which is a continuous cause of depletion of sulphur containing amino acids and reduces the blood thyroxine levels (Tewe, 1992). At high concentration (>100 ppm), HCN may be lethal for the animal through the inhibition of cytochrome oxidase in the mitochondria. The lethal dose for most animal species is approximately 2 mg HCN /kg BW (body weight) (Kahn, 2010). However, intake rate is also important. Animals that eat rapidly are more likely to be poisoned as the drop in pH in the stomach destroys the enzymes responsible for the release of HCN. Finally, variety, maturity and fertilizer application levels also play a role in the possibility to use some cyanide-containing plants as forage for pig. *Manihot esculenta* for example displays HCN contents in foliage ranging from 80 to 2000 mg/kg DM, depending on the previously mentioned factors (Feedipedia, 2013).

Some alkaloids are hepatotoxic and can reduce growth rate of pigs, mainly by decreasing feed intake and affecting feed efficiency (Gdala *et al.*, 1996). For example, alkaloids in *Erythrina glauca* did not affect feed intake and health likely due to restrictively feeding and moderate rate of this plant in diet. Despite this, this plant showed a low nutritive value (-0.328 and 0.266 for CP and energy respectively) (Régnier *et al.*, 2013).

Oxalic acid is found at high levels (34.3 to 48.2 mg/g DM) in some cocoyam species (Oscarsson and Savage, 2007). With its astringent taste, it decreases intake levels and affects the physical properties of the oral mucosa by denaturing proteins in the surface epithelium, by increasing friction of mucosa caused via aggregation of saliva (De Wijk and Prinz, 2006) and causes irritations of the gastrointestinal tract (Leterme *et al.*, 2005). In addition to these negative effects, one notices increased kidney and liver weight (Kaensombath and Lindberg, 2013) probably due to deposit of crystals of calcium oxalate.

Mimosine is known to act as a tyrosine analogue inhibiting protein biosynthesis (ter Meulen *et al.*, 1979) and metal-containing enzymes due to its ability to chelate metal ions, reducing plasma amino acid and mineral concentrations, reducing the absorption of some amino acids from the gastrointestinal tract (Smuts *et al.*, 1995), and causing toxic symptoms including retardation of growth. In the pig diet, mimosine decreases feed intake (ter Meulen *et al.*, 1979). Although very few research report signs of acute short term poisoning, long term exposure to levels of 772 ppm in rat diets induced mild alopecia, cataracts, reversible paralysis of the hind limbs, severe retardation of growth and mortality as high as 50 %, while the addition of 2% of $FeSO_4$ protected the animals against these symptoms (El-Harith *et al.*, 1979).

Considering these PSM negative impacts, it is important to bear in mind that (1) some treatments such as heat or ensiling are able to significantly reduce the content in some PSM (see Martens *et al.*, 2012 for a review), and (2) forage is not intended to be fed alone and that inclusion with other feed ingredients will possibly mitigate these deleterious effects. For example, HCN content in fresh cassava leaves can be as high as 349 mg/kg DM (Ty *et al.*, 2007). However, when cassava is included at a level of 0.21 on DM basis in a broken rice and sugar palm juice-based diet, the HCN content of the diet is reduced to 73 mg/kg DM, a moderately poisonous range and pigs show no symptoms of ill-health neither effects on DM intake and nitrogen retention.

6. Effect of preservation method on feeding value

Preservation methods are used to ensure a longer availability of the forage resource on the farm than the growing season itself. But, preservation can also have an interesting influence on the feeding value: enhancement in palatability, intake and digestibility, detoxication of PSM, and concentration of some nutrients (Martens *et al.*. in press).

Nonetheless, changes in feeding value vary between preservation methods and plant species. DM intake was higher in sun-dried than fresh and ensiled *Ipomoea batatas* leaves owing to their higher water content (An *et al.*, 2004; Khieu *et al.*, 2005). Drying can reduce the volume of forage to more than half and increase intake in pigs of water-rich aquatic ferns such as *Azolla* sp. and *Salvinia molesta* (Leterme *et al.*, 2010). Milling dried forage reduces the volume and animal selectivity and increases feed efficiency (Kim *et al.*, 2009; Martens *et al.*, 2012).

An *et al.* (2004) noticed changes of AA profiles and fibre fraction between fresh, dried and ensiled *Ipomoea batatas*, with the highest contents of NDF and ADF in fresh leaves and lowest in ensiled leaves. The reduction of NDF during ensiling (Hunt *et al.*, 1993; Bagheripour *et al.*, 2008) originates from cell wall degradation by plant and bacterial enzymes as for example cellulase produced by Clostridia, cellulolytic clostridia, acid hydrolysis (McDonald *et al.*, 1991) and small amount of hydrolysis of hemicellulose (Hunt *et al.*, 1993). A decrease in protein content may also be observed, resulting from proteolysis after harvesting, during wilting and in the silage itself. This decrease is more important when wilting occurs in a poor humid environment than under dry conditions (McDonald *et al.*, 2010).

As a consequence of these changes, *Manihot esculenta* leaves silage had a higher total tract apparent digestibility (TTAD) (0.84 *vs* 0.79, 0.71 *vs* 0.48, 0.54 *vs* 0.42 and 0.77 *vs* 0.70

respectively for DM, CP, crude fibre (CF) and NDF) than sun-dried leaves (Khieu *et al.*, 2005). A similar trend was noticed with ensiled *Ipomoea batatas* leaves except for proteins (Nguyen *et al.*, 2012). In contrast, no difference was observed between fresh, ensiled and sun-dried sweet potato diets in TTAD (An *et al*., 2004).

Besides major nutrients, preservation also affects PSM contents in forage (reviewed by Martens *et al.*, 2012). Preparation steps for conservation can be necessary to eliminate the anti-nutrient in forage. For example HCN is strongly reduced when plants are sun-wilted and chopped into small pieces before silage probably due to the action of endogenous linamarase on cyanogenic glucosides (Santana *et al.*, 2002). In addition, a combination of shredding and sun-drying can simultaneously reduce high HCN (by 96%), tannin (by 38%) and phytic acid (by 59%) contents of *Manihot esculenta* leaves (Fasuyi, 2005). Mechanical damage of plant tissues during chopping, wilting and ensiling promotes the contact between endogenous enzymes and PSM and thus facilitates their removal (Lyon, 1985).

6. Forage utilization by pigs

Forage feeding value not only depends on the forage plant itself. As it contains high levels of fibre and sometimes PSM, the age of the animal, its bodyweight, its breed and the inclusion levels in the diet are other factors determining the efficiency of forage utilization as feed ingredient by pigs.

1. Influence of physiological status

Forage is rich in fibre and has a high bulking capacity, reducing the energy density of the diet as showed before. The efficiency with which pigs are able to cope with this reduction in energy density by increasing feed intake, strongly varies with their physiological status. Whittemore *et al*. (2003) showed that the ability of pig to ingest bulk feeds was correlated to live weight. While 600 g sugar beet pulp /kg of diet was constraining for pigs of 12kg, 600 g/kg and 800 g/kg did not limit the live weight gain at 36 kg and 108 kg respectively. High bulk feed causes a significant size increase of parts of gut involved in digestion and fermentation (Whittemore *et al.*, 2003, Len *et al.*, 2009a). Furthermore, adult pigs have a larger hindgut in proportion to their live weight and a lower feed intake relative to gut size compared to young pigs which increases retention and fermentation times in the intestines. This change in hindgut volume affects the ability of the pig to digest fibre and consequently explains partially the higher digestibility of energy originating from fibre in adult sows (Noblet and Le Goff, 2001). Besides fibre and energy, protein digestibility of plant leaves is also influenced by live weight. Leterme *et al.* (2006b) observed that when tropical foliage was included at 300 g/kg DM diet, protein digestibility was higher (0.49) in sows than (0.12 to 0.36) in 18 to 35 kg pigs for which the digestibility of the diet decreased sharply when the rate of incorporation of leaves increased from 0 to 200 g/kg diet (Leterme *et al.*, 2005; Leterme *et al.*, 2009). Therefore, in farming systems in the tropics relying partly on forage to feed pigs, this feed resource should be preferentially fed to gestating sows.

2. Differences in pig breeds in the ability to thrive on forage-based diets

Besides live weight as discussed above, the breed can also strongly influence the potential of animals to thrive on forage and fibre rich diets. Nevertheless, whether indigenous tropical breeds have a superior ability than genetically improved breeds remains controversial according to which parameter is taken into account: (1) the ability to consume large amount of forage, (2) the ability to digest fibre more extensively, or (3) the feed conversion potential when eating high levels of dietary fibre. Indeed, the negative impact of forage inclusion on performances is usually lower in local breeds with lower requirements as compared to exotic breed with high requirements but also high growth potential. The results of a literature overview on the comparison of indigenous and improved breeds regarding TTAD and dry matter intake when fed on fibre-rich diets are displayed in Table 5. When Zimbabwean Mukota (Ndindana *et al.*, 2002) and Vietnamese Mong Cai (Ngoc *et al.*, 2013) were compared with Large White pigs, those breeds showed no difference in intake levels when fed a high fibre diet. However, in other studies, Mong Cai consumed more (70 *vs* 60 and 85 *vs* 78 g/kg metabolic body weight) than improved pigs (Landrace x Yorkshire) (Len *et al.*, 2009a and 2009b). This ability is important as low energy density of forage requires a compensation by an increase in intake to maintain energy intake in line with the requirement levels.

Regarding digestibility, Mong Cai (Len *et al.*, 2009b) and Mukota pigs (Ndindana *et al.*, 2002) showed higher (0.63 *vs* 0.57 and 0.87 *vs* 0.83 respectively) TTAD than improved pigs. Other studies showed similar trends (Len *et al.*, 2009b, Ngoc *et al.*, 2013). Khieu *et al.* (2005) with Mong Cai found a higher digestibility by local breeds but only for the fibre fraction of the feed. Genetic selection of indigenous pig also seems to allow improving fibre digestibility. When Macías *et al.* (2008) compared native Cuban Creole pigs to 12 years improved Cuban Creole pigs, the latter showed an increase of ileal fibre digestibility from 12 to 16%. Although quite intriguing, the authors provided no insight on the reasons why this influence of selection was specifically observed with fibre. These first observations therefore deserve further research. The differences in digestibilty between indigenous and improved breeds are however more frequent regarding TTAD than ileal digestibilty (Table 5). Researches on the effects of genotype on digestibility have been mostly carried out during a single stage of growth, either on growing or finishing pigs. This can partially explain the lack of consistency between some studies reported in Table 5. Barea *et al.* (2011) found two different trends in digestibility during growth and fattening periods when comparing Iberian and Landrace × Large White pigs. While digestibility of OM and energy seems not to differ between breeds during the growing period, they were higher for Iberian pigs than Landrace during the finishing period. This difference in response to breed effect with weight possibly originates from differences in digestive tract development between Iberian and Landrace × Large White pigs. In Barea *et al.* (2011) study, Iberian pigs had a lighter and shorter small intestine per kg BW whatever their age. However, the size to the stomach was significantly increased between 30 and 80 kg and turned to be higher in Iberian pigs when the animals weighed 80 kg. Therefore, one can assume that the higher digestive tract development in 80 kg-Iberian pigs as opposed to 80 kg-Landrace × Large White pigs induces differences that are not observed with younger animals. These observations on Iberian pigs could apply to tropical pig breeds, especially those from Latin America. The high fibre digestibility of native breeds is also explained by a better adaptation to the high-fibre content ascribable to high digestive enzyme activity and better adaptation of hindgut microbiota to degrade cell wall constituents of the diet (Freire *et al.*, 1998 and 2003), greater size of gastrointestinal tract and longer retention time (Ngoc *et al.*, 2013). The ability of indigenous pigs to digest fibrous fractions is more pronounced in high fibre diets (Len *et al.*, 2009b) which take place in hindgut because ileal digestibility of high fibre diet are usually similar between breeds in the same trial.

Finally, tropical breeds have a lower ADG and a poorer feed conversion potential (1.86 *vs* 1.50 [Len *et al.*, 2009a], 2.27 *vs* 2.05 [Ngoc *et al*., 2013] and 4.6 *vs* 2.9 [Kaensombath and Lindberg, 2013]) than improved ones even on high fibre diets. As reviewed by Ly (2008) for Cuban and other creole breeds, indigenous pigs have lower N retention per N intake (e.g 0.28 *vs* 0.44 [Khieu *et al.*, 2005], 0.55 *vs* 0.58 [Ly, 2008]), because of their lower growth rate inducing low protein-to-energy requirements in their diets as opposed to improved breeds (Barea *et al.*, 2007). The ADG difference is even greater when the protein content of the diet is higher than the protein requirements of the indigenous breeds (Barea *et al.*, 2011). This can be explained by the low selection of indigenous pigs for high growth rate and lean tissues deposition, or either their natural high fat tissue deposition which is more energy demanding that lean tissue (Renaudeau *et al.*, 2006; Barea *et al.*, 2011). Generally when indigenous pigs are compared to improved breeds, the dietary crude protein of trial diets is fixed to meet the requirements of improved breeds.

Nevertheless, trials comparing valorisation by tropical and improved breeds of forage actually used by farmers under field conditions are scarce (Lopez-Bote, 1998) and it is likely that raised under small-holder conditions, improved breeds will probably not show such a better performance than indigenous pigs.

3. Growth performances on forage-based diets

Despite the fact that inclusion of forage reduces digestibility and some inconsistency on the ability of indigenous pigs to digest fibrous feed ingredients, recent studies have shown that a significant proportion of conventional protein concentrates can be replaced by protein-rich forage without affecting neither growth performances nor carcass quality. Fed during about 100 days with a diet in which soybean meal was substituted on protein basis up to 0.50 with either ensiled *Stylosanthes guianensis* or *Colocasia esculenta*, growth performance and carcass traits of local and improved pigs were comparable to the control diet (Kaensombath and Lindberg, 2013, Kaensombath *et al.*, 2013). Similar results were found when fattening pigs were fed a diet containing 0.30 of *Vigna unguiculata* (Sarria *et al.*, 2010). Furthermore, Kaensombath *et al.* (2013) reported that when *Stylosanthes guianensis* silage was used, growth performance was two to three times higher than the same local breeds fed diets based on locally available agricultural by-products and green plant materials. For this reason, it is essential to select suitable preservation method and forage species with high nutritive value to adequately balance the diet for the breed that is used. Therefore, grasses showing low intake (Sarria *et al.*, 2012) and lower digestibility compared to other plant groups should be avoided even for local breeds (Dung *et al.*, 2006).

4. Inclusion levels

Inclusion rate is of utter importance when supplementing pigs with forage ingredients because of (1) the presence of PSM, (2) their specific AA profile, (3) and their impact on nutrients digestibility of the basal diet which can be linear or quadratic. For example, the inclusion of *Stylosanthes* at 0.21 improved the ADG (312 g/d *vs* 205 g/d) for the non-supplemented diet while an inclusion level of 0.37 decreased the ADG to 190 g/d (Phengsavanh and Lindberg, 2013). When pig diets were supplemented with *Acacia karroo,* *Colophospermum mopane* and *Acacia nilotica* at 100, 200 and 300 g/kg, the increased intake was striking for pigs fed *Acacia karroo* diet, especially at 100 and 200 g/kg (1.6 and 1.7 kg/day *vs* 1.2 kg and 1.4 kg for the two other species) and animals performed better for both inclusion rates with an ADG of 855 g and 820 g *vs* 716 g and 668 g for *Colophospermum mopane* and 604 g and 586 g for *Acacia nilotica* due to phenolic constituents. As a consequence, Halimani *et al.* (2005) recommend limiting inclusion level of these legumes to 100 g/kg DM. Leterme *et al.* (2009) advise no more than 150 g/kg DM of aquatic fens in fattening pigs owing to their bulking capacity.

The composition in AA will also influence the optimal inclusion ratio of plants in diets. Hang (1998) fixed the acceptable incorporation limit of ensiled cassava leaves to 0.20 in a diet containing fish meal, which is rich in methionine, resulting in a well-balanced AA profile. In comparison, Phuc *et al.* (1996) established an optimal incorporation level of cassava leaves at 0.15 in a diet containing soybean meal proteins, which are low in methionine but rich in lysine like cassava leaves. This means that combined with a methionine-rich source, inclusion rate of cassava could be revised upwards. Indeed, supplementing *Manihot esculenta* leaves with 0.2 % methionine, a sulphur-containing amino acid essential among others in the detoxication pathway of HCN, as mentioned previously, increased ADG of indigenous pigs from 540 to 712 g (Ly et al., 2012; Hang et al., 2009). Daily weight gains were increased from 482 g to 536 g when lysine was added to a diet containing Ipomoea batatas leaves (An et al., 2005).

Moreover, as stated before, PSM in forage can impose stricter limits to the inclusion levels than would the contents in fibre and other nutrients, owing to their antinutritive effects or toxicity. Finally, from a more practical perspective, the optimal inclusion rate varies also according to the time of distribution and if it is mixed or not with the basal diet. Dung *et al.* (2006) observed that forage is more consumed when it is offered before a basal diet than after (150 to 330 g per day *vs* 30 to 150 g/day).

Table 5. Comparison of digestibility and forage-based diets DM intake (DMI, g/kg$^{0.75}$) between tropical and improved breeds

Breeds	*DM*	*OM*	*Energy*	*Protein*	*NDF*	*ADF*	*DMI*	*Ref*
Mukota	*0.63**	*nd*[4]	*0.67*[a]	*0.72*[a]	*0.36*[a]	*0.28*[a]	*nd*	*1*
Large White	*0.57**	*nd*	*0.51*[b]	*0.55*[b]	*0.31*[b]	*0.21*[b]	*nd*	
Mong Cai	*nd*	*0.82*[a]	*0.81*[a]	*0.83*[a]	*0.64*[a 5]	*nd*	*116*[5]	*2*
Landrace x Yorkshire	*nd*	*0.81*[b]	*0.78*[b]	*0.79*[b]	*0.61*[b 5]	*nd*	*82*[5]	
Mong Cai	*nd*	*0.83*[a]	*0.80*[a]	*0.80*[a]	*0.52*[a]	*nd*	*70*[a]	*3*
Landrace x Yorkshire	*nd*	*0.80*[b]	*0.77*[b]	*0.78*[b]	*0.46*[b]	*nd*	*60*[b]	
Mong Cai	*nd*	*0.87*[a]	*nd*	*0.83*[a]	*0.55*[a]	*0.43*[a]	*85*[a]	*4*
Landrace x Yorkshire	*nd*	*0.83*[b]	*nd*	*0.80*[b]	*0.51*[b]	*0.41*[b]	*78*[b]	
Mong Cai	*0.81*	*0.82*	*nd*	*0.58*	*0.76*	*0.55*[a]	*34*[4]	*5*
Landrace x Yorkshire	*0.81*	*0.82*	*nd*	*0.60*	*0.71*	*0.43*[b]	*33*[4]	
Rustic Cuban Creole	*0.79*	*0.78*	*nd*	*0.75*	*0.12*[b 8]	*nd*	*nd*	*6*
Improved Cuban Creole	*0.77*	*0.76*	*nd*	*0.75*	*0.16*[a 8]	*nd*	*nd*	

[1] Ref, references: (1) Ndindana *et al.* (2002); (2) Ngoc *et al.* (2013) ; (3) Len *et al.* (2009a) ; (4) Len *et al.* (2009b); (5) Khieu *et al.* (2005); (6) Macías *et al.* (2008)
[2] Value with different superscripts for same referenced manuscript within column are significantly different between pair of breeds on the parameter in the considered study ($P<0.05$).
[3] dry matter intake is expressed in g/kg body weight instead of g/kg$^{0.75}$
[4] nd, not determined
[5] Fibre is expressed as total non-starch polysaccharides instead of NDF
[6] Author value was expressed in daily feed intake (g/day) without considering weight of pigs which was different
[7] Fibre is expressed as total dietary fibre instead of NDF
[8] Fibre is expressed as total crude fibre instead of NDF

5. Implications on the farming system of using forage in the diets of pigs

As shown previously in this review, including forage in well-balanced grain-based diets reduces growth performances of pigs, but, under particular conditions, this detrimental impact is lower for indigenous breeds than high performance European or American breeds. However, for regions where the access to balanced diets is difficult for economical or accessibility reasons, forage can improve the quality of the diet, especially by supplying proteins. For example, forage such as *Stylosanthes guianensis* or *Aeschynomene histrix* were shown to improve growth performances (ADG of 394 and 396 g, respectively) of animals fed traditional poorly balanced diets (ADG of 205 g), especially regarding protein total content and amino acid profiles (Phengsavanh and Lindberg, 2013). Nonetheless, it is not possible to definitely conclude on the actual positive outcomes of this practice without a proper socio-economic and environmental assessment of the consequences of using forage on the whole production system. Few studies report the actual feeding costs of forage-based diets as opposed to commercial concentrate diets, probably because of the difficulty to calculate opportunity costs of cultivating, collecting and handling forage against concentrate feeds. Heat treatment such as cooking mixed forage with agriculture byproduct as practiced by many pig smallholders in South-East Asia (Chittavong *et al.*, 2012) efficiently reduces the content of heat-labile antinutritive factors and increases feed conversion. But little is known on how effective this practice is from an environmental and economic perspective. In another example, the inclusion of *Azolla pinnata* as a protein replacer in the concentrate feed at 0, 10 and 20%, respectively in grower and finisher diets reduced significantly the diet cost per kg weight gain by 8% for the 10% forage inclusion level (Cherryl *et al.*, 2013). The same trend was found when *Morus alba was* included at 25, 30 and 35% in commercial pig diets. The feeding cost was reduced by 28% for the 30% inclusion rate (Ordóñez, 2010). In contrast, Keansombath and Lindberg (2013) report similar prices per kg weight gain for concentrate and ensiled forage-based diets, but, as in most studies, the opportunity cost of forage cultivation and silage making on the farm is poorly documented. Preservation seems indeed very important to solve the problems of seasonality of feed availability, but they require knowledge, investment and time especially in low input smallholder conditions. Silage seems to be ideal during the rainy season when sun-drying becomes difficult to perform.

Moreover, the cost of concentrates strongly varies in a same country or district according to the very location of the farms, especially when distance to feed mills increases. As such, the use of forage might be less interesting in periurban areas than on remote countryside farms. Cultivating forage or using forage by-products of other crops to feed pigs on mixed farms associating pig production to crops have several implications on the use of land, labour and nutrients cycles at the farm level that impact the sustainability of the farm as a whole. Some green plant materials used in pig diets are crop by-products that would be merely left on the fields if they had not be used in the animals' diets. For example, the yield of *Manihot esculenta* leaves as by-products of cassava root can reach 4.6 tonnes of DM/ha with an average content in protein of 21 % DM (Ravindran and Ravindran, 1988). As a defoliation 6 months after planting does not decrease tuber yield (Fasae *et al.* 2009), feeding cassava leaves to pigs would increase the total amount of product harvested from a field. Legumes used as dual purpose crops such as cowpea (*Vigna unguiculata*) or cover crops such as *Stylosanthes* *guianensis* to fight erosion decrease the need for N-fertilizer (Husson *et al.*, 2008) and increase the OM content of the soils while they can at the same time produce high amounts of protein-rich forage valuable to a certain extent as feed ingredients for pigs without affecting their beneficial effects on soil fertility. When pigs are fed forage, harvesting shares the highest cost under hand-labour. Mechanization still requires developments because of the diversity of physiognomy between forage species: trees, shrubs or vines. One alternative could be keeping grazing pigs outdoors to let them harvest the forage for themselves on the fields as studied in tropical conditions in Guadeloupe (Burel et al., 2013). However, this method is challenging in areas where cisticercosis is still a major issue and where African swine fever is endemic. Moreover, some forage species are not accessible to grazing pigs: trees, shrubs or climbing vines and other plants such as *Stylosanthes guianensis* or *Psophocarpus scandens* would be destroyed by grazing pigs, impeding several harvests per year.

In order to properly address these questions it is essential to conduct life cycle multi-criteria assessments at farm level to compare social, economic and environmental performances of pigs fed partially with forage as opposed to concentrate-fed animals. Such studies exist for production systems in developed countries (Alig *et al.*, 2012) but unfortunately they are still too scarce in developing countries.

7. Conclusion

Forage is an interesting source of proteins, especially for smallholder pig feeding systems in tropical areas since protein concentrates are either seldom available or expensive and inaccessible to most farmers. However, using forage for pigs is not obvious as forage plants have numerous disadvantages mainly related to high fibre and low energy contents and the presence of PSM. Their inappropriate use results in nutritionally unbalanced diets and leads to poor pig performance, both for indigenous and improved breeds. However, this review showed that including some forage species in the right proportion in the diet allows to improve the poor nutritional quality of traditional pig diets by increasing the crude protein and mineral intake and possibly maintaining the feeding cost at a low level. However, proper assessment of the social, economical and environmental consequences of feeding pigs with forage is required at the farm level to support claims for improved sustainability thanks to this practice as opposed to concentrate-fed pigs.

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CHAPTER II

As seen before, forage is widely used in the tropics to feed pigs with varying efficiency. Since little nformation is available regarding pig production in the Western part of the DRC in order to build on this information to improve the feeding systems, we started our field works by characterizing the pig production systems used by smallholders in periurban and rural areas of Kinshasa and the Bas-Congo province, respectively. The results of this investigation is presented in Chapter 2. More specifically, this work focuses on feed resources and feeding management, breeding system, productivity and sanitary issues and analyses if the resources or constraints driving those systems differ according to periurban-rural gradient. It appears from this chapter that there are no general differences between the four rural and the four periurban sites. Moreover pig production system depends on the local environment as strong differences were observed between rural sites, particularly in terms of workforces, herd structure and characteristics, production parameters, pig building materials, selling price and especially in feed resources. Farmers used several alternative feed ingredients to fed pigs such as agro-industrial by-products as long as the industry was not located too far away and the cost of transportation could be coped with thanks to high pig selling prices. However, whatever the types of diet fed to the pigs, farmers supplement with some forage. Thus, an improvement in pig diets quality requires further research on the nutritional value of different feed resources, especially forage species which seem to be the available potential source of protein that pig smallholders can afford. About forty-three plant species were mentioned during the survey among which 33 could be formally identified. The choice of forage species is a key issue to ensure their rational use to feed pigs. The use of forage plants without knowing their nutritive value can lead to unbalanced diets, low pigs growth and reproduction performances, and low incomes for the farmers. Therefore, it is necessery be useful to assess their nutritive value.

Article 2:
Smallholder pig production systems along a periurban-rural gradient in the Western provinces of the Democratic Republic of the Congo.

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Bienvenu Kambashi[1,2], Pascale Picron[2], Christelle Boudry[2], André Théwis[2], Honoré Kiatoko[1], Jérôme Bindelle[2,3]

[1]*University of Kinshasa, Department of Animal Science, Mont-Amba, Lemba, Kinshasa, Democratic Republic of the Congo*

[2]*University of Liège, Gembloux Agro-Bio Tech, Animal Science Unit, Passage des Déportés, 2, 5030 Gembloux, Belgium*

[3]*To whom correspondence should be addressed: jerome.bindelle@ulg.ac.be, phone: +3281622609 fax: +3281622115*

1. Abstract

In the Democratic Republic of the Congo (DRC), pigs are raised almost exclusively by smallholders either in periurban areas of major cities such as Kinshasa or in rural villages. Unfortunately, little information is available regarding pig production in the Western part of the DRC, wherefore a survey was carried out to characterize and compare 319 pig production systems in their management and feeding strategies, along a periurban - rural gradient in Western provinces of the DRC. Pig breeding was the main source of income (43 %) and half of respondent were active in mixed pig and crop production, mainly vegetable garden. Depending on the location, smallholders owned on average 18 pigs, including four sows. Piglet mortality rate varied from 9.5 to 21.8% while average weaned age ranged between 2.2 and 2.8 months. The major causes of mortality reported by the farmers were African swine fever 98%, Swine erysipelas (60%), erysipelas trypanosomiasis (31 %), Swine worm infection (17 %), and diarrhoea (12 %). The majority of the pigs were reared in pens without free roaming and fed essentially with locally available by-products and forage plants whose nature varied according to the location of the farm. The pig production systems depended on the local environment; particularly in terms of workforces, herd structure and characteristics, production parameters, pig building materials, selling price and in feed resources. It can be concluded that an improvement of Congolese pig production systems should consider (1) a reduction of inbreeding, (2) an improvement in biosafety to reduce the incidence of African swine fever and the spread of other diseases, and (3) an improvement in feeding practices.

Keywords: Pig rearing; Smallholder farming; Feeding strategies; Health

2. Introduction

Raising pigs plays an important role in many tropical countries. Smallholder farming systems improve livelihood and food security for the poorest people (Dixon et al., 2001; Keoboualapheth and Mikled, 2003; Kumaresan *et al.*, 2007). In addition to providing protein for human consumption, pigs are often one of the main sources of cash income in rural areas and provide manure for cropping (Le Van *et al.*, 2004).

In the Democratic Republic of the Congo (DRC), pigs are raised almost exclusively by smallholders either in periurban areas of major cities such as Kinshasa or in rural villages. Industrial pig production is barely developed (CAVTK, 2003). According to different reports it appears that there are an increasing number of small and medium size semi-intensive pig-keeping enterprises at the expense of intensive pig farms in and around towns and cities (CAVTK, 2003; NEPAD & FAO, 2006). This situation is probably related to the political situation. The lack of employment caused by the wars of 1996-1998, the steady insecurity in the eastern part of the country, the injustice in the distribution of national wealth, etc. have encouraged the practice of informal activities including pig breeding. This informal economy in general, and pig production in particular promotes greater self-sufficiency, provides a greater food security to urban households (Mougeot, 2000) and increases incomes. Nonetheless, pig farms are under the influence of variables laying constraints or offering opportunities that vary according to the location of the farm. This is likely to yield variability in the production systems that will possibly reflect in differing needs regarding development programs. For instance, periurban sites in Kinshasa have an easier access to profitable markets, commercial concentrates and agro-industrial by-products while rural producers do not have all of these three aforementioned advantages. However, pig farmer in rural sites have the opportunity to obtain agricultural products such as cassava and maize at an affordable price. The absence of profitable market is due to people's poverty, suitable means of transformation and the high costs of product transportation to Kinshasa and its approximately eight millions of potential customers. Taking actions in order to make the pig rearing activity more efficient and sustainable requires the availability of data on its management in order to address the major constraints laid on pig smallholders. Unfortunately, little information is available regarding pig production in the Western part of the DRC, wherefore this study aims at characterizing and comparing smallholder pig production systems along a periurban - rural gradient of the Kinshasa and the Bas-Congo province. More specifically, this work focuses on feed resources, feeding management, breeding system, productivity and sanitary issues of pig production systems by considering differences in resources and constraints on local scale.

3. Materials and methods

A survey was conducted in four periurban municipalities of Kinshasa and in four rural areas in the Bas-Congo Province. The four periurban municipalities were N'djili (N'djili), Kimbanseke (Kimba), Mont-Ngafula (Mont), and N'sele (N'sele) (4° 19′ 19″ S 15° 19′ 16″ E). N'djili and Kimbanseke are located to the southeast of Kinshasa, N'sele to the east and Mont-Ngafula to southwest. These four municipalities cover an area of 11.4, 273.8, 358.9 and 273.8 km², with 29123, 2495, 630 and 176 inhabitant per km² respectively for N'djili, Kimbanseke, Mont-Ngafula and N'sele. Except for N'djili, the other three sites are considered as periurban municipalities characterized by intense agriculture and husbandry and related activities including firewood exploitation and harvest of caterpillars, nuts, exotic fruits, mushrooms, raffia and palm wine, ferns and others (Biloso Moyene, 2008). N'djili is located more in the middle of the city. However, the presence of an agricultural perimeter with lower population density along the N'djili river favoured the installation of numerous small pig farms. The four rural areas that were surveyed in the Bas-Congo Province are Kasangulu (Kasang : 4° 43 '24" S, 15 ° 17' 23" E), Kisantu (Kisan: 5° 7' 25" S, 15° 5' 46" E), Mbanza-Ngungu (Mbanza: 5° 20' 23" S, 14° 50' 14" E) and Boma (Boma: 5 ° 46 '40"S, 13 ° 6' 32"E). All eight sites were selected because they are known for having a high density of pig farms. They have almost the same climate, characterised by a rainy season of eight months from mid-September to mid-May with a drop in rainfall between December and February and a dry season of four months extending from mid-May to mid-September. The average annual temperature is 25 °C and the relative humidity is 79% (Department of Land Affairs, Environment, Nature Conservation, Fisheries and Forestry, 1999).

1. Survey organisation

The present study involved surveys and direct on site observations from July 13 to September 13 2010. Only smallholders showing over 1.5 years of experience in pig production were considered. A total of 319 farmers were interviewed, 40 smallholders in each site except Kasangulu where only 39 farmers were interviewed. Smallholders were randomly selected on the basis of a list obtained either from farmers associations or local authorities. Lists from different sources were merged per surveyed site and farmers were continuously numbered. Numbers were randomly drawn until the sample size was reached.

Four agricultural engineers were trained for the survey before going on field. They were trained to use spring scales. The questionnaire had previously been tested by surveyors in farms located in the valley of the Funa (Kinshasa). The results of this pre-survey are not included in this paper. The questionnaire was administered in a single pass. The technique of data collection consisted of questions followed by a discussion when needed for clarity in relation to breed, names of plants and their use and the common causes of death. The questionnaire had six main sections including the characterisation of the farm organisation and household, breeding management and productivity parameters, feed resources and feeding strategies, housing conditions, health issues and marketing. Where farmers had their own records of pigs' weight, those data were used in this study. If not, when animals of both categories considered for weight data (around weaning and around first mating) were present on the farm at least three animals for each category were weighed by the farmer with spring scales provided by the surveyors to serve as reference to estimate the weight of the others pigs. The weight of an animal was accepted only when surveyors and farmer's estimations agreed. If not, that animal was also weighed. Questions regarding feeding systems were open questions in order to allow the farmer to give enough details about his system.

2. Survey statistical analysis

Chi-squared analyses were used to test the independence of variable between survey sites using SPSS. The MIXED procedure of SAS was performed to compare means of quantitative data between sites. Correspondence analysis of SAS was used to study the reconciliation between the sites location and the ingredients fed to the pigs.

4. Results

1. Family structure and organization people

The nucleus family was composed of 5.9 to 7.5 people on average (Table 6). Pig breeding was either a male (47%) or a family-run business (42 %). Few pig farms were under the supervision of women (11 %). No effect of the location was found in terms of family composition (P>0.05). However, workforces, mains sources of income and children's participation in the activity were dependent on the location (P<0.001). In Kisantu and Kasangulu the caretaking of pigs was performed almost exclusively by men who were the head of the households, while in Mbanza-Ngunu the whole family was involved in this activity. Family members were the major contributors to the farm workforce, while hired workers were on average present in 35 % of the farms.

Table 6. Family structure and farm organization of smallholder pig production systems in the Western provinces of the Democratic Republic of the Congo (% of households) (n=40 per site).

	Kinshasa				*Bas-Congo*				*Mean percentage*
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*	
Family size (χ^2,P=0.069)[1]									
Lowest through 5	*26*	*24*	*50*	*29*	*23*	*16*	*41*	*35*	*31*
6 to10	*64*	*71*	*47*	*66*	*73*	*76*	*42*	*60*	*62*
More than 10	*10*	*5*	*3*	*5*	*5*	*8*	*17*	*5*	*7*
Average size of households	*7.3*	*6.8*	*5.9*	*6.5*	*6.8*	*7.5*	*6.7*	*6.1*	
Workforces (χ^2, P=0.001)									
Family	*58*	*62*	*49*	*58*	*100*	*61*	*43*	*85*	*65*
Hired workers	*42*	*38*	*51*	*42*	*0*	*39*	*57*	*15*	*35*
Rearing and feeding (χ^2,P<0.001)									
Men	*40*	*26*	*51*	*68*	*17*	*3*	*80*	*90*	*47*
Women	*12*	*6*	*5*	*11*	*30*	*8*	*7*	*5*	*11*
All Familly	*46*	*68*	*44*	*21*	*53*	*89*	*13*	*5*	*42*

[1]P: Chi-square tests, probability between sites

2. Level of specialisation

The level of specialisation of smallholders varied (P<0.001) according to location and province. Among them, some combined cropping and pig production, others were merely breeders while the majority had formal or informal activities in addition to agriculture (Table 7). Nevertheless, pig breeding was the main source of income of most farmers, followed by cropping and other off-farm activities such as a formal job (Table 2). The types of agricultural crop were mostly vegetable crops and cassava (7 %), except in Boma (P<0.001) Farmers (21 %) also owned other animal species, mainly indigenous chicken (32 %), ducks (28 %), goats (14 %) and sheep (8 %). Farms were often located near water points (stream and pond).

Table 7. Farmer speciality and main source of income of smallholder pig production systems in the Democratic Republic of Congo (% of households) (n=40 per site).

	Kinshasa				*Bas-Congo*			
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
Specialty (χ^2,P<0.001)[1]								
Pig production	*17.5*	*2.6*	*10.3*	*20.5*	*2.6*	*7.3*	*13.8*	*5.1*
Pig production and cropping	*20.0*	*53.8*	*51.3*	*9.1*	*10.3*	*14.6*	*10.3*	*23.1*
Pig production, cropping and other activities	*62.5*	*43.6*	*38.4*	*70.4*	*87.1*	*78.1*	*75.9*	*71.8*
Main source of income (χ^2,P=0.042)								
Pig production	*39.6*	*45.2*	*44.1*	*47.7*	*48.1*	*47.7*	*38.8*	*31.2*
Cropping	*20.9*	*36.9*	*35.5*	*26.1*	*8.6*	*12.8*	*16.5*	*28.6*
Salary, petty trade and donation	*39.5*	*17.9*	*20.4*	*26.2*	*43.3*	*39.5*	*44.7*	*40.2*
Agricultural crops (χ^2,P<0.001)								
Vegetables	*88.0*	*96.7*	*100*	*95.5*	*33.3*	*100*	*82.4*	*59.5*
Food crops	*12.0*	*3.3*	*0*	*4.5*	*66.7*	*0*	*17.6*	*40.5*

[1]P: Chi-square tests, probability between sites

3. Herd structure and characteristics

The average number of pigs per farm was 17.9±0.9 for the 319 farms and varied from 12.4 in Boma to 25.4 in Kasangulu (Table 8). The average number of sows, litter size and weaned piglets was different between sites and varied from 2.6 to 4.6, 7.4 to 9.7 and 6.7 to 8.5, respectively. Pre-weaning mortality rates varied from 9.5 to 21.8 % between sites. The age of the piglets at weaning ranged between 2.2 and 2.8 months according to the site. Globally, piglets were weaned on an average age of 2.5 months but between 1.5 and 2 months in 70 % of the cases. At that stage, piglet's weight ranges about 7.9 and 11.7 kg. However, when post-weaning feed was lacking, the breeder may keep piglets suckling for up to 4 months. First mating occurred when the gilt was about 7.3 to 8.9 months old but male first mating depended more on its weight rather than its age., Although this parameter was not constant across the different locations that were surveyed, reform of sows was practiced early. Indeed, on average,, 76% of the farmers reformed sows not later than after the third parturition. Boars were not kept for a long time either as they were sold before they reached the age of 3 years of use in 71.0 % of the farms (Table 9).

Table 8. Reproductive performance, birth and weaning litter size of 319 smallholder pig production systems in the Western provinces of the Democratic Republic of the Congo (% of households) (n=40 per site).

	Kinshasa				*Bas-Congo*							*P values of sites effect*
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*				
	Mean								*Min*	*Max*	*S.E.M*	
Number of pigs per farm	*14,5*[a1]	*14,7*[a]	*22,2*[bc]	*18,5*[ab]	*12,4*[a]	*23,2*[bc]	*25,4*[c]	*12,7*[a]	*2,0*	*102,0*	*0,86*	*<.001*
Number of sows per farm	*3,1*[a]	*3,9*[a]	*4,5*[b]	*4,0*[ab]	*4,0*[ab]	*4,6*[b]	*5,3*[b]	*2,6*[a]	*1*	*25*	*0,18*	*<.05*
Number of boars per farm	*0,5*[a]	*0,7*[a]	*0,9*[ab]	*0,7*[a]	*1,1*[b]	*0,7*[a]	*1,2*[b]	*0,6*[a]	*0*	*4*	*0,04*	*<.001*
Gilt weight at first mating (kg)	*50,3*[b]	*52,9*[bc]	*50,7*[b]	*52,1*[bc]	*43,6*[a]	*43,1*[a]	*56.2*[c]	*45,8*	*35*	*90*	*0,54*	*<.001*
Gilt age at first mating (month)	*7,3*[a]	*8,2*[ab]	*8,1*[a]	*8,7*[b]	*7,8*[a]	*8,5*[b]	*7,3*[a]	*8,9*[b]	*5*	*12*	*0.09*	*<.001*
Boar weight at first mating (kg)	*55,4*	*57,2*	*55,0*	*53,8*	*53,9*	*57,0*	*57,6*	*53,5*	*40*	*90*	*0.72*	*0.083*
Boar age at first mating (month)	*8,4*[ab]	*8,8*[b]	*9,1*[b]	*8,9*[b]	*8,8*[b]	*11,1*[c]	*7,5*[a]	*9,7*	*6*	*18*	*0,14*	*<.001*
Piglets born alive per litter	*8,0*[ab]	*8,7*[b]	*8,6*[b]	*8,7*[b]	*7,4*[a]	*9,6*[c]	*9,7*[c]	*7,6*[a]	*4*	*12*	*0,11*	*<.001*
Piglets weaned per litter	*7,0*[a]	*7,4*[a]	*7,7*[ab]	*6,8*[a]	*6,7*[a]	*8,0*[b]	*8,5*[b]	*6,7*[a]	*3*	*12*	*0,11*	*<.001*
Age at weaning (month)	*2,3*[a]	*2,2*[a]	*2,2*[a]	*2,2*[a]	*2,8*[b]	*2,3*[a]	*2,2*[a]	*2,4*[a]	*2*	*4*	*0,03*	*<.001*
Weight at weaning (kg)	*8,6*[b]	*7,9*[a]	*8,6*[b]	*9,2*[c]	*8,0*[a]	*9,9*[c]	*11,7*[d]	*8,1*[ab]	*4*	*15*	*0,15*	*<.001*

[1]In a row, means followed by a different letter differ at a significance level of 0.05

4. Breeds

It was difficult to identify the actual proportions of the different breeds of pigs found in the study area. According to the statements of the breeders, it would be Large White, Piétrain, local pork (large black), Landrace and hybrids resulting from local breeds crossed with exotic breeds. However, some animals considered as Large White or Piétrain did not show all the phenotypical characteristics of these breeds while others had offsprings with highly diversified phenotypical characteristics (dress color, shape of the ears and the profile of the back of the animal). The most prevalent dress colors were white, spotted black and black.

Table 9. Phenotypical characteristics of pigs of 319 smallholder pig production systems in the Democratic Republic of Congo (% of response).

	Kinshasa				*Bas-Congo*			
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
Dress color (χ^2,P<0.0001)[1]								
White	*62.9*	*57.6*	*58.7*	*57.8*	*84.4*	*65.6*	*50.9*	*61.6*
Black	*6.5*	*17.0*	*17.5*	*9.4*	*0.0*	*32.8*	*12.3*	*14.0*
Spotted black	*30.6*	*25.4*	*23.8*	*32.8*	*15.6*	*1.6*	*36.8*	*24.5*

[1]P: Chi-square tests, probability between sites

5. Reproductive management

Breeding systems were very similar among smallholders. They can be assimilated to a "breeder-fattener" structure. Farmers bred sows and their piglets until the fattening pigs reached the expected slaughter weight. However, they sometimes sold weaned piglets. Sometimes sows and boars were never really reformed but sold before they reached the end of their reproductive career (Table 10). The number of farmers who own at least one boar varied from one location to the other (P<0.001). Nsele displayed to lowest rate of boar presence with 37% while Boma the highest (88%). In the other locations, boars were present, in 62, 65, 57, 56, 74 and 59 % of the farms, for N'djili, Kimbanseke, Mont-Ngafula, Mbanza-Ngungu, Kasangulu and Kisantu, respectively The other farmers borrow boars to avoid maintenance costs. Mating is then either paid in cash or by giving a female piglet at weaning. Some farmers do not charge friends or relatives for mating with their boar.

Table 10. Reform of sows (number of parturition) and boars (number of years use) (% of households) (n=40 per site).

	Kinshasa				Bas-Congo			
	N'sele	N'djili	Kimba	Mont	Boma	Mbanza	Kasang	Kisan
Sows (parturition)(χ^2, P<0.001)[1]								
1 to 2	*8,6*	*24,3*	*12,9*	*18,2*	*30*	*50*	*7,4*	*23,1*
3	*68,6*	*59,5*	*54,8*	*51,5*	*57,5*	*47,5*	*44,4*	*56,4*
4	*14,3*	*10,8*	*9,7*	*18,2*	*10*	*0*	*22,2*	*15,4*
5	*8,6*	*5,4*	*22,6*	*12,1*	*2,5*	*2,5*	*25,9*	*5,1*
Boars (years)(χ^2, P<0.001)								
1	*22.7*	*70.8*	*46.2*	*3,6*	*77,5*	*0*	*12,5*	*25,8*
2	*50.0*	*12.5*	*30.8*	*60,7*	*12,5*	*61,5*	*50,0*	*25,8*
3	*18.2*	*12.5*	*7.7*	*25,0*	*2,5*	*38,5*	*25,0*	*29,0*
≥4	*9.1*	*4.2*	*15.4*	*10,7*	*7,5*	*0,0*	*12,5*	*19,4*

[1]P: Chi-square tests, probability between sites

6. Health issues

The main disease constraints mentioned by the farmers, were African swine fever (ASF) (95 %), swine erysipelas, diarrhoea, trypanosomiasis, worm infections (Table 6) and to a lower extent various diseases such as mange, enteritis, cysticercosis, colibacillosis, respiratory disease, coccidiosis, paralysis, pneumonia and smallpox.

Table 11. Main diseases reported by pig smallholders in the Democratic Republic of Congo (% of farmer) (n=40 per site and per disease).

	Kinshasa				Bas-Congo				
	N'sele	N'djili	Kimba	Mont	Boma	Mbanza	Kasang	Kisan	χ^2, P[1]
ASF	*71*	*100*	*100*	*95*	*92*	*100*	*100*	*100*	*<0.001*
Swine erysipelas	*55*	*65*	*73*	*18*	*78*	*95*	*91*	*8*	*<0.001*
Trypanosomiasis	*45*	*23*	*42*	*18*	*41*	*31*	*52*	*0*	*<0.001*
Diarrhoea	*58*	*23*	*37*	*39*	*54*	*49*	*12*	*3*	*<0.001*
Worm infection	*18*	*10*	*15*	*13*	*35*	*33*	*9*	*0*	*<0.001*

[1]P: Chi-square tests, probability between sites

Globally, ASF was the most feared by almost 100% of the pig smallholders. The noted diseases were identified by the farmer or by a veterinarian according to the symptoms, seldom by sample analysis in a laboratory. The majority of farmers (74%) never called a veterinarian and there was no site difference (P=0.099). Except for the Mont-Ngafula site, most of those who did not call a veterinarian, practice self-medicine while the remaining did not take any action because of a lack of financial resources. The use of vaccine depended on the investigated site (Table 7). Some farmers declared to have vaccinated their herd against swine erysipelas (43%). Moreover, some farmers declared that they had vaccinated their animals against ASF (53%) and trypanosomiasis (45%) while to our knowledge no vaccine exists against any of these two diseases.

Table 12. Type of vaccine administered to pigs in the Democratic Republic of Congo (% of response).

	Kinshasa				*Bas-Congo*			
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
(χ^2, P<0.001)[1]								
Trypanosomiasis	*64*	*17*	*60*	*16*	*7*	*21*	*23*	*14*
Swine erysipelas	*8*	*34*	*31*	*24*	*7*	*29*	*38*	*43*
ASF	*20*	*48*	*6*	*16*	*86*	*46*	*39*	*14*
Other	*8*	*0*	*2*	*44*	*0*	*4*	*0*	*29*

[1]P: Chi-square tests, probability between sites

7. Housing system

Permanent housing was practiced among all sites (P=0.31) with very little free-roaming pigs that were found in Kasangulu and Kisantu (Table 8). Four types of materials used to build walls were identified: (i) concrete, (ii) burnt-brick, (iii) mud-brick and (iv) wood and showed significant differences between sites (P<0.001). Durable materials (cement bricks and corrugated galvanized iron) were used in almost all urban sites (Kinshasa) while Mud bricks or wood and straw were used in rural sites (Bas-Congo) (Table 8). All the farmers used almost the same housing management and had separated fattening and maternity pens.

Table 13. Pigsties building material and feeding equipment in the Democratic Republic of Congo (n=40 per site).

	Kinshasa				*Bas-Congo*			
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
Housing (χ^2,P=0.31)[1]								
Permanent	*100*	*100*	*100*	*100*	*100*	*100*	*97*	*95*
Periodic	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*5*
Building material (χ^2,P<0.001)								
Durable	*8*	*90*	*80*	*85*	*38*	*67*	*7*	*15*
Semi-durable	*3*	*5*	*2*	*10*	*56*	*5*	*93*	*85*
Wood and straw	*90*	*5*	*17*	*5*	*5*	*29*	*0*	*0*
Feeding equipment (χ^2,P <0.001)								
Feeders	*69*	*33*	*41*	*61*	*77*	*44*	*17*	*34*
Drinkers	*90*	*95*	*95*	*90*	*80*	*68*	*100*	*94*

[1]P: Chi-square tests, probability between sites

There were site differences in presence of feeders and drinkers in pigsties. Feeders were present in only 47 % of the farms and drinkers in 89 %. Materials used as feeders/drinkers were plastic basin, open plastic containers placed in an open wooden box or in large aluminum pot. Pigs‘drinking water depends on location and came either from tap water, wells, rivers or from springs (Table 9).

Table 14. Origin of drinking water in 319 Congolese pig production systems.

	Kinshasa				*Bas-Congo*			
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
Origin of water (χ^2,P <0.001)[1]								
Tap water	*10*	*24*	*0*	*12*	*82*	*12*	*9*	*89*
Rivers	*51*	*5*	*16*	*26*	*0*	*73*	*31*	*5*
Wells	*18*	*63*	*76*	*26*	*18*	*2*	*3*	*5*
Springs	*21*	*8*	*8*	*37*	*0*	*12*	*57*	*0*

[1]P: Chi-square tests, probability between sites

8. Feeding system

Correspondence analysis revealed that the various ingredients used in pig feed depended on location (Figure 1). Dimension 1 contrasted agro-industrial by-products with cassava. Dimension 2 did not provide enough information because the feed ingredients they tend to contrast are poorly used. The approximation of Boma to urban sites was due the use of palm kernel cakes and brewers grains. Kimbanseke was isolated from the other urban sites due to the high frequency of use of rice and corn bran.

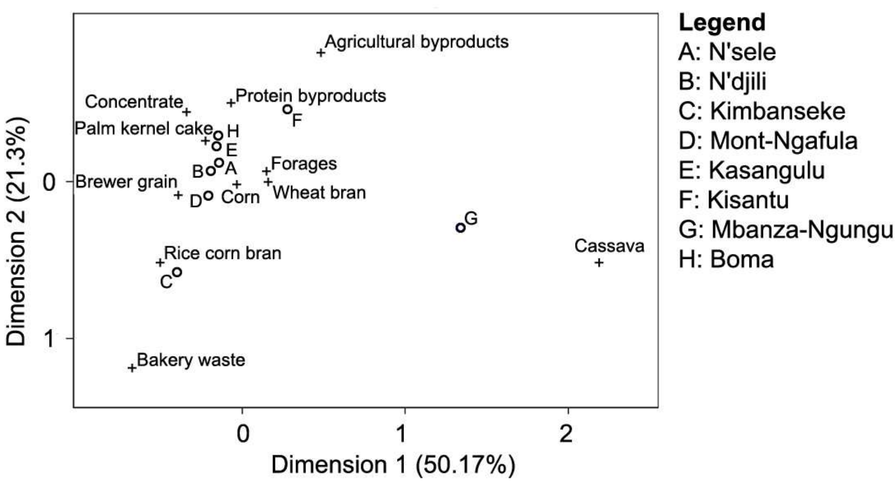

Figure 1 Reconciliation between sites in terms of feed ingredients in Congolese pig production systems

Ingredients used in pig diets varied with the location (Table 10) and only 4% of farmers used commercial concentrate. Forage plants were fed to the pigs by almost all the farmers among all sites, with exception of Mont-Ngafula and Kasangulu where only up to 2/3 of the farmers used forages to fed the animals (P = 0.035).

Table 15. Percentage of response for the use of feed ingredients by pig producing farmers in Congo.

	Kinshasa				*Bas-Congo*				
	N'sele	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*	χ^2, *P*[1]
Wheat bran	*100*	*87*	*85*	*93*	*9*	*88*	*82*	*92*	*<0.001*
Palm kernel cake	*95*	*87*	*75*	*64*	*94*	*10*	*91*	*79*	*<0.001*
Brewers grain	*63*	*82*	*78*	*66*	*57*	*5*	*42*	*5*	*<0.001*
Corn	*54*	*85*	*40*	*27*	*3*	*29*	*36*	*26*	*<0.001*
Rice and corn bran	*29*	*18*	*65*	*39*	*0*	*0*	*21*	*5*	*<0.001*
Cassava	*2*	*0*	*0*	*2*	*3*	*88*	*3*	*13*	*<0.001*
Bakery waste	*2*	*15*	*65*	*16*	*0*	*0*	*0*	*0*	*<0.001*
Protein by-products[2]	*12*	*26*	*0*	*7*	*3*	*2*	*12*	*16*	*<0.001*
Agricultural by-products[3]	*2*	*5*	*0*	*9*	*0*	*5*	*0*	*37*	*<0.001*
Commercial feed	*7*	*0*	*0*	*7*	*0*	*0*	*21*	*0*	*<0.001*
Forage plants	*95*	*95*	*95*	*67,5*	*100*	*100*	*62,5*	*97,5*	*0.035*

[1]P: Chi-square tests, probability between sites

[2]Protein by-products include fish meal and fresh gills, caterpillar meal, and okara.

[3]Agricultural by-product include corn bran, cassava and sweet potato peelings and flour by-products, palm kernels, and wheat bran

Forty-three plant species were mentioned during the survey among which 33 could be formally identified. The most cited were vegetable crop by-products as well as *Manihot esculenta* leaves, *Ipomoea batatas* leaves, *Eichornia crassipes*, *Psophocarpus scandens*, *Pueraria phaseoloides*, *Boerhavia diffusa*, *Musa* spp. leaves and *Carica papaya* leaves (Table 16). The used plant species varied among the study sites.

Table 16. Plant species and plant parts that were used by 319 Congolese farmers to fed pigs (% of response).

		Kinshasa				*Bas-Congo*				*χ^2, P*[2]
	Plant part	*N'sele*	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*	
Manihot esculenta	*Leaves*	*13*	*5*	*8*	*10*	*75*	*90*	*41*	*26*	*<0.001*
Ipomoea batatas	*Aerial parts*	*13*	*30*	*18*	*23*	*15*	*85*	*27*	*16*	*<0.001*
Vegetables[1]	*Leaves and roots*	*5*	*57*	*47*	*20*	*13*	*10*	*41*	*95*	*<0.001*
Eichornia crassipes	*Whole plant*	*56*	*38*	*53*	*13*	*10*	*0*	*5*	*3*	*<0.001*
Psophocarpus scandens	*Aerial parts*	*36*	*32*	*18*	*20*	*55*	*2*	*0*	*3*	*<0.001*
Pueraria phaseoloides	*Aerial parts*	*0*	*0*	*3*	*20*	*3*	*78*	*5*	*21*	*<0.001*
Boerhavia diffusa	*Aerial parts*	*8*	*3*	*11*	*7*	*68*	*0*	*9*	*3*	*<0.001*
Musa spp	*Leaves*	*3*	*11*	*5*	*10*	*35*	*0*	*9*	*13*	*<0.001*
Carica papaya	*Leaves and fruits*	*15*	*8*	*8*	*13*	*20*	*0*	*5*	*13*	*<0.001*

[1]unfit for human consumption or unsold;
[2]P: Chi-square tests, probability between sites for the same plant species

9. Marketing

There was no difference in origin of starting animal stocks between sites. In general, animals were purchased in the neighbourhood from other smallholders (97%) without breeding selection, seldom in industrial pig farms (2.5%) or religious congregations (0.5%). The two latter generally raise improved European pig breeds. Finished pigs were sold alive or slaughtered directly for the end consumers. The average selling price depended on site ($P<0.0001$) and ranged from 2.00±0.2 USD in Boma to 4.12±1.0 USD in Kasangulu per kg live weight and from 3.00±0.1 USD/kg in Boma to 4.96±0.8 USD/kg in Mont-Ngafula for pork (Table 17).

Table 17. Average selling price of live animal and pork on eight study sites in the Democratic Republic of Congo ($ USD/kg).

	Kinshasa				*Bas-Congo*			
	N'sele[1]	*N'djili*	*Kimba*	*Mont*	*Boma*	*Mbanza*	*Kasang*	*Kisan*
Live animal	$3.24^{b} \pm 1.1$	$3.28^{b} \pm 0.9$	$3.00^{b} \pm 0.7$	3.91 ± 1.1	$2.00^{a} \pm 0.2$	$2.17^{a} \pm 0.9$	4.12 ± 1.0	$2.18^{a} \pm 1.1$
Pork	$3.75^{bc} \pm 0.8$	$4.28^{cd} \pm 0.8$	$4.35^{bcd} \pm 1.1$	$4.96^{d} \pm 0.8$	$3.00^{a} \pm 0.1$	$3.39^{ab} \pm 0.6$	$4.50^{d} \pm 1.1$	$3.39^{ab} \pm 0.9$

[1]Values within row with differing superscript letters are significantly different

Pigs were slaughtered, sold and consumed mainly for great feasts such as New Year, Christmas or Wedding parties (45%) or when an unexpected need of money occured (20 %). Some breeders (20%) consumed only the fifth quarter (bowels, liver, kidney, lung, stomach sometimes the head) of the slaughtered animals while the best pieces were sold for cash income.

5. Discussion

The purpose of this study was to understand whether and how smallholder pig production systems varied in management and feeding strategies in periurban and rural areas in the Western provinces of the Democratic Republic of Congo. Although the four periurban sites were quite similar across all investigated variables, no specific variable could be found that discriminated the four periurban sites from the four urban sites due to strong differences within the four rural locations.

Regardless of the location, all family members played a role in the pig raising activity. Nonetheless, women were usually kept away from pig daily activities which differed from results of surveys conducted in Kenya (Kagira *et al.*, 2010), where women were shown to play a bigger part in pig raising activities. The low participation of women however agreed with data collected in Botswana (Nsoso *et al.*, 2006). The implication of the family workforce into pig breeding can contribute positively to a reduction in production cost and improve livelihood and hence shows the importance of this activity as a source of family income

The average herd size was higher (18 individuals) than what has been reported in Northeast India (Kumaresan et al., 2009a) and in most developing countries, e.g. herd size of six indivuals in Vietnam (Lemke et al., 2007), three individuals in Nigeria (Ajala *et al.*, 2007) or approximately 4 individuals per herd in western Kenya (Kagira *et al.*, 2010). This herd size can be considered as indication of market orientation. Sites in the outskirts of the metropolis of Kinshasa had a herd of swine of greater size than those in rural areas. Kasangulu is in Bas-Congo closest to Kinshasa. This position justified the large size of livestock and high price of livestock products. The large average herd size in Mbanza-Ngungu is probably related to the fact that it is located far from fishing sites (as opposed to Boma) and the low cost imports of Kinshasa which forces the population to raise their own pigs to be supplied with animal protein sources. Pig production received less attention in Boma because of supply of Congo River fish. The productive outputs in Kasangulu are higher than in most of the other sites, especially regarding weaning weight and the number of born and weaned piglets per litter (Table 8). Kansangulu is located quite close to Kinshasa (approx. 50 km) which with its 8 million inhabitants represents a huge market. Farms in Kansangulu still benefit from low costs of transportation for both pig products and feed and agro-industrial by-products for feeding pigs. Farmers are more prone to increase productivity by, among others, feeding more concentrate and agro-industrial by products (Table 13) and hire skilled workers (Table 6). Moreover, farmers in Kansangulu do not suffer from environmental constraints as the farms located in more densely populated periurban municipalities. Herd size is also likely to be related to availability of land (Katongole *et al*., 2012). This explains why bigger herds were observed in the rural location close to Kinshasa (Kasangulu) than in the periurban areas of Kinshasa. In the studied system, the majority of the farmers were breeding sows for the production of piglets. They fatten their offspring and sometimes additional piglets are bought from other pig smallholders. A weakness of this system is that a large number of farmers do not have their own boars which may lead to inbreeding (Kagira *et al.*, 2010; Lemke *et al.*, 2007). Mating fees practices, charging or by submitting a female piglet at weaning, is similar to what has been observed in other smallholder systems (Lañada *et al.*, 2005; Mutua *et al.*, 2011).

Weaning occured late compared to what was observed with native pigs in Kenya (Mutua *et al.*, 2011) and Creole piglets in Guadeloupe (Gourdine *et al.*, 2006) but coincided with observations from free-range systems in western Kenya (Kagira *et al.*, 2010). The weaning age was more determined by the health of the piglets and the sow as well as the quality and availability of feed rather than by managerial decision based on age or weight of the litter. Late weaning age was probably related to insufficient and unbalanced diet and resulted in a reduction in the numbers of litters per years. The distribution of unbalanced diets to pigs is known for causing a decrease in animal performances (Kumaresan et al., 2009b). Because of these probably unbalanced diets weaning weight was low, although piglets were weaned quite late and some of the surveyed pigs were hybrids of improved breeds which performances were expected to be better than those of local pigs.

The average number of pigs born alive was consistent with what was observed in other developing countries for native breeds (Mutua *et al.*, 2011; Ocampo *et al.*, 2005) but lower than that for improved breeds raised on well balanced diets in open-air stables in the tropics (Suriyasomboon *et al.*, 2006; Tantasuparuk *et al.*, 2000). The small litter size can be attributed to poor diets and inbreeding because inbreeding negatively affects litter size (Toro et al., 1988), birth weight (Brandt et al., 2002) daily gain and final weight (Fernandez et al., 2002). Inbreeding also stems from the fact that pig farmers started generally this activity with poor breeders purchased from neighbors without breeding selection. In addition, farmers reformed sows early (after three parities) which reduced the possibility of having large litter sizes since it is known that litter size is usually smaller in the first parity and rises to a maximum between the third and fifth litter (Koketsu & Dial, 1998; Tummaruk *et al.*, 2001).

All the diseases mentioned by the farmers in this survey were also reported in African free-range pig systems (Ajala *et al.*, 2007; Kagira *et al.*, 2010). The greatest health risks associated with pig farming in this region are ASF and cysticercosis (Praet *et al.*, 2010), although in our study, cysticercosis was neither mentioned by the Congolese pig farmers nor by the area’s veterinaries, probably because it has no overt disease-specific manifestations (Praet *et al.*, 2010) and its prevalence is higher in free-roaming and scavenging pig systems. ASF causes major economic losses, threatens food security and limits pig production in affected areas (Costard *et al.*, 2009; Fasina *et al.*, 2011). It spreads quickly among smallholders for several reasons: transfer of animals from one farm to another without quarantine, moving boars for mating, buying feed to retailers who own livestock themselves, and closeness between farms. The current study also put in evidence that farmers are often misinformed or misadvised over the effectiveness of some veterinary treatments and vaccines.

Pig trypanosomiasis as zoonosis deserves a special attention to avoid circulation of this disease between humans, pigs and tsetse flies. *Trypanosoma brucei gambiense* was identified in tsetse fly with a blood meal from a pig in Kinshasa. In addition, pigsties occurred to be the most favorable biotope for tsetse flies (Simo *et al.*, 2006a and 2006b). Poor hygienic conditions make pigs less productive and more susceptible to diseases (Renaudeau, 2009). Absence of feeders and subsequent distribution of feeds on the floor lead likely to contaminations and increase the incidence of worm infection.

The results of the current study showed that the animals were mainly given agro-industrials and agricultural by-products and plants even when other feed ingredients more energetic such as corn, cassava and potato tubers were available. Also, ingredients used in pig diets varied with location (Table 15) depending on local availabilities and what potential customers were willing to pay. Unlike other sites, pig breeders of the rural Kasangulu area seemed to use the same pig feeds as the farmer in urban sites. Brewer’s grains were used near breweries which were located in Kinshasa and Boma and were used thus by more pig farmers in Kinshasa than by those farmers in Kasangulu and Boma and rarely by farmers in Kisantu and Mbanza-Ngungu. For the same reasons, also forage plants were less used in Kasangulu than in other sites. Palm cakes were less used in Mbanza-Ngungu probably due to the high transport cost because this site is located at 150 km from Kinshasa and 370 km from Boma were oil cakes were pressed. Cassava is the main source of energy used in Mbanza Ngungu probably because of its affordability due to its availability. Most of these feed ingredients are low in protein. The use of corn to feed pigs was considered as a waste of money by rural pig farmers as they considered that they earn more money by selling the grain directly than using it to feed their pigs. Instead of using corn, cassava or potato tubers, they used fiber-rich ingredients such as wheat bran, palm kernel cake, brewers’ grains or plants to feed the animals. They used those ingredients regardless of the nutrients that they provide. The majority of farmers producing pig and crops were even not able to cover household self-sufficiency with their crop production. Their exceeding crop products were rather a source of income than used as feed ingredients. They preferred to use plants as feed ingredients instead. This choice not to divert food resources such as corn that could be eaten by the family or sold on the market to feed pigs was a consequence of a least developed country production environment where humans and animals are in direct competition for grains. Cooked cassava leaves were more frequently used in rural sites than Kinshasa because in the capital city of DRC, there is a high demand for cassava leaves to prepare the traditional dish called *pondu*, and hence only few leaves were available for pigs. Sweet potato leaves were more used in Mbanza Ngungu where there is a large production of potato tubers. *Eichornia crassipes* is fed to pigs in Kinshasa close to the places where it can be found floating on rivers and ponds. *Psophocarpus scandens* a protein-rich legume (Bindelle et al., 2009) is offered to pigs in Kinshasa and in Boma only. The system of raising pigs on locally available resources has been already reported in Northeast India (Kumaresan *et al.*, 2009a) and in North Vietnam (Lemke *et al.*, 2006). However, the choice of plant as feed for pigs was not motivated by their palatability or nutritional value, but rather by their availability. The lack of information on the chemical composition and the role of each nutrient on pig growth is an obstacle to formulate balanced diet for weaned piglets, and gestating and lactating sows which have highest nutrient requirements. Determining the chemical composition and nutritive value would allow farmers to select plants that are nutrient-dense, palatable, digestible and capable of covering the requirements of the animals to obtain a good growth from their pigs.

A large proportion of the Congolese smallholder pig production were market directed, as already mentioned for other African areas (Ajala *et al.*, 2007; Kagira *et al.*, 2010), aiming, first, to provide cash to the family. Supporting the family's consumption of animal products came only in the second position. This lies in contrast with Asian areas where pigs are less market oriented but fulfil functions related to savings and household consumption (Kumaresan *et al.*, 2009a; Lemke *et al.*, 2006).

Although no general differences were observed between the four rural and the four periurban sites, it can be concluded that pig husbandry depends on the local environment as strong differences were observed between rural sites, particularly in terms of workforces, herd structure and characteristics, production parameters, pig building materials, selling price and especially in feed resources. Farmers used several alternative feed ingredients to fed pigs such as agro-industrial by-products as long as the industry was not located too far away and the cost of transportation could be coped with thanks to high pig selling prices. Any further actions to improve pig production in Congolese pig production systems should consider differences in system‘s resources and constraints. Such actions should be articulated around three major pillars that were identified in this survey as the most critical: (1) a reduction in inbreeding, (2) an improvement in biosafety to reduce the incidence of African swine fever and the spread of other diseases, and (3) an improvement in feeding practices. The first two aims can be reached by training pig producing farmers, while an improvement in pig diets quality requires further research on the nutritional value of different feed resources and plant materials locally available, especially those rich in protein.

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CHAPTER III

Measuring the nutritive value on all forage species identified during the survey (Chapter 2) using *in vivo* models would have been tedious, expensive and time-consuming and useless for the less interesting species. Thus, we decided to use a funnel approach by starting with the screening of the nutritive value of the forage species the most commonly used by smallholders farmers in Western DRC. The most promising species then were properly assessed in an *in vivo* model. The result of chemical screening and *in vitro* digestibility have shown that among the forage plants, *A. hybridus, I. batatas, M. esculenta, M. oleifera, P. scandens* and *V. unguiculata* combine several interesting nutritive traits including moderate to high IVDMD, IVED, DCP, R_M, SCFA, Ca and low NDF contents. They represent potentially useful sources of proteins and minerals that might be used at low cost to improve pig feeding, mineral intake and intestinal health. Grasses as well as *A. mangium*, *E. crassipes* and *C. cajan* should be discouraged in pig diet because of their low nutritive value.

Article 3:
Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo

Kambashi et al., 2014

Animal Feed Science and Technology 191, 47-56

B. Kambashi[1,2], P. Picron[2], C. Boudry[2], A. Théwis[2], H. Kiatoko[1], J. Bindelle[2,*]

[1]*University of Kinshasa, Animal Science Unit, Mont-Amba, Lemba, Kinshasa, Democratic Republic of the Congo*

[2]*University of Liège, Gembloux Agro-Bio Tech, Animal Science Unit, Passage des Déportés, 2, 5030, Gembloux, Belgium*

1. Abstract

The nutritive value of 20 forage plants commonly used for feeding pigs in the Democratic Republic of the Congo was studied to determine chemical composition, protein amino acid profiles, mineral content, and *in vitro* digestibility using a two-steps method combining an enzymatic pepsin and pancreatin hydrolysis followed by a 72h gas-test fermentation. The highest protein contents (270-320 g/kg DM) were obtained for *Vigna unguiculata, Psophocarpus scandens*, *Leucaena leucocephala, Manihot esculenta,* and *Moringa oleifera*. Grasses, *Acacia mangium*, and *Eichhornia crassipes*, showed the lowest crude protein (CP) and highest NDF contents. *Cajanus cajan* and *Trypsacum andersonii* had the most balanced amino acid profile, being deficient in Lysine and slightly deficient in Histidine, while *Megathyrsus maximus* displayed the highest number of essential amino acids deficiencies. High mineral contents were obtained from, in ascending order, with *Moringa oleifera, Vigna unguiculata*, *Eichhornia crassipes*, *Ipomea batatas* and *Amaranthus hybridus.* In vitro dry matter digestibility ranged from 0.25 to 0.52, in-vitro CP digestibility from 0.23 to 0.80, in vitro energy digestibility from 0.23 to 0.52. *M. esculenta*, *M. oleifera, I. batatas, Mucuna pruriens, V. unguiculata, P. scandens and A. hybridus* showed high digestibilities for all nutrients. Gas production during fermentation of the pepsin and pancreatin-indigestible fraction of the plants varied from 42 ml/g DM for *A. mangium* to 202 ml/g DM for *I. batatas* ($P<0.001$). Short-chain fatty acid production during fermentation varied from 157 to 405 mg/g of the pepsin and pancreatin indigestible fraction. It is concluded that some of these species are interesting sources of proteins and minerals with a good digestibility that might be used more economically than concentrate, especially in smallholder production systems, to improve pig feeding, mineral intake and intestinal health in pigs reared in the tropics.

Keywords: Fermentation, Forage, Nutritive value, Pigs, Short chain fatty acids

2. Introduction

In the tropics, pig production is only tolerated if pigs do not compete with humans for food (Leterme et al., 2006), especially in developing countries where monogastrics are in direct competition with humans for the resources required to produce concentrate feed. Because of the high and volatile prices of the latter (Braun, 2007; FAO, 2012), smallholders often replace the cereals and oilseed by-products in pig feeds with large amounts of cheap and unconventional fibre-rich ingredients such as crop residues, agro-industrial by-products, and grass and legume forage collected in the forest or in fallow fields near pigsties (Kumaresan et al., 2009; Phengsavanh et al., 2010). A recent survey realised in the Kinshasa and the Bas-Congo Provinces of the Democratic Republic of the Congo (DRC) (Kambashi et al., submitted) confirmed that less than 2% of the farmers use commercial feeds and the most abundant cereal resource, namely corn, is used as an ingredient in pig feed on less than 10% of the farms. Although the growth performances of forage-fed pigs is often lower than that of concentrate-fed and is negatively correlated with the inclusion rate of the forages (Phengsavanh and Lindberg, 2013; Régnier et al., 2013), farmers in Western DRC do not feed crop grains to their pigs because they consider it a waste of crops even in mixed farming systems producing both pigs and crops.

The use of forage resources as pig feeds does have several drawbacks including low digestibility of forage owing to their high content in fibre, the presence of anti-nutritive compounds and the lack of suitable conservation methods. However, compared to cereals, they have distinct advantages justifying their use by farmers: low cost, non-competitiveness with human food, high levels of protein, minerals and vitamins (reviewed by Martens et al., 2012). As feed is the most critical expense in pig rearing activity, it can be profitable to substitute a significant part of a concentrate-based diet with some forage ingredients (Kaensombath et al., 2013b). Unfortunately, the lack of information on the nutritive value of most of the forage resources used in tropical areas in general and in Western DRC specifically can lead to unbalanced diets, low pigs growth and reproduction performances, low incomes for the farmers and less locally produced animal protein available on the market. The aim of this work is to assess using an *in vitro* model of the pigs gastro-intestinal tract, the nutritive value of the forage species the most commonly used by smallholder farmers in Western DRC in order to provide information that could guide them in the choice of forage resources for improved pig performances.

3. Materials and methods

1. Plant material

Samples of 20 forage species used as pig feed by farmers in the Kinshasa and Bas-Congo Provinces of the DRC and identified as the most commonly used during a survey of 319 pig smallholders (Kambashi et al. submitted) were gathered from the smallholders' farms (Table 6). For each species, 4 independent samples were collected on different farms. All forage samples were harvested during the vegetative growth phase before flowering and, depending on the species, whole plants or only leaves were sampled according to the farmers' common practices.

2. In vitro digestion and fermentation

Forage samples were oven-dried at 60°C and ground to pass through a 1 mm mesh screen in a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark). The digestibility of their nutrients was assessed using the *in vitro* model developed by Bindelle et al. (2007a). Briefly, this method simulates the digestion in the pig gastro-intestinal tract in two steps. The stomach and small intestinal digestion are mimicked by an enzymatic hydrolysis with porcine pepsin (2h, 39°C, pH 2) and porcine pancreatin (4h, 39°C, pH 6.8), respectively. The indigestible residue recovered by filtration through a nylon cloth (42 µm), after washing with ethanol and acetone, is subsequently fermented with faecal bacteria of sows in a carbonate-based buffer (72h, 39°C, pH 6.8) to simulate the fermentation processes occurring in the large intestine. The volume of gas produced during fermentation was modelled according to Groot et al. (1996). Four parameters describing the fermentation kinetics were calculated: final gas volume (A, ml g/DM)), mid-fermentation time (B, h), maximum rate of gas production ($R_{M,}$ ml g/DM) and time at which the maximum rate of gas production is reached

($tR_{M,}$ h). Fermentation broth collected after 72 h was centrifuged at 13 000 g 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 4 samples of each forage species, hydrolysis was performed between 4 to 6 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 forage sample.

3. Chemical analysis

Forage ingredients and hydrolysis residues pooled by forage sample (N=4 per species) were analysed for their content in dry matter (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), N according to the Kjeldahl method and calculating the crude protein (CP) content (N × 6.25; method 981.10; AOAC, 1990), and gross energy by means of an adiabatic oxygen bomb calorimeter (1241 Adiabatic Calorimeter, PARR Instrument Co., Illinois, USA). Forage ingredients were also analysed for their content in ether extract (EE) with the Soxhlet method by using diethyl ether (method 920.29; AOAC, 1990), in neutral detergent fibre (NDF) using thermostable amylase (Termamyl®, Novo Nordisk, Bagsværd, Denmark) and corrected for ash, in acid detergent fibre (ADF) corrected for ash, in acid detergent lignin (ADL) according to Van Soest et al. (1991) using an ANKOM-Fiber Analyzer (ANKOM-Technology, Fairport, NY), and in total amino acids (excluding methionine, cysteine and tryptophan) by HPLC after hydrolysis with a mixture of 6 mol HCl/l containing 1 g phenol/l at 110°C for 24 h and derivatization with AccQ-Fluor reagent Kit. DL-2-aminobutyric acid was used as internal standard. Ca, P, Mg, K, Cl, S, Se, Ni, Na, Fe, Mn, Cu and Zn contents of one sample per plant (N=1 per species) were analysed by atomic absorption spectrophotometry using a PerkinElmer AAS-800 (Wellesley, MA, USA).

The supernatants of the fermentation broth were analysed for SCFA contents after 72 h of fermentation with a Waters 2690 HPLC system (Waters, Milford, MA, USA) fitted with an HPX 87H column (Bio-Rad, Hercules, CA, USA) combined with an UV detector (210 nm, Waters, Milford, MA, USA).

4. Calculation and statistical analyses

The *in vitro* dry matter digestibility (IVDMD), crude protein digestibility (IVCPD) and gross energy digestibility (IVED) during the pepsin and pancreatin hydrolysis were calculated as follows: IVDMD = (X-Y)/X; where X is the weight of the sample before hydrolysis and Y the weight of the residue ; and $IVXD = 1 - \frac{Y \times (1 - IVDMD)}{X}$,where X is the nutrient content (CP, energy) in the sample before hydrolysis and Y the nutrient content in the residue after hydrolysis.

Potential contribution of fermentation in the large intestine to metabolic energy supply through SCFA was calculated according to Gaedeken et al. (1989) by multiplying the energy value of each SCFA (acetate 14.56 kJ/g, propionate 20.51 kJ/g, and butyrate 24.78 kJ/g) (Livesey and Elia, 1995) by the SCFA production during the fermentation of the hydrolysed forage ingredients.

Statistical analyses were performed by means of an analysis of variance and a classification of means by the Least Significant Difference method using the MIXED procedure of the SAS 8.02 software (SAS inc., Cary, NC, USA). Correlation was calculated according to the PROC CORR procedure of the SAS 9.2 software (SAS inc., Cary, NC, USA). For all the analyses, the individual forage sample was considered as the experimental unit and the species was the effect that was tested (N = 4).

4. Results

1. Chemical composition

Crude protein contents of the forage species ranged from 88 to 324 g/kg DM and NDF content ranged from 279 to 688 g/kg DM (Table 18). The lowest CP values (88 to 147 g kg^{-1} DM) and the highest NDF contents (554 to 688 g/kg DM) were found in grasses (*M. maximus, P. purpureum, S. officinarum, U. ruziziensis, T. andersonii*) and *Eichhornia crassipes*. In contrast, the dicotyledons such as *A. hybridus, I. batatas, M. pruriens, V. unguiculata, P. scandens, L. Leucocephala, M. esculenta* and *M. oleifera* showed CP contents ranged from 225 to 326 g/kg DM and NDF content ranged from 208 to 395 g/kg DM.

Table 18. Chemical composition (g/kg DM) and gross energy (MJ/kg DM) content of the forages (N = 4)

Species	*Family*	*Name*	*Plant parts*	*OM*[1]	*CP*[2]	*GE*[3]	*aNDFom*[4]	*ADFom*[5]	*ADL(sa)*[6]	*EE*[7]
Acacia mangium	*Fabaceae*	*Lack wattle*	*leaves*	970^{b8}	177^{efg}	21.7^{a}	505^{bcd}	344^{ab}	176^{a}	46.2^{bcd}
Amaranthus hybridus spp	*Amaranthaceae*	*Smooth pigweed*	*whole plant*	839^{h}	225^{d}	15.1^{h}	373^{ef}	208^{d}	22^{g}	21.3^{hi}
Cajanus cajan	*Fabaceae*	*Pigeon pea*	*whole plant*	951^{abcd}	217^{de}	22.5^{a}	545^{bc}	362^{ab}	176^{a}	60.6^{ab}
Calopogonium muconoides	*Fabaceae*	*Wild ground nut*	*whole plant*	914^{defg}	179^{efg}	19.6^{d}	489^{cd}	357^{ab}	70^{cde}	42.0^{cde}
Centrosema pubescens	*Fabaceae*	*Centro*	*whole plant*	936^{abcdef}	216^{de}	19.8^{cd}	543^{bc}	381^{a}	95^{bcd}	31.3^{defghi}
Eichhornia crassipes	*Pontederiaceae,*	*Water hyacinth*	*whole plant*	917^{cdefg}	138^{gh}	16.1^{h}	574^{b}	316^{ab}	31^{fg}	20.5^{i}
Ipomoea batatas	*Convolvulaceae*	*Sweet potato*	*whole plant*	899^{fg}	225^{d}	17.6^{fg}	389^{ef}	334^{ab}	99^{bc}	37.4^{cdefgh}
Leucaena leucocephala	*Fabaceae*	*Leucena*	*leaves*	927^{cdefg}	279^{ab}	20.5^{bc}	394^{ef}	213^{d}	96^{bcd}	49.7^{bc}
Manihot esculenta	*Euphorbiaceae*	*Cassava*	*leaves*	926^{cdefg}	280^{ab}	21.3^{ab}	313^{fg}	225^{cd}	86^{bcd}	68.0^{a}
Megathyrsus maximus	*Poaceae*	*Guinea grass*	*whole plant*	955^{abc}	147^{fgh}	18.8^{def}	688^{a}	397^{a}	47^{efg}	21.9^{ghi}
Moringa oleifera	*Moringaceae*	*Moringa*	*leaves*	888^{g}	324^{a}	19.4^{de}	279^{g}	183^{d}	31^{fg}	70.0^{a}
Mucuna pruriens	*Fabaceae*	*Velvet bean*	*whole plant*	933^{bcdef}	228^{cd}	19.1^{de}	499^{bcd}	395^{a}	109^{b}	40.0^{cdef}
Pennisetum purpureum	*Poaceae*	*Elephant grass*	*whole plant*	908^{efg}	110^{hi}	17.4^{g}	674^{a}	363^{ab}	43^{efg}	21.8^{ghi}
Psophocarpus scandens	*Fabaceae*	*African winged-bean*	*whole plant*	941^{abcde}	277^{b}	19.1^{de}	540^{bc}	345^{ab}	97^{bc}	28.2^{efghi}
Pueraria phaseoloides	*Fabaceae*	*Tropical kudzu*	*whole plant*	941^{abcde}	180^{efg}	19.4^{de}	519^{bc}	385^{a}	85^{bcd}	31.9^{defghi}
Saccharum officinarum	*Poaceae*	*Sugarcane*	*leaves*	977^{a}	88^{i}	18.8^{def}	685^{a}	389^{a}	48^{efg}	23.2^{fghi}
Stylosanthes guianensis	*Fabaceae*	*Common stylo*	*whole plant*	920^{cdefg}	194^{def}	18.2^{efg}	559^{bc}	396^{a}	77^{bcde}	30.4^{defghi}
Trypsacum andersonii	*Poaceae*	*Guatemala grass*	*whole plant*	935^{bcdef}	104^{hi}	18.9^{de}	678^{a}	372^{ab}	46^{efg}	22.4^{ghi}
Urochloa ruziziensis	*Poaceae*	*Ruzi grass*	*whole plant*	937^{abcdef}	101^{hi}	18.4^{defg}	672^{a}	358^{ab}	31^{fg}	20.8^{hi}
Vigna unguiculata	*Fabaceae*	*Cowpea*	*whole plant*	908^{efg}	272^{bc}	18.6^{defg}	422^{de}	302^{bc}	60^{def}	38.2^{cdefg}
SEM[9]				*4.46*	*8.34*	*0.21*	*15.26*	*9.27*	*5.55*	*2.11*
P values				*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*

[1]OM, organic matter
[2]CP, crude protein (N × 6.25)[3]GE, gross energy
[4]aNDFom, neutral detergent fibre using thermostable amylase and corrected for ash content
[5]ADFom, acid detergent fibre corrected for ash content
[6]ADL(sa), acid detergent lignin
[7]EE, ether extract
[8]For one column, means followed by different letters differ (P<0.05)
[9]SEM, standard error of the means

The AA profile differed between forages but all species were highly deficient in Lysine, with values ranging between 3.08 and 4.76 g/16g N against recommendations of 7.14 g/16g N (NRC, 2012), with grasses being the most deficient. The legume *C. cajan* and more surprisingly the grass *T. andersonii* had the most balanced protein profile being deficient in Lysine (4,76 and 3.04 g/16g N, respectively) and slightly deficient in Histidine (2.23 and 1.83 g/16g N, respectively). Conversely, *M. maximus* appeared to have the most unbalanced protein profile. In terms of total amount of total AA per gram of protein, the lowest value were obtained with *C. pubescens* , *M. pruriens, M. maximus* and *P. scandens* (59 to 63 g/16g N) while the highest values were found in *C. cajan, M. esculenta and, V. unguiculata* (77 to 80 g/16g N).

2. In vitro digestibility and fermentation

IVDMD ranged from 0.25 to 0.53, depending on the species ($P<0.001$), while IVCPD ranged from 0.23 to 0.81($P<0.001$) and that of energy (IVED) ranged from 0.23 to 0.52 ($P<0.001$) (Table 19). *M. esculenta*, *M. oleifera, I. batatas, C. muconoides, V. unguiculata, P. scandens* and *A. hybridus* had the highest IVDMD, IVED and IVCPD values. Although it had a low IVDMD of 0.40, *P. phaseoloides* scored among the highest for IVCPD with 0.75. Gas production kinetics of the fibre-rich residues recovered after the pepsin and pancreatin hydrolysis showed that different forage species have different fermentabilities. Final gas production (A) varied from 42 ml/g DM for *A. mangium* to 202 ml/g DM for *I. batatas* ($P<0.001$).

Table 19. In vitro dry matter (IVDMD), energy (IVED) and crude protein (IVCPD) digestibility during pepsin-pancreatin hydrolysis and kinetic parameters of the gas production curves modelled according to Groot et al. (1996) for the hydrolysed forages incubated with pigs faeces (N = 4).

Scientific name	*IVDMD (−)*	*IVED (−)*	*IVCPD (−)*	*DP g /kg DM*	*Hydrolysed DE*[1] *MJ /kg DM*	*Total DE*[2] *MJ /kg DM*	*A*[3] *(ml/g DM)*	R_M[4] *(ml/h per g DM)*	tR_M[5] *(h)*
Acacia mangium	0.31[fgh6]	0.26[gh]	0.23[j]	40[h]	5.7[def]	7.6[gh]	42[k]	1.5[i]	11.6[d]
Amaranthus hybridus	0.53[a]	0.47[ab]	0.78[a]	176[cd]	7.1[cd]	10.2[cde]	196[ab]	14.7[b]	10.2[de]
Cajanus cajan	0.33[efg]	0.32[efg]	0.33[j]	71[gh]	7.2[bcd]	9.2[efg]	68[j]	3.0[i]	11.4[d]
Calopogonium muconoides	0.44[bc]	0.45[abc]	0.74[abc]	130[ef]	8.9[ab]	11.7[abc]	134[fgh]	9.1[e]	9.9[de]
Centrosema pubescens	0.37[def]	0.37[cde]	0.69[bcde]	147[de]	7.4[bcd]	10.1[cde]	116[hi]	5.4[fgh]	10.7[d]
Eichhornia crassipes	0.33[efg]	0.25[gh]	0.51[hi]	70[gh]	3.9[f]	6.8[h]	116[hi]	4.5[gh]	13.8[c]
Ipomoea batatas	0.47[ab]	0.43[bcd]	0.61[efg]	137[de]	7.6[bc]	10.9[bcd]	202[a]	16.7[a]	10.2[de]
Leucaena leucocephala	0.39[cde]	0.39[cde]	0.47[i]	130[ef]	7.9[bc]	10.3[cde]	108[i]	5.9[f]	11.2[d]
Manihot esculenta	0.45[bc]	0.47[ab]	0.64[cdefg]	177[cd]	10.1[a]	13.0[a]	164[cde]	13.3[bc]	10.5[de]
Megathyrsus maximus	0.29[gh]	0.28[fg]	0.62[defg]	92[fg]	5.3[ef]	9.2[efg]	170[cd]	6.3[f]	16.5[b]
Moringa oleifera	0.53[a]	0.52[a]	0.80[a]	261[a]	10.1[a]	12.8[a]	170[cd]	13.5[bc]	8.4[e]
Mucuna pruriens	0.37[de]	0.35[def]	0.61[efg]	138[de]	6.8[cde]	9.7[def]	145[efg]	8.2[e]	10.0[de]
Pennisetum purpureum	0.25[h]	0.23[h]	0.53[ghi]	58[gh]	3.9[f]	8.2[fgh]	164[cd]	5.8[fg]	17.6[ab]
Psophocarpus scandens	0.43[bcd]	0.42[bcd]	0.69[bcde]	192[bc]	7.9[bc]	11.1[bcd]	152[def]	8.2[e]	11.4[d]
Pueraria phaseoloides	0.40[cde]	0.41[bcd]	0.75[ab]	134[e]	7.9[bc]	11.0[bcd]	131[gh]	8.8[e]	11.0[d]
Saccharum offinarum	0.30[gh]	0.25[gh]	0.58[fgh]	48[h]	5.0[ef]	8.2[fgh]	116[hi]	4.4[h]	16.0[b]
Stylosanthes guianensis	0.33[efg]	0.35[def]	0.67[bcdef]	129[ef]	6.4[cde]	10.6[bcde]	170[cd]	10.9[d]	10.8[d]

Scientific name	IVDMD (−)	IVED (−)	IVCPD (−)	DP g /kg DM	Hydrolysed DE[1] MJ /kg DM	Total DE[2] MJ /kg DM	A[3] (ml/g DM)	R_M[4] (ml/h per g DM)	tR_M[5] (h)
Trypsacum andersonii	0.27[gh]	0.27[gh]	0.50[hi]	52[h]	5.2[ef]	9.4[def]	153[de]	5.4[fgh]	18.7[a]
Urochloa ruziziensis	0.30[fgh]	0.28[fg]	0.73[abcd]	73[gh]	5.2[ef]	9.5[def]	198[ab]	8.0[e]	15.6[bc]
Vigna unguiculata	0.47[ab]	0.48[ab]	0.81[a]	219[b]	8.9[ab]	12.3[ab]	179[bc]	12.4[c]	11.6[d]
SEM[7]	0.013	0.014	0.022	7.49	0.24	0.22	3.03	0.29	0.25
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1] Digestible energy from enzymatically hydrolyzed fraction
[2] Value is the sum of the digested energy from the enzyme hydrolyzed fraction plus the contribution of SCFA from fermentation.
[3] *A*, final gas volume
[4] R_M, maximum rate of gas production
[5] t_{RM}, time at which the rate of gas production reaches R_M
[6] For one parameter, means followed by different letters in the columns differ at a significance level of 0.05.
[7] SEM, standard error of the means

These two species also gave the extreme values for the maximum rate of fermentation (R_M) which ranged from 1.5 to 16.7 ml/h per g DM (P<0.001). Mid-fermentation times (B) and time at which R_M is reached (t_{RM}) ranged from 11.8 to 24.5 h and 8.4 to 18.7 h (P<0.001), respectively.

As a consequence of their lower CP content as well as their lower IVCPD and fermentability, all grasses (*M. maximus, P. purpureum, S. officinarum, U. ruziziensis*, and *T. andersonii*) as well as *A. mangium, C. cajan and E. crassipes*, ranked amongst the species with the lowest *in vitro* digestible protein (DP) values (40 to 92 g/kg DM). With DP ranging from 129 to 147 g/kg DM, *S. guianensis, C. muconoides, L. leucocephala, P. phaseoloides, I. batatas, M. pruriens,* and *C. pubescens* showed low

DP values ranging from 129 to 147 g/kg DM in contrast to *A. hybridus, M. esculenta, P. scandens V. unguiculata* and *M. oleifera*, whose DP contents ranged from 176 to 261 g/kg DM. All grasses as well as *A. mangium and E. crassipes* had the poorest digestible energy (DE) contents with values as low as 5.7 MJ/kg. The species with the highest total energy, including the DE released from enzymatic hydrolysis and the contribution of SCFA from fermentation, were: *C. mucunoides* (11.7 MJ/kg), *V. unguiculata* (12.3 MJ/kg), *M. Oleifera* (12.8 MJ/kg) and *M. esculenta* (13.0 MJ/kg)

3. Short chain fatty acids

Total SCFA production during the *in vitro* fermentation (Table 20) differed between forage species (P<0.001). These differences were consistent with those observed during fermentation kinetics as total SCFA production was correlated to maximum rate of gas production (r = 0.72, P<0.001) and final gas volume (r = 0.85, P<0.001). The fibre-rich residue of *V. unguiculata, I batatas, S. guianensis, A. hybridus, U. ruziziensis* and, *M. oleifera*, produced more SCFA (375 to 405 mg/g DM of enzymatically hydrolysed forage) than the other species (157 to 359 mg/g DM).

Table 20. Short chain fatty acids (SCFA) production (mg/g DM) of the hydrolyzed forage ingredients during in vitro fermentation and potential contribution of SCFA to the metabolic energy supply from the initial ingredient to the pig (N=4).

Plants	*SCFA (mg/g DM)*	*Acetate (mol//mol)*	*Propionate (mol//mol)*	*Butyrate (mol//mol)*	*BCFA (mol//mol)*	*Contribution of fermentation[c] to energy supply (MJ/kg DM)*
Acacia mangium	157^{i1}	0.594^{fghi}	0.257^{fgh}	0.074^{ab}	0.021^{a}	1.68^{i}
Amaranthus hybridus	389^{ab}	0.624^{bc}	0.263^{efgh}	0.063^{cde}	0.014^{cdef}	2.97^{def}
Cajanus cajan	195^{h}	0.620^{bcde}	0.234^{i}	0.075^{a}	0.020^{a}	2.03^{h}
Calopogonium muconoides	321de	0.605^{efg}	0.273^{de}	0.064^{cde}	0.016^{cde}	2.84^{ef}
Centrosema pubescens	267^{fg}	0.599^{fgh}	0.283^{bcd}	0.061^{cde}	0.017^{bc}	2.66^{fg}
Eichhornia crassipes	272^{fg}	0.631^{ab}	0.255^{gh}	0.060^{de}	0.016^{cde}	2.86^{ef}
Ipomoea batatas	401^{a}	0.629^{ab}	0.251^{h}	0.067^{bcd}	0.014^{def}	3.38^{c}
Leucaena leucocephala	262^{g}	0.608^{def}	0.252^{h}	0.068^{abcd}	0.019^{ab}	2.45^{g}
Manihot esculenta	342^{cd}	0.642^{a}	0.230^{i}	0.067^{abcde}	0.015^{cde}	2.92^{def}
Megathyrsus maximus	342^{cd}	0.583^{hi}	0.298^{ab}	0.066^{cde}	0.014^{cdef}	3.89^{b}
Moringa oleifera	375^{abc}	0.631^{ab}	0.231^{i}	0.069^{abc}	0.016^{bcd}	2.71^{fg}
Mucuna pruriens	299^{ef}	0.609^{cdef}	0.273^{def}	0.060^{de}	0.016^{cde}	2.96^{def}
Pennisetum purpureum	351^{cd}	0.589^{hi}	0.293^{bc}	0.067^{abcd}	0.013^{ef}	4.24^{a}
Psophocarpus scandens	347^{cd}	0.594^{fghi}	0.285^{bcd}	0.061^{cde}	0.016^{cde}	3.14^{cde}
Pueraria phaseoloides	320de	0.607^{ef}	0.276^{cde}	0.061^{cde}	0.015^{cde}	3.07^{cde}
Saccharum officinarum	292^{efg}	0.581^{i}	0.297^{ab}	0.066^{bcd}	0.015^{cde}	3.27^{cd}
Stylosanthes guianensis	397^{a}	0.621^{bcde}	0.260^{efgh}	0.060^{cde}	0.015^{cdef}	4.18^{ab}
Trypsacum andersonii	359^{bc}	0.582^{hi}	0.312^{a}	0.062^{cde}	0.013^{ef}	4.30^{a}
Urochloa ruziziensis	389^{ab}	0.589^{ghi}	0.297^{ab}	0.070^{abc}	0.012^{f}	4.43^{a}
Vigna unguiculata	405^{a}	0.622^{bcd}	0.269^{defg}	0.058^{e}	0.014^{cdef}	3.39^{c}
SEM[2]	5.14	0.002	0.002	0.001	<0.001	0.05
P-value	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.01$	$P<0.001$	$P<0.001$

[1]In each column; means followed by a different letter differ at a significance level of 0.05,
[2]SEM, standard error of means

M. esculenta, *E. crassipes*, *I. batatas* showed the highest acetate molar ratio (0.629 to 0.642) while grasses (*M. maximus, P. purpureum, T. andersonii*, *U. ruziziensis*) had the lowest acetate (0.581 to 0.589) and the highest propionate molar ratio (0.293 to 0.312). Although significant differences between forage species in butyrate and BCFA molar ratios were quite little in absolute value.

The NDF content affected IVDMD (r = -0.82, P<0.001) and IVED (r = -0.80, P<0.001). There was also a negative correlation (r = -0.71, P<0.001) between DP and NDF content for all forages.

4. Mineral content of forages

The contents of macro- and micro-minerals in the sampled forage species varied widely. Sulphur content ranged from 1.5 in *P. purpureum* to 20.9 g/kg DM in *M. oleifera.* Calcium content ranged from 3.6 in *P. purpureum* to 37.0 g/kg DM in *V. unguiculata* while phosphorus content ranged from 0.17 in *S. officinarum* to 6.0 g/kg DM in *A. hybridus*. Magnesium content ranged from 1.1 to 11.6 g/kg DM sodium and potassium content ranged from 0.2 to 3.8 g/kg DM and 7.0 to 62.9 g/kg DM, respectively. The highest macro mineral contents were obtained from, in ascending order, *M. oleifera, V. unguiculata, E. crassipes, I. batatas* and *A. hybridus.*

Levels of copper and nickel levels were low in all the forage plants compared to those of other minerals. Cobalt and selenium levels were very low, and in some species below detection levels. The iron levels were relatively high while phosphorus content was low in almost all forage species compared to nutritional requirements (Table 21). Calcium-to-phosphorus ratio was high in all plants. Among the studied plants, *A. hybridus* had the highest macro- and micro-nutrient levels.

5. Discussion

Feeding is the most important component in the efficiency of pig production systems, yet a recent survey (Kambashi et al., submitted) showed that in the Kinshasa and Bas-Congo provinces of the DRC, smallholders feed their pigs with by-products and locally available forage plants. The efficiency of such a system depends on the nutrients that are provided by forage and the capacity with which these nutrients are assimilated and converted into meat.

Table 21. Mineral content of forage ingredients (N=1)

	Macro-minerals (%)							Micro-minerals (ppm)						
	S	Cl	Ca	P	Mg	K	Na	Mn	Zn	Fe	Cu	Se	Co	Ni
Requirements for growing pigs (%) (20-50 kg) (NRC, 2012)	*N/A*[1]	*0.08*	*0.60*	*0.50*	*0.04*	*0.23*	*0.10*	*2*	*60*	*60*	*4*	*0.15*	*N/A*	*N/A*
Acacia mangium	*0.35*	*0.92*	*0.68*	*0.10*	*0.11*	*1.49*	*0.13*	*57*	*16*	*252*	*5.9*	*0.38*	*<0.1*	*2*
Amaranthus hybridus	*0.88*	*0.45*	*2.29*	*0.60*	*1.16*	*6.29*	*0.12*	*33*	*47*	*1345*	*10.4*	*1.53*	*0.4*	*74*
Urochloa ruziziensis	*0.26*	*0.57*	*0.62*	*0.16*	*0.21*	*2.08*	*0.03*	*75*	*54*	*244*	*7.3*	*0.05*	*<0.1*	*13*
Cajanus cajan	*0.18*	*0.04*	*0.74*	*0.13*	*0.18*	*0.81*	*0.03*	*93*	*23*	*755*	*8.2*	*0.05*	*<0.1*	*22*
Calopogonium muconoides	*0.38*	*0.34*	*1.74*	*0.14*	*0.33*	*0.77*	*0.03*	*44*	*33*	*665*	*5.8*	*0.08*	*0.2*	*14*
Centrosema pubescens	*0.47*	*0.46*	*1.58*	*0.16*	*0.31*	*1.19*	*0.04*	*65*	*38*	*625*	*9.8*	*0.09*	*0.3*	*18*
Eichhornia crassipes	*0.49*	*2.52*	*1.08*	*0.11*	*0.51*	*3.98*	*0.32*	*396*	*50*	*220*	*4.9*	*<0.01*	*<0.1*	*6*
Ipomoea batatas	*0.75*	*1.56*	*1.57*	*0.28*	*0.33*	*5.13*	*0.14*	*54*	*32*	*520*	*8*	*0.02*	*0.3*	*16*
Leucaena leucocephala	*0.51*	*0.59*	*2.42*	*0.10*	*0.22*	*1.48*	*0.02*	*40*	*23*	*294*	*6.2*	*0.87*	*0.7*	*3*
Manihot esculenta	*0.43*	*0.09*	*2.07*	*0.31*	*0.33*	*1.40*	*0.03*	*30*	*90*	*136*	*8.4*	*0.15*	*0.8*	*2*
Moringa oleifera	*2.09*	*0.07*	*2.83*	*0.26*	*0.27*	*1.59*	*0.02*	*21*	*20*	*182*	*6.8*	*0.19*	*0.5*	*3*
Mucuna pruriens	*0.24*	*0.08*	*2.63*	*0.16*	*0.25*	*1.39*	*0.03*	*136*	*53*	*183*	*3.7*	*<0.01*	*0.2*	*3*
Megathyrsus maximus	*0.36*	*0.85*	*0.74*	*0.21*	*0.34*	*2.38*	*0.05*	*61*	*49*	*385*	*11.3*	*<0.01*	*<0.1*	*23*
Pennisetum purpureum	*0.15*	*0.74*	*0.36*	*0.12*	*0.16*	*3.36*	*0.03*	*80*	*23*	*230*	*8.9*	*0.86*	*0.3*	*5*
Psophocarpus scandens	*0.67*	*0.39*	*1.45*	*0.27*	*0.21*	*2.44*	*0.02*	*43*	*42*	*206*	*11.8*	*0.01*	*0.4*	*2*
Pueraria phaseoloides	*0.27*	*0.13*	*1.05*	*0.21*	*0.25*	*1.43*	*0.03*	*95*	*32*	*145*	*8.8*	*0.05*	*0.2*	*5*
Saccharum officinarum	*0.61*	*0.29*	*0.46*	*0.07*	*0.12*	*0.70*	*0.05*	*23*	*24*	*218*	*3*	*0.02*	*0.2*	*9*
Stylosanthes guianensis	*0.52*	*0.49*	*2.19*	*0.38*	*0.41*	*1.14*	*0.03*	*64*	*73*	*308*	*12.8*	*0.17*	*<0.1*	*13*
Trypsacum andersonii	*0.32*	*0.25*	*0.40*	*0.15*	*0.22*	*1.54*	*0.03*	*51*	*20*	*437*	*8.8*	*0.07*	*0.9*	*20*
Vigna unguiculata	*0.49*	*0.33*	*3.70*	*0.27*	*0.48*	*2.11*	*0.03*	*27*	*71*	*375*	*11.5*	*0.02*	*0.1*	*1*

[1]N/A, not available

The *in vitro* approach used in this research allowed to evaluate the potential nutritive value of a large number of forage species providing an insight, not only on their chemical composition, but also on their enzymatic digestibility and the fermentability of their indigestible fraction in the large intestine. However, this methodology is not perfect as the capacity of a feed ingredient to supply nutrients to an animal depends on both the quantity that an animal will voluntary ingest and how much nutrients present will be digested and metabolised by the animal. Intake was not assessed here and not all the features regarding digestion are assessed using the *in vitro* method. For example, the impact of toxic compounds in the plant and their consequences on the intake and the digestive processes (Acamovic and Brooker, 2005, Martens et al. 2012) are not modelled in the *in vitro* method. Another example is the interaction between feed ingredients and with digestive processes. Some forage species are rich in fibre with high water-holding capacity. The swelling of such fibre in the upper tract of the pig will impact the digestibility of the whole diet by reducing transit time and contact between the feed particles and the digestive enzymes (Partanen et al., 2007; Régnier et al., 2013). This effect cannot be evaluated in the chosen *in vitro* model either.

Considering chemical composition, except for *A. mangium* and *C. cajan,* all Fabaceae have CP contents that meet the requirements for growing pigs (200 g/kg DM; NRC, 2012) and yield high DP content. More specifically, the high protein content of *M. oleifera, M. esculenta,* and the Fabaceae *L. leucocephala, P. scandens* and *V. unguiculata*, with 324, 280, 279, 277 and 272 g/kg DM, respectively, justifies their use in pig feeding since protein is the most limiting factor in smallholder pig feeding systems in tropical areas (Leterme et al., 2005). These protein-rich plants also have an interesting amino acid profile (Table 22). However, none of them covers the essential amino acids requirement of growing pigs, especially in Lysine which was 45 to 68 % of the Lysine requirement per g/16g N for growing pigs (NRC, 2012). Therefore using the above-mentioned forage species to supplement Lysine-deficient basal diets, such as brewers grains and wheat bran (Kambashi et al., submitted), requires to feed the animals above requirement levels for protein content or to supplement forage-based diets with synthetic lysine. Moreover, the total AA contents presented here do not consider digestibility of AA which can greatly vary between species and could modify the ranking of the forages based on protein profile.

Table 22. Indispensable and total amino acids (AA) of forage ingredients (g/16 g total N) (N=4)

	Indispensable Amino Acids								
	Arg	*His*	*Ile*	*Leu*	*Lys*	*Phe*	*Thr*	*Val*	*Σ AAs*[1]
Acacia mangium	4.92^{abcde}[2]	2.22^{ab}	4.01^{bcde}	6.83^{abc}	4.53^{ab}	4.51^{bcde}	4.24^{bcd}	5.37^{ab}	70.6^{abcd}
Amaranthus hybridus spp	4.73^{abcde}	1.71^{cd}	3.96^{bcdef}	6.21^{cdefg}	4.03^{bc}	3.97^{fg}	3.90^{bcde}	4.81^{bcdef}	67.4^{cdef}
Urochloa ruziziensis	5.69^{ab}	2.66^{a}	3.77^{bcdefg}	6.57^{abcdef}	2.20^{h}	4.24^{defg}	5.84^{a}	5.17^{bc}	73.0^{abcd}
Cajanus cajan	5.59^{a}	2.23^{ab}	4.76^{a}	7.76^{a}	4.76^{a}	5.26^{b}	4.64^{abcd}	6.01^{a}	79.5^{a}
Calopogonium muconoides	4.53^{abcde}	2.00^{bc}	4.28^{ab}	6.89^{abcd}	3.83^{bcdf}	4.77^{bcde}	4.17^{bcde}	5.31^{b}	71.4^{abcd}
Centrosema pubescens	3.53^{ef}	1.55^{cd}	3.16^{gh}	5.01^{g}	3.31^{cdeg}	3.59^{fg}	3.13^{e}	4.24^{ef}	59.1^{ef}
Eichhornia crassipes	4.73^{abcde}	1.87^{bcd}	4.15^{bcd}	6.95^{abc}	4.09^{b}	4.61^{bcde}	4.33^{bcde}	5.20^{b}	74.0^{abc}
Ipomoea batatas	4.53^{abcde}	1.63^{cd}	3.90^{bcdefg}	6.66^{abcdef}	3.19^{efg}	4.30^{defg}	4.35^{bcde}	5.13^{bcd}	69.7^{abcde}
Leucaena leucocephala	4.97^{abcde}	1.93^{bc}	3.67^{cdefg}	6.24^{bcdefg}	3.97^{bc}	4.28^{defg}	4.22^{bcde}	4.76^{bcdef}	66.4^{cdef}
Manihot esculenta	5.39^{abc}	2.08^{abc}	4.32^{abc}	7.13^{abc}	4.33^{ab}	4.75^{bcde}	4.36^{bcde}	5.41^{ab}	78.1^{ab}
Moringa oleifera	5.68^{a}	1.89^{bc}	3.77^{bcdefg}	6.20^{cdefg}	3.78^{bcde}	6.60^{a}	4.18^{bcde}	4.82^{bcdef}	74.5^{abc}
Mucuna pruriens	3.75^{def}	1.69^{cd}	3.57^{defgh}	5.58^{fg}	3.22^{eg}	3.80^{fg}	3.63^{cde}	4.52^{cdef}	63.2^{def}
Megathyrsus maximus	2.95^{f}	1.35^{d}	3.05^{h}	5.15^{g}	3.08^{g}	3.56^{g}	3.45^{e}	4.36^{ef}	63.3^{def}
Pennisetum purpureum	4.41^{abcde}	1.83^{bcd}	3.80^{bcdefg}	6.79^{abcde}	3.65^{bcdeg}	4.83^{bcde}	4.65^{abcd}	4.99^{bcde}	73.1^{abc}
Psophocarpus scandens	3.98^{cdef}	1.92^{bc}	3.45^{efgh}	5.77^{defg}	3.33^{deg}	4.36^{def}	4.33^{bcde}	4.27^{f}	63.8^{def}
Pueraria phaseoloides	4.15^{bcdef}	1.91^{bc}	3.77^{bcdefg}	6.13^{cdefg}	3.41^{cdeg}	4.46^{cdef}	4.44^{bcde}	4.81^{bcdef}	69.4^{bcd}
Saccharum officinarum	4.37^{abcde}	1.83^{bcd}	3.73^{bcdefg}	6.49^{bcdef}	3.11^{g}	4.78^{bcde}	4.69^{abc}	5.08^{bc}	73.0^{abc}
Stylosanthes guianensis	5.24^{abcd}	2.07^{abc}	3.98^{bcdef}	6.63^{abcdef}	3.60^{bcdeg}	5.14^{bcd}	4.78^{abcd}	4.77^{bcdef}	72.6^{abcd}
Trypsacum andersonii	5.34^{abc}	1.83^{bcd}	4.02^{bcde}	7.36^{ab}	3.04^{g}	5.21^{bc}	4.91^{ab}	5.22^{b}	74.2^{abc}
Vigna unguiculata	5.12^{abcd}	1.93^{bc}	3.80^{bcdefg}	6.35^{bcdef}	3.33^{deg}	4.93^{bcd}	4.90^{ab}	4.87^{bcdef}	77.0^{ab}
SEM[3]	*0.136*	*0.084*	*0.067*	*0.121*	*0.082*	*0.117*	*0.110*	*0.074*	*1.010*
P value	*0.022*	*0.049*	*0.001*	*0.004*	*<0.001*	*<0.001*	*0.049*	*0.001*	*<0.001*

[1]Sum of total AA including essential and non-essential amino acids (except sulfur AA and tryptophan)
[2]In each column; means followed by a different letter differ at a significance level of 0.05
[3]SEM, standard error of the means

As an example, the best protein profile was found in *C. cajan*. However, the amino acid availability in this species is expected to be limited by the low digestibility of the crude protein (0.33).

The high NDF and ADF contents of the grasses and *E. crassipes* explain their low *in vitro* digestibility, as illustrated by the correlation linking NDF to IVDMD and IVED (r = -0.71 and -0.84 respectively, P<0.001) in this study and the more general observations by Noblet and van Milgen (2004). The digestibility and fermentability of *A. mangium* and *C. cajan* were low, probably because of the presence of plant secondary metabolites together with their high lignin contents (176g/kg DM of ADL, respectively). Clavero and Razz (2011) and Uwangbaoje (2012) found these plants to contain condensed tannins (4.8 and 38.7 mg/g DM) and phenols (29.1 and 2.2 mg/g). ,

In contrast to CP, the total digestible energy (DE) contents of the forages not meet the requirements for growing pigs (15.8 MJ/kg DM; NRC, 2012). *V. unguiculata* and *C. muconoides* present DE contents of 11.7 and 12.3 MJ/kg DM, respectively whereas *M. oleifera* and *M. esculenta* scored even better with 12.8 and 13.0 MJ/kg DM, respectively. In addition, to hydrolysed DE, the SCFA released through fermentation in the large intestine of the indigestible fibrous residue can supply up to 4 MJ/kg DM of additional metabolic energy that significantly increases the energy value of some forage species. Interestingly, grasses displayed high hemicellulose contents (calculated as the difference NDF-ADF) as opposed to many legumes which show lower NDF values but ADF values similar to grasses. This leads to distinct fermentation profile in grasses, yielding more propionate and less acetate than legumes and other dicots, and induces a significant contribution of hindgut fermentation to ME supply in the animal as a combination of (1) high indigestible feed particles reaching the intestine, (2) high fermentability of the fibrous matrix, and (3) the higher energy content of propionate as opposed to acetate (20.51 kJ/g vs. 14.56 kJ/g, respectively). Nevertheless, SCFA production are measured in the in vitro model after 72 h fermentation. It represents a long transit time in the large intestine that would be more consistent with sows than finishing pigs and growing pigs (Le Goff et al., 2002)

The high fermentability related to greater SCFA results in a decrease in pH, which in turn influences the composition of colonic microflora, decreases the solubility of bile acids and increases absorption of some minerals (Hijova and Chmelarova, 2007). Low pH values are also believed to prevent the overgrowth of pH-sensitive pathogenic bacteria. For example, propionate or formate have been shown to kill *E. coli* or *Salmonella* under conditions of high acidity (pH 5) (Cherrington et al., 1991). Some *in vivo* studies support these findings, with greater SCFA production being related to lower numbers of potential pathogens (such as *Salmonella*) in swine (Pieper et al., 2012). Some species combining high DP and DE contents with high SCFA production can potentially contribute significantly to efficient nutrition together with the development of health-promoting bacteria in pig intestines by providing metabolizable energy (Bindelle et al., 2007b; Hijova and Chmelarova, 2007) and other metabolic end products for pig use, as well as nutrients for the colonic epithelium, modulators of colonic and intracellular pH, cell volume and other associated functions (Hijova and Chmelarova, 2007).

Nonetheless, attention must be paid to the maximum levels of forage incorporation in pig diets as some forage species may contain variable amounts of anti-nutritional or toxic factors such as tannins, as discussed earlier: HCN in *M. esculenta*, mimosine in *L. leucocephala,* and lectins in *I. batatas* and *P. scandens*. These compounds might reduce voluntary intake and *in vivo* digestibility (Régnier et al., 2012). However, with moderate inclusion rate of these forages, anti-nutritional effect is not significant. For example, the incorporation of 350 g/kg DM of *I. batatas* leaves or 150 g/kg DM of *M. esculenta* leaves or *L. leucocephala* in pig diets have shown ileal digestibility up to 74% (Phuc and Lindberg, 2000; An et al., 2004). However, the *in vitro* approach adopted in this research does not allow considering these issues and the presented results should be taken as a first orientation on the feeding value of one species. Obviously, one species scoring poorly on *in vitro* digestibility trials as performed here will be of little value as pig feed ingredient. Nevertheless, the opposite conclusion is not straightforward. A species scoring with high nutritive characteristics as evaluated *in vitro* might not necessarily be well consumed or digested *in vivo* possibly because of poor palatability, of the presence of plant secondary metabolites displaying anti-nutritive or toxic attributes that are not always noticeable using an *in vitro* approach.

The use of forage to supplement local feed resources can provide a better balanced diet that improves growth performances keeping feeding costs under control (Lemke and Valle Zárate, 2008) and in a sustainable way. For example, it has been reported that the inclusion of ensiled *S. guianensis* in the diet of local pigs improved growth performance up to three times compared to pigs fed ill-balanced diets based on locally available by-products (Kaensombath et al., 2013b). However, the replacement of conventional sources of protein, such as soybean meal, by protein-rich forage must be partial because Phengsavanh and Lindberg (2013) reported that it reduces feed intake and growth performance. In another study, Kaensombath and Lindberg (2013a) showed that when 50% of soybean protein was replaced with proteins from ensiled *Colocasia esculenta*, growth performance and carcass traits of local and improved pigs were not affected. Surprisingly, Men et al. (2006) report high cost effectiveness of *E. crassipes*-based diets in Vietnam while this species scored really bad in terms of nutritive value in the present investigation. This allows expecting even higher efficiencies of feeding systems based on low cost forage with higher nutritive value than water hyacinth.

Despite the expected high variability within species that was not assessed in this study as only one sample per species was analysed, legumes seem to be a richer and better balanced source of minerals than grasses. Yet variability among species, specifically with regard to the bioavailability of minerals, must be considered as it ranges from 0.41 to 58% for P (Poulsen et al., 2010), 3 to 27% for Fe (Kumari et al., 2004), 11 to 26% for Zn and 18 to 48% for Cu (Agte et al., 2000). Due to the high calcium-to-phosphorus ratio, which decreases absorption of phosphorus (Liu et al., 2000), as well as the low phosphorus content in most forages, these species seem to perfectly supplement basal ingredients usually used by farmers, namely brewers grains and wheat bran, which are deficient in Ca (2.1 and 1.4 g/kg, respectively) and rich in P (5.8 and 9.9 g/kg, respectively). The outstanding mineral content of *A. hybridus* deserves further attention, as according to NRC (2012), its Se level is quite high compared to the requirements (0.3 ppm) but is still below the toxicity level (5 ppm). Co, Cu and Ni were below toxicity levels in all forages, but with regard to this it must be noted that forage are rarely fed to pigs alone; but rather, mixed with other ingredients.

It can be concluded that among the investigated plants in this study, *A. hybridus, I. batatas, M. esculenta, M. oleifera, P. scandens* and *V. unguiculata* combine several interesting nutritive traits including moderate to high IVDMD, IVED, DCP, R_M, SCFA, Ca and low NDF contents. They represent potentially useful sources of proteins and minerals that might be used at low cost to improve pig feeding, mineral intake and intestinal health. Grasses as well as *A. mangium*, *E. crassipes* and *C. cajan* should be discouraged in pig diet because of their low nutritive value. Further studies are required to determine voluntary intake and *in vivo* nutritive value for the potentially useful species and their ideal inclusion level in pig diets for optimum performance in production environments with low quality basal diets.

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CHAPTER IV

The capacity of a feed ingredient to supply nutrients to an animal depends on both the quantity that an animal will voluntary ingest and how much nutrient will be digested and metabolised by the animal. In addition, the interactions between feed ingredients and with digestive processes affect also the amount of retained nutrients. Thus, four forage species among the most frequently cited by the farmers during the survey (Chapter 2) and presenting interesting in vitro nutritive value were investigated in Chapter 4. The aim of this paper was to determine voluntary intake and *in vivo* nutritive value with diets containing increasing levels of hays of the four forage plants. Briefly, the results of the experiments surprisingly showed that pigs did not increase their DM intake to cope with the decrease in energy content of the diet that followed the inclusion of any of the 4 forage species. Furthermore, increasing the forage level in diets resulted in a linear decrease in digestibility for all nutrients and a decrease in N retention. Nonetheless differences in digestibility between species were observed. Digestibility was lower for *P. phasoeloides* as opposed to the 3 other species.

Article 4
Feeding value of hays of four tropical forage legumes in pigs: Vigna unguiculata, Psophocarpus scandens, Pueraria phaseoloides and Stylosanthes guianensis

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Bienvenu Kambashi[1,2], Christelle Boudry[2], Pascale Picron[2], Honoré Kiatoko[1], Jérôme Bindelle[2,3]

[1]Université de Kinshasa, Mont-Amba, Lemba, Kinshasa, Democratic Republic of the Congo
[2]University of Liège, Gembloux Agro-Bio Tech, Animal Science Unit, Passage des Déportés, 2, 5030, Gembloux, Belgium
[3]To whom correspondence should be addressed: jerome.bindelle@ulg.ac.be, phone: +3281622609 fax: +3281622115

1. Abstract

Forage is used by smallholders in many tropical countries as a substitute for concentrate feed ingredients in pig diets, often disregarding the actual consequences on the pig's nutrition. The effects of the inclusion 4 tropical forage legume hays on voluntary intake and their nutritive value (*Vigna unguiculata*, *Psophocarpus scandens*, *Pueraria phaseoloides*, and *Stylosanthes guianensis*) were studied in Large White × Duroc growing pigs using a corn-soybean meal-based diet containing various proportions of one of the forage legume hays (0, 10, 20, 40% or 0, 12.5, 25% for the voluntary intake assessment and the nutritive value determination, respectively). No difference in voluntary feed intake was observed between species (P>0.20) but a linear response to forage inclusion level (P<0.05) was observed decreasing from 126 for the control to approx. 84 g/kg of body weight for the 40% forage diets, except for *V. unguiculata*, where a quadratic response was observed (P=0.01). All 4 forage species linearly decreased the total tract apparent digestibility (TTAD) from 0.76 to 0.61, 0.80 to 0.68, 0.54 to 0.40 and 0.58 to 0.31 except for *S. guianensis* (0.44) for DM, N, NDF and N retention, respectively. Differences in digestibility (P<0.05) between species were observed only for

25% forage-based diets. TTAD (DM, N and NDF) was lower for *P. phaseoloides* as opposed to the 3 other species. Due to their negative influence on the overall digestibility of the diets, the contribution of TFL to the diet should not exceed 12.5%, except for *S. guinensis,* in which N-retention remained quite high (0.44) at the highest inclusion level (25%). *P. phaseoloides* hay should be avoided in pigs as it combines the lowest voluntary intake with the lowest nutrient digestibility.

2. Introduction

In developing countries, pigs are still fed locally available resources, including vegetation, crop residues, kitchen wastes, and agro-industrial by-products, especially by poor farmers and those living in inaccessible areas (Ocampo et al., 2005; Kumaresan et al., 2007; Phengsavanh et al., 2010; Kambashi et al., submitted to JARTS). The high cost and low availability of conventional livestock feedstuffs have driven rural pig smallholders to use fibre-rich feedstuffs and forage species, even if their efficiency of utilisation is lower than for concentrate feed ingredients. However, earlier studies have shown that some forage plants or parts of plants have a high nutritive value and are potential resources for use as pig feed (Leterme et al., 2005; Leterme et al., 2009; Negesse et al., 2009). These forage species have both advantages of adaptation to local environmental conditions and high biomass yield with high protein content. However, the biomass yield varies throughout the year and depends mainly on seasonality, agricultural practices in the area, and the traditional experience of the farmer. Some plants used as feedstuffs such as *Ipomoea batatas* (An et al., 2004), *Manihot esculenta* (Phuc et al., 2000; Phuc and Lindberg, 2001) and *Leucaena leucocephala* (Phuc and Lindberg, 2000) have both high protein content and high digestibility, and have been used successfully in the diets of growing pigs in Laos and Vietnam, while the protein content of other plants and their digestibility vary from relatively high (*Azolla filiculoides* 232 g of crude protein (CP)/kg DM and 0.33-0.50 [Leterme et al., 2009], *Trichanthera gigantea* 203-216 g CP/kg DM and 0.47-0.49, *Morus alba* 170-194 g CP/kg DM and 0.56-0.64, and *Xanthosoma sagittifolium* 231-240 g CP/kg DM and 0.57-0.71 [Leterme et al., 2005]) to low (*Salvinia molesta* 232 g CP/kg DM and 0.29-0.33 [Leterme et al., 2009]). The use of forage in the diet of pigs is constrained by its high fibre content, which may have a negative impact on feed intake and growth performance (Phengsavanh and Lindberg, 2013). When not compensated by an increase in intake by the animal, the reduction of energy content in forage-based diets may be dealt with by the addition of high-energy ingredients such as vegetable oil. Regardless of this, replacing soybean with ensiled *Colocasia esculenta* and *Stylosanthes guianensis* up to 50% in the diet on protein basis did not affect intake, growth performance, or carcass traits of pigs (Kaensombath and Lindberg, 2013; Kaensombath et al., 2013). This means that forage can partially replace conventional protein sources in pig diets. In an earlier study on 21 of the most frequently used species by pig smallholders in the Western part of the Democratic Republic of the Congo (DRC), some species showed a high *in-vitro* digestibility, among them *Psophocarpus scandens*, *Pueraria phaseoloides*, *Stylosanthes guianensis*, and *Vigna unguiculata* (Kambashi et al., 2014). Besides its chemical composition, the extent to which a given forage species can efficiently supply pigs in nutrients for growth and reproduction will depend on its relative cost against concentrate feed ingredients and on its feeding value. The feeding value combines the voluntary feed intake as well as the nutritive value measured through the digestibility of the nutrients of both the forage and the diet in which it is incorporated. Both parameters, i.e. intake and digestibility, can vary according to the breed (Renaudeau et al., 2006; Len et al., 2009) and the physiological status of the animal, especially when considering fibre-rich ingredients (Noblet and Le Goff, 2001). If sows are better at digesting fibrous ingredients owing to their higher digestive tract volume:intake ratio, in a breeding-fattening operation, the highest feeding cost is held by the growing and fattening pigs (IFIP, 2012). Hence, feeding practices aiming at reducing the cost of growing and finishing pigs' diets by adding forage ingredients are sensible, as long as their negative impacts are limited. The present manuscript assesses the feeding value in growing pigs of 4 forage ingredients that are usually fed to pigs in the western provinces of DRC. For this purpose, 2 experiments were realised: a voluntary intake experiment and a digestibility trial.

3. Material and Methods

Two experiments were conducted: in Exp. 1, voluntary intake of a corn-soybean meal-based diet with four inclusion levels (0, 10, 20 and 40%) of 4 forage species (*V. unguiculata*, *P. scandens*, *P. phaseoloides*, and *S. guianensis*) was determined; in Exp. 2, total tract apparent digestibility (TTAD) and nitrogen retention were measured to determine the nutritive value of these 4 forage species. Although no regulation is actually in force regarding animal welfare during experiments at the University of Kinshasa in DRC, the protocols were conducted according to the best practices accepted by the Ethical Committee of the University of Liège (Liège, Belgium) when conducting similar experiments.

1. Production of forage legumes hays

Four forage species, namely *Vigna unguiculata*, *Psophocarpus scandens*, *Pueraria phaseoloides* and *Stylosanthes guianensis* were chosen according to a previous survey on the feeding practices by smallholders in the working area and a preliminary in vitro assessment of their feeding value (Kambashi et al., 2014). Forage was cultivated on a field of the Society of Large Farms of Ndama in Central Africa (SOGENAC) in the DRC, located in Kolo-Fuma between 5°15' and 5°52' latitude south, about 180 km southwest of Kinshasa (Bas-Congo, DRC). Rainfall during forage production was 139, 179 and 530 mm for February, March and April 2011, respectively. The average monthly temperature ranged from 21.5 to 25.4°C (SOGENAC, personal communication). The fields have a ferralitic soil with a sand-clay texture (Renard et al., 1995). Except for S. guianensis which was harvested twice, at 3 months of growth and again 1 month after the first harvest, the 3 others species were harvested once at 2 months of growth. The plant material consisted of all above ground biomass, namely leaves and stem. Immediately after harvest, forage was chopped to 10-cm stalks, sun-dried for 2 to 3 days and stored in a dry place. The dried material was then ground with a hammer-mill to pass through a 5-mm mesh screen.

2. Experiment 1. Voluntary feed intake

Animals: Twenty-four castrated male growing pigs (Large White x Duroc) were used. The pigs were divided in 12 groups of 2 pigs. The pigs had an average body weight of 35.5±2.7 kg at the beginning and 74.1±5.8 kg at the end of the experiment.

Diets: A corn-soybean meal commercial diet purchased from the local production factory (MIDEMA, Matadi, Bas-Congo, DRC) (basal diet) was substituted with 0, 10, 20, or 40% of one of the legume hays to form 13 experimental diets (Table 24), offered in a dried, ground form. The diets were mixed with water (1.5 l/kg diet) before distribution to the pigs.

Methodology: Each group of 2 pigs was offered one of the 13 diets ad libitum, over 4 consecutive experimental periods. The experiment lasted 68 days in total. Each of the 4 periods lasted 17 days with 12 days of adaptation to the diet and 5 days of data collection. Diets' allocation to each group was randomly changed from one period to the next in order for each group to receive 4 different diets over the 4 periods, including the basal diet at least once. Therefore, during each period, 3 groups were fed the basal diet. Except for the basal diet, which was tested in 12 groups, each diet was tested on 3 different groups. They were fed ad libitum 3 times a day (at 7 a.m., 12 a.m., and 5 p.m.). The refusals were collected before each meal, weighed, and dried to determine dry matter intake (DMI).

3. Experiment 2. Digestibility of forage legumes hays

Animals: Thirty-six castrated male growing pigs (Large White x Duroc) with an average body weight of 40.7±4.5 kg at the beginning of the experiment were used and kept in metabolic cages designed to collect total urine and faeces separately. The pigs had permanent access to fresh water.

Diets: A commercial concentrate (corn-soybean meal) was used as basal diet (MIDEMA, Matadi, Bas-Congo, DRC). Then, 12.5 or 25% of the basal diet was substituted with one of the 4 legume hays to form 9 experimental diets in total (Table 25), offered in a dried, ground form. Pigs received daily 90 g/kg0.75 BW divided in 2 meals. Forage legume hays were prepared as described above. The diets were mixed with water just before feeding (1.5 l/kg diet).

Table 23. Chemical characteristics of tropical legumes

Item	*Psophocarpus scandens*	*Pueraria phaseoloides*	*Stylosanthes guianensis*	*Vigna unguiculata*
Chemical composition (g/kg DM)				
Dry matter	*906*	*901*	*890*	*917*
Organic matter	*899*	*910*	*870*	*866*
Crude protein (N x 6.25)	*207*	*145*	*155*	*166*
Neutral detergent fibre	*578*	*691*	*583*	*476*
Acid detergent fibre	*433*	*570*	*505*	*406*
Acid detergeant lignin	*94*	*133*	*91*	*84*
Gross energy (kcal/kg DM)	*4448*	*4310*	*4142*	*3954*
Total phenol (mg/g DM tannic acid equivalent)	*6.3*	*5.8*	*5.1*	*3.4*
Tannin (mg/g DM tannic acid equivalent)	*3.5*	*3.3*	*3.1*	*1.9*
Water Holding Capacity (g water/g DM)	*7.1*	*8.3*	*7.5*	*5.9*
N-NDF (g/100 g N DM)	*39*	*46*	*27*	*27*
Essential amino acids (g/16 g N)				
Arginine	*3.15*	*3.23*	*3.20*	*3.21*
Histidine	*1.52*	*1.55*	*1.54*	*1.34*
Isoleucine	*3.24*	*3.30*	*3.08*	*3.42*
Leucine	*5.23*	*5.29*	*4.85*	*5.40*
Lysine	*3.80*	*3.76*	*3.14*	*3.19*
Methionine	*1.38*	*1.33*	*1.23*	*1.33*
Phenylalanine	*3.41*	*3.41*	*3.24*	*3.51*
Threonine	*3.55*	*3.60*	*3.19*	*3.64*
Tyrosine	*1.74*	*1.69*	*1.53*	*1.69*
Valine	*4.12*	*4.23*	*3.88*	*4.34*

Methodology: The diets were randomly assigned to the pigs (4 per diet). After 14 days of adaptation to the diet with the last 3 days spent in the metabolic cages, faeces and urine were totally collected every morning, for 5 days and homogenised. An aliquot of 10% of the faeces was kept at -20°C and cumulated over the 5-d collecting period. Samples of faeces were freeze-dried before the laboratory analyses were performed.

The refusals were taken at 1 h after each meal, weighed, and divided in 2 parts. These 2 parts were immediately dried, one at 60°C for 48 h for further chemical analysis and the other at 105°C for 12 h in order to determine DMI. Every morning, 100 ml of 10% H2SO4 was placed in the tub of urine collection to avoid ammonia losses during collection and storage. Daily urine was weighed, and an aliquot of 10% of the daily production was stored at -18°C and cumulated over the 5-d collection period. The temperature varied from 17 to 32°C, for night and day respectively, and was quite constant during the experiment. After each collection period, all pigs were fed the standard commercial diet. Subsequently, the animals were randomly allocated to another experimental diet and the procedure described above was repeated for a second period.

4. Chemical composition

Dried forage legume hays, basal diet, and faeces were ground to pass a 1-mm mesh screen in a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark) and analysed for their contents in DM (105°C for 24 h, method 967.03; AOAC, 1990), ash (550°C for 8 h, method 923.03; AOAC, 1990), N (Kjeldahl method with crude protein (CP) = N × 6.25; method 981.10; AOAC, 1990), gross energy by means of an adiabatic oxygen bomb calorimeter (1241 Adiabatic Calorimeter, PARR Instrument Co., Illinois, USA), and neutral detergent fibre (NDF) content using thermostable amylase (Termamyl®, Novo Nordisk, Bagsværd, Denmark) and correcting for ash content. Urine samples were analysed for their N content. Hays and basal diet were analysed for their contents in N bound to the NDF by running a Kjeldahl analysis on the NDF residue, and for their contents in acid detergent fibre (ADF) and in acid detergent lignin (ADL), both corrected for ash, according to Van Soest et al. (1991), using an ANKOM-Fiber Analyzer (ANKOM-Technology, Fairport, NY, USA). Hays and basal diet were also analysed for their amino acid (AA) contents by high-performance liquid chromatography (HPLC) after hydrolysis with 6 mol/l HCl containing 1 g/l phenol at 110°C for 24 h and derivatisation with the AccQ-Fluor reagent Kit (Waters, USA). Methionine and cysteine underwent a performic oxidation before hydrolysis. Water holding capacity (WHC) was measured according to Leterme et al. (1998) and Régnier et al. (2013). Briefly, 1 g of leaf meal was placed in a centrifuge tube with 20 ml of distilled water. After 16 h of soaking at ambient temperature, the tubes were centrifuged (2000 × g, 50 min at 20°C) and kept for 8 min before the supernatant (water) was discarded and the sediment (the remaining water mixed with feed) was weighed. Total phenols and tannin were determined according to the colorimetric method of Hagerman et al. (2000) after removing the fat content using petrol ether in a Soxhlet apparatus.

5. Calculations and statistical analyses

Voluntary feed intake was determined as the difference between the amount offered and the amount refused. The Total Tract Apparent Digestibility (TTAD) of DM, organic matter (OM), CP (N content × 6.25), and energy were calculated by the difference between the nutrient intake in feed and the nutrient excreted in faeces.

Table 24. Chemical composition of experimental diets used to assess voluntary intake of forage legume hays (Exp.1)

	Basal diet	*Psophocarpus scandens*			*Pueraria phaseoloides*			*Stylosanthes guianensis*			*Vigna unguiculata*		
		Ps10	*Ps20*	*Ps40*	*Pu10*	*Pu20*	*Pu40*	*St10*	*St20*	*St40*	*Vi10*	*Vi20*	*Vi40*
Composition (g/kg DM)													
Basal diet	*1000*	*900*	*800*	*600*	*900*	*800*	*600*	*900*	*800*	*600*	*900*	*800*	*600*
Forage	*0*	*100*	*200*	*400*	*100*	*200*	*400*	*100*	*200*	*400*	*100*	*200*	*400*
Chemical composition (g/kg DM)													
Dry matter	*890*	*892*	*895*	*897*	*896*	*899*	*903*	*888*	*894*	*895*	*890*	*895*	*901*
Organic matter	*921*	*928*	*922*	*921*	*921*	*924*	*921*	*921*	*920*	*912*	*901*	*918*	*913*
Crude protein (N × 6.25)	*188*	*186*	*187*	*189*	*182*	*180*	*175*	*188*	*185*	*177*	*185*	*183*	*171*
Neutral detergent fibre	*233*	*273*	*302*	*343*	*263*	*314*	*386*	*251*	*280*	*365*	*263*	*291*	*325*
Acid detergent fibre	*73*	*112*	*123*	*183*	*123*	*185*	*274*	*121*	*172*	*237*	*103*	*150*	*270*
Acid detergent lignin	*14*	*24*	*25*	*40*	*26*	*32*	*50*	*23*	*34*	*50*	*21*	*33*	*61*
Gross energy (kcal/kg DM)	*4418*	*4432*	*4357*	*4334*	*4371*	*4370*	*4360*	*4369*	*4305*	*4187*	*4379*	*4305*	*4220*
Water Holding Capacity (g water/g DM)	*2.2*	*2.69*	*3.18*	*4.16*	*2.81*	*3.42*	*4.64*	*2.73*	*3.26*	*4.32*	*2.57*	*2.94*	*3.68*

Table 25. Chemical composition of the nutritive value experimental diets (Exp.2)

	Basal diet	Psophocarpus Scandens		Pueraria phaseoloides		Stylosanthes guianensis		Vigna unguiculata	
		12.5%	25%	12.5 %	25%	12.5 %	25%	12.5 %	25%
Chemical composition (g/kg DM)									
Dry matter (g/kg)	893	891	893	894	902	889	893	889	897
Organic matter	928	924	923	923	926	920	918	907	899
Crude protein (N x 6,25)	187	196	197	187	181	189	188	190	188
Neutral detergent fibre	243	284	321	309	361	275	308	271	290
Acid detergent fibre	71	118	162	143	193	124	168	110	153
Acid detergent lignin	14	24	36	33	44	26	33	22	28
Gross energy (kcal/kg DM)	4423	4385	4347	4338	4330	4321	4283	4270	4218
Water holding capacity (g water/g DM)	2.2	2.8	3.4	3.0	3.7	2.9	3.5	2.7	3.1
Essential amino acids (g/100g CP)[1]									
Arginine	6.09	5.72	5.36	5.73	5.38	5.73	5.37	5.73	5.37
Histidine	2.55	2.42	2.30	2.43	2.30	2.43	2.30	2.40	2.25
Isoleucine	3.73	3.66	3.60	3.67	3.62	3.64	3.56	3.69	3.65
Leucine	6.95	6.74	6.52	6.74	6.54	6.69	6.43	6.76	6.56
Lysine	3.93	3.91	3.90	3.91	3.89	3.83	3.73	3.84	3.75
Methionine	1.74	1.69	1.65	1.69	1.64	1.68	1.61	1.69	1.64
Phenylalanine	4.23	4.13	4.02	4.13	4.02	4.10	3.98	4.14	4.05
Threonine	3.80	3.77	3.74	3.78	3.75	3.73	3.65	3.78	3.76
Tyrosine	2.37	2.29	2.21	2.28	2.20	2.26	2.16	2.28	2.20
Valine	4.77	4.69	4.61	4.71	4.64	4.66	4.55	4.72	4.67

[1]Except for the basal diet, amino acids were calculated based on forage:basal diet ratio

Nitrogen retention was calculated as the difference between apparently digested N and N discharged in urine. The metabolizable energy content (ME) of the diets was calculated as the difference between digestible energy (DE) and energy loss in the urine estimated from N loss (g/d) according to the equation of Noblet and Le Goff (2001): energy loss in urine (kJ/d) = 345 + 31.1 × N loss in urine (g/d).

In the voluntary intake experiment (Exp. 1), the group of pigs was the experimental unit in the statistical analyses. Feed intakes were compared between species and inclusion levels by means of an analysis of variance using the mixed procedure in SAS 9.02, using the following model:

$Y = \mu + S_i + L_j + S_i \times L + A_k + \varepsilon$

where Y is the result, μ is the mean, S_i is the class effect of forage species (i = 1, ..,4), L, the continuous effect of forage level (L = 10, 20, 40), A_k is the random effect of the group of pigs (k = 1,…,12), and ε is the error term. The analysis was followed by a comparison of the diets using the LSMEANS statement. For this analysis, basal diet was left out. In addition, the influence on feed intake was analysed for linear and quadratic effects of the concentrations in each forage species separately by means of the MIXED procedure (SAS Inst. Inc., Cary, NC), using the following linear and quadratic regression models:

$$Y = \mu + \alpha \times L + A + \varepsilon$$

and $Y = \mu + \alpha \times L + \beta \times L^2 + A + \varepsilon$

where Y is the result, μ is the mean, L is the continuous effect of forage concentration in Exp. 1 (L = 0, 10, 20, 40), α is the linear regression coefficient for L, A is the random effect of the group, β is the quadratic regression coefficient for L^2, and ε is the error term. For this analysis, the basal diet was included.

In the digestibility experiment (Exp. 2), the animal was the experimental unit. The nutrients digestibility as well as N-retention values were compared between species and inclusion level by means of an analysis of variance using the mixed procedure in SAS 9.02, using the following model:

$$Y = \mu + S_i + L_j + S_i \times L + A + \varepsilon$$

where Y is the result, μ is the mean, S_i is the class effect of forage species (i = 1, ..,4), L is the continuous effect of forage level (L = 12.5, 25), A is the random effect of the pigs, and ε is the error term. The analysis was followed by a comparison of the diets using the LSMEANS statement. For this analysis, the basal diet was omitted. In addition, the influence on feed intake was analysed for linear effects of the concentrations in each forage species separately by means of the MIXED procedure (SAS Inst. Inc., Cary, NC), using the following linear regression model:

$$Y = \mu + \alpha \times L + A + \varepsilon$$

where Y is the result, μ is the mean, L is the continuous effect of forage concentration in Exp. 1 (L = 0, 12.5, 25), α is the linear regression coefficient for L, A is the random effect of the pigs, and ε is the error term. For this analysis, the basal diet was included.

4. Results

CP contents of the 4 forage species ranged from 145 g/kg DM for *Pueraria phaseoloides* to 207 g/kg DM for *Psophocarpus scandens* and the NDF content ranged from 476 g/kg DM for *Vigna unguiculata* to 691 g/kg DM for *P. phaseoloides* (Table 23). The AA profile differed but all species were highly deficient in lysine, with values ranging between 3.31 and 4.76 g/g16N against recommendations of 7.14 g/16 g N (NRC, 2012). Except for *V. unguiculata* which had a low tannin content (1.9 mg/g DM), the total tannin content of the 3 others species ranged from 3.1 to 3.5 mg/g DM. The WHC ranged from 5.9 for *V. unguiculata* to 8.3 for *P. phaseoloides*.

As displayed in Table 26, voluntary intake was not different between species (P=0.53). However, an effect of the inclusion rate (P<0.001) and an interaction between the species and the inclusion rate (P<0.001) were highlighted. *P. scandens* added at 10% and *Stylosanthes guianensis* and *V. unguiculata* added up to 20% in the basal diet did not affect the feed intake. *P. phaseoloides*, even incorporated at 10%, tended to have a negative effect on the voluntary intake compared to the 3 other species (P=0.06). Except for *V. unguiculata*, for which a quadratic response (P=0.017) was observed, a linear response to forage level (P<0.05) was observed, decreasing from 132 g/kg$^{0.75}$ liveweight for *S. guianensis* incorporated at 10% to approx. 84 g/kg$^{0.75}$ liveweight for 40% of this forage in the diet.

The TTAD and the energy (DE and ME) contents of forage-based diets (Table 27) decreased linearly with the inclusion level (P<0.01). Moreover, the incorporation level and interaction (species × level) effects on the analysed parameters were significant for all nutrients (P<0.001). DM digestibility was not different between species for a same inclusion level, except for *P. phaseoloides* at 25%.

Crude protein digestibility was high for *V. unguiculata* and *P. scandens* incorporated at 12.5%, and low for *S. guianensis*, *P. scandens*, and *P. phaseoloides* incorporated at 25%. NDF digestibility was lower for *P. phaseoloides* incorporated at 12.5%, which has a comparable value to *S. guianensis*, *P. scandens*, and *V. unguiculata* incorporated at 25%. Nitrogen retention was low for *P. phaseoloides* incorporated at 12.5% and lower than *S. guianensis* incorporated at 25%. The digestible and metabolic energy of diets made with *P. phaseoloides* incorporated at 12.5% was also low and similar to the values for incorporation at 25% of the 3 other species.

5. Discussion

Psophocarpus scandens, Pueraria phaseoloides, Stylosanthes guianensis and *Vigna unguiculata* are 4 of the forage species that are most commonly fed to pigs by smallholders in Western DRC. Those species were reported to have high protein contents, ranging from 180 to 277 g/kg DM and high *in vitro* digestibility (Kambashi et al., 2014).

However, in this study, protein content of the forage ingredients was lower (145-207 g/kg DM) than in the above-mentioned study possibly because of the hay making process inducing protein degradation and losses of leaves leading to a higher stems:leaves ratio than in fresh forage.

Except for *P. phaseoloides*, the general shape of response of VDMI with increasing concentration of forage in the diets showed a slight or negligible increase in intake followed by a linear reduction ($P < 0.05$) when including 20% then 40% of forage in the diets. Surprisingly, pigs did not increase their DM intake to cope with the decrease in energy content of the diet that followed the inclusion of any of the 4 forage species, as demonstrated in Exp. 2 (Table 27). A similar observation was recently reported by Phengsavanh and Lindberg (2013) on Moo Lath pigs in Laos when soybean meal was replaced by *Aeschynomene histrix* and *S. guianensis* leaf meal on a protein basis. Explanation to this observation probably lies in the water-holding capacity (WHC) of the investigated forages and their contents in plant secondary metabolites (PSM). WHC of the forage-substituted diets is double to that of the basal diet with the highest inclusion rates (Table 24). Moreover, *P. phaseoloides,* which induces the sharpest decrease in intake even when included at 10% in the diet, has the highest WHC of the 4 tested species (Table 23). High WHC results in high bulkiness inside the digestive tract of the pig, due to the swelling of the fibre component (Bach Knudsen, 2001). This bulkiness reduces the feed intake through reduced emptying rate of the stomach (Leterme et al., 2006). Furthermore, the lack of increase in intake when including forage in the basal diet also probably originates from its composition. The basal diet sold in DRC by MIDEMA is low in DE and ME (3303 and 2921 kcal/kg DM, respectively) as opposed to nutrient requirements for growing pigs: 3402 kcal DE/kg and 3300 kcal DE/kg (NRC 2012). Actually, it is suspected that the corn-soybean meal-based basal diet has a high wheat bran content as one of the major activities of this company is the milling of wheat for flour. The high NDF content of the basal diet points out to a possible proportion of wheat bran in the diet as high as 30%. This high NDF and low energy contents led the animals to have already high intake levels, even when no forage was included in the diet (126 g/d $kg^{0.75}$ BW).

Table 26. Voluntary intake of tropical forage legumes-based diets in growing pig (N=3, except for basal diet where N = 12)

	Basal diet	*Psophocarpus scandens*			*Pueraria phaseoloides*			*Stylosanthes guinanensis*			*Vigna unguiculata*			SEM[1]	P-values		
															Species	Level	Species × Level
Forage incorporation level (%)	0	10	20	40	10	20	40	10	20	40	10	20	40				
Voluntary Intake (gDM/kg $BW^{0.75}$)	126	129[ab2]	103[cde]	94[de]	107[bcd]	99[bcd]	81[e]	132[a]	114[abc]	85[de]	128[ab]	123[abc]	84[de]	3.48	0.525	<0.001	<0.001
P-values for the regression coefficients for forage incorporation levels in the diets																	
Linear		0.0069			0.0005			0.0062			0.0027						
Quadratic		0.9959			0.8698			0.2492			0.0172						

[1]SEM, standard error of the mean
[2]Means followed by a different letter differ at a significance level of P < 0.05.

Table 27. Total tract apparent digestibility (%), N retention and energy digestibility of tropical forage legumes-based diets in growing pig (N=8)

	Basal diet	*Psophocarpus scandens*		*Pueraria phaseoloides*		*Stylosanthes guinanensis*		*Vigna unguiculata*		*SEM*[1]	*P-value*		
Incorporation Level		*12.5%*	*25%*	*12.5%*	*25%*	*12.5%*	*25%*	*12.5%*	*25%*		*Species*	*Level*	*Species × level*
Digestibility (%)													
Dry matter	*76.0*	*71.0*[a1]	*64.9*[b]	*69.8*[a]	*61.0*[c]	*70.0*[a]	*64.8*[b]	*72.5*[a]	*65.6*[b]	*0.66*	*0.015*	*<0.001*	*<0.001*
Organic matter	*78.6*	*73.2*[ab]	*67.4*[c]	*72.3*[b]	*63.6*[c]	*72.3*[b]	*67.2*[c]	*75.0*[a]	*68.6*[c]	*0.64*	*0.028*	*<0.001*	*<0.001*
Crude protein	*80.4*	*76.3*[a]	*69.5*[cd]	*75.2*[ab]	*68.0*[d]	*75.6*[ab]	*70.9*[cd]	*77.4*[a]	*72.2*[bc]	*0.65*	*0.083*	*<0.001*	*<0.001*
Neutral detergent fibre	*53.5*	*49.3*[abc]	*40.9*[d]	*47.3*[bcd]	*40.3*[d]	*51.4*[ab]	*44.3*[cd]	*54.7*[a]	*43.7*[d]	*0.97*	*0.011*	*<0.001*	*<0.001*
Energy	*75.4*	*69.9*[a]	*63.7*[bc]	*69.3*[a]	*60.7*[c]	*69.3*[a]	*63.7*[bc]	*71.6*[a]	*65.2*[b]	*0.70*	*0.060*	*<0.001*	*<0.001*
Nitrogen retention	*58.4*	*48.6*[ab]	*33.0*[c]	*40.8*[bc]	*31.1*[c]	*50.4*[a]	*43.8*[ab]	*50.0*[a]	*35.8*[c]	*1.44*	*0.083*	*<0.001*	*<0.001*
Digestible energy (kcal/kg DM)	*3303*	*3250*[a]	*2810*[b]	*2941*[ab]	*2727*[b]	*3254*[a]	*2830*[b]	*3278*[a]	*2827*[b]	*52.4*	*0.265*	*<0.001*	*0.005*
Metabolisable energy (kcal/kg DM)	*2921*	*2741*[a]	*2272*[b]	*2421*[ab]	*2204*[b]	*2769*[a]	*2354*[b]	*2772*[a]	*2251*[b]	*55.3*	*0.303*	*<0.001*	*0.003*

[1]SEM, standard error of the mean
[2]Means followed by a different letter differ at a significance level of P < 0.05.

Despite these general observations, for *V. unguiculata*, a decrease in DM intake became sharp only at the 40% inclusion level, leading to a quadratic evolution of DMI against forage level (P = 0.0107). With this species, pigs seemed to be much more able to cope with the decrease in energy content by maintaining their DM intake to a high level, even for 20% of forage in the diet.

In addition to the fibre content and the WHC, the investigated plants are likely to contain several PSM with bitter or astringent taste and decreasing intake by negatively affecting the physico-chemical properties of saliva and/or oral mucosa or inducing post-ingestion syndromes (Acamovic and Brooker, 2005, De Wijk and Prinz, 2006). In this study, only tannins were analysed. Consistently with our hypothesis, *V. unguiculata*, having the lowest tannin content, allowed the best response in DM intake of the 4 investigated species as the decrease in intake was rather limited to 20% of this forage in the diet.

Even when included at 10%, *P. phaseoloides* was less consumed than the other species, due to the combined effect of its high WHC and tannin content. Processing forage may increase intake or delay the reduction in intake, as found in recent studies with *S. guianensis*, which was more frequently consumed as silage than as leaf meal (Kaensombath et al., 2013; Phengsavanh and Lindberg, 2013). Martens et al. (2013) stressed that ensiling is a suitable fermentation method for both grains and whole crop forage, reducing anti-nutritive compounds in forage and, consequently, increasing digestibility and intake in pigs. Those techniques therefore deserve further investigation for pig feeding uses.

As expected, increasing the forage level in diets resulted in a linear decrease of TTAD of DM, OM, CP, NDF, and gross energy (GE), a decrease in N retention, and a decrease in energy contents ($P<0.001$). The decrease in TTAD was likely due to the increase in NDF content, as reported in the literature (Len et al., 2007; Lynch et al., 2007). Fibre fractions increase the chyme and digesta passage rate, reducing the accessibility and time of action of digestive enzymes and reducing global digestibility (Partanen et al., 2007). NDF significantly influences digestibility, especially energy digestibility (Noblet and Le Goff, 2001). The results of faecal protein digestibility are in agreement with the data obtained for other tropical forage species in sows (0.30 to 0.57; Leterme et al., 2006) but are markedly higher than those (0.07 to 0.21) obtained by Régnier et al. (2013) in Creole pigs with other forage species.

The inclusion of forage legumes reduced crude protein digestibility from 0.80 to 0.68 and N retention from 0.58 to 0.33, for the basal diet and *P. phaseoloides* incorporated at 25%, respectively. The reduction in digestibility could partially be due to the bounds between protein and the NDF fraction, preventing them from being hydrolysed by the digestive enzymes of the pigs (Bindelle et al., 2005). The results of this study show that up to 36% to 46% of the N, for *P. phaseoloides* and *P. scandens,* respectively, was bound to the NDF fraction, negatively affecting protein digestibility, as reported by Leterme et al. (2006). However, low faecal N digestibility values do not always mean low protein values. The high fermentable fibre content of some forage species reduces the apparent faecal digestibility of N through a shift of N excretion from urinary N as urea to faecal N as bacterial protein without systematic alteration of the protein value of the diet (Bindelle et al., 2009). This explains why *S. guianensis* shows similar faecal N apparent digestibility to *P. scandens* and *V. unguiculata* but its N retention value at the 25% forage inclusion level remains higher. This is probably a combined effect of urea uptake by bacteria in the large intestine when fermenting the fibre fraction of the forage, as shown by the high NDF digestion value of *S. guianensis*-based diets. Nevertheless, further determination on the protein value of the forage species will require ileal digestibility values for protein and amino acids, which could not be measured in the framework of this experiment.

Finally, in both experiments, the decreases in voluntary intake and digestibility can be partly ascribed to the fact that young pigs have a low capacity to ingest high-fibre diets and digest them as compared to larger animals such as sows (Noblet and van Milgen, 2004).

In conclusion, the intake of up to 200 g of *S. guianensis* and *V. unguiculata* per kg DM intake does not affect the voluntary intake of growing pigs. Due to their negative effect on the overall digestibility of the diets, their contribution to the diet should not exceed 12.5%, except for *S. guianensis,* in which N-retention remained quite high (0.44) at the highest inclusion level (25%). Due to its low intake and low digestibility, the use of *P. phaseoloides* in pig feed should be discouraged.

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CHAPTER V

The results from the previous chapter, namely the decreases in voluntary intake and digestibility with increasing levels of forage in the diets can be partly ascribed to the fact that young pigs have a low capacity to ingest high-fibre diets and digest them as compared to larger animals such as sows. In addition, both experiments were performed during a short period. To properly assess the effects of these decreases in feeding performances on smallholders it was necessary to conduct a growth experiment for a longer period time during which the pigs were fed a forage-based diets and measure growth performances and production costs. This work was carried out in Chapter 5 that aimed at assessing feed intake and growth performance of pigs restrictely fed a soybean-corn diet supplemented with fresh forage legumes.

Article 5
Impact of feeding three tropical forage legumes on growth performance, carcass traits, organ weights, and production costs of pigs

Prepared for submission to Tropical Animal Health and Production

Bienvenu Kambashi[1,2], Christelle Boudry[2], Pascale Picron[2], Jérôme Bindelle[2,3]

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

[2]University of Liège, Gembloux Agro-Bio Tech, Animal Science Unit, Passage des Déportés, 2, 5030, Gembloux, Belgium

[3]To whom correspondence should be addressed: jerome.bindelle@ulg.ac.be, phone: +3281622609 fax: +3281622115

1. Abstract

The effects of tropical forage legumes on feed intake, growth performance and carcass traits were investigated in 16 groups of 2 Large White pigs. The diets consisted of a commercial corn-soybean-meal diet as the basal diet and 3 forage-based 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 3 forage legumes (*Psophocarpus scandens*, *Stylosanthes guianensis* and *Vigna unguiculata*) *ad libitum.* Feeding forage legumes lowered the dry matter intake (DMI) by 4.5 to 9.6 % ($P < 0.001$), final body weight ($P=0.013$), slaughter weight, average daily gain (ADG) and hot carcass weight ($P < 0.05$) without affecting the feed conversion ratio (FCR), dressing percentage and back fat thickness. Except for stomach weight, there was no forage effect on internal organ weight. In conclusion, using forage to feed pig could be interesting in pig smallholder production with limited access to concentrate as long as the forage production costs are marginal.

Keywords: Forage, Nutritive value, Pigs, Body Weight, Average Daily Gain, Feed Costs.

2. 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, i.e. < 5% in Western DRC (Kambashi et al., in press), mostly around and near highly populated cities and in market-oriented production systems. Others 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, 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 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., 2007; Kambashi et al., 2014; 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., 2014). Psophocarpus is a common wild plant that grows in lowlands up to an altitude of 1,000 m, in areas with an average annual rainfall of 1,220–1,800 mm and a mean annual temperature of 25°C. Psophocarpus was introduced as leafy vegetable in several African countries, but it has received limited acceptance (Schippers, 2004). Stylosanthes grows from an altitude of 0 to 1,600 m, between 600 mm to over 3,000 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.

As most data available on these species is limited to the nutritive value in pigs, the present study aimed at assessing how feeding forage legumes to pigs actually affects 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.

3. Material and methods

Forage legumes were produced on a farm field of the SOGENAC (Société des grands élevage de Ndama en Afrique centrale) in the DRC, 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 1,418 mm in 2012 (SOGENAC, personal communication). The average monthly temperature ranged from 21.5 to 25.4 °C. The field had a ferralitic 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. Vigna was grown 3 times in different fields, 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 regular basis. Since the experiment on pigs lasted for 90 days, forage samples were taken daily and pooled over 10-days periods to make up a total of 9 independent samples for each forage species. The chemical composition as well as the amino acid profiles of the forage used in the experiment are displayed in Table 28. Amino acids were determined only on 6 randomly chosen samples out of the 9 that were available as explained previously.

1. Animals, feeding and management

Thirty-two castrated male growing pigs (Large White × Duroc) with an average body weight of 25.5 ± 4.2 kg at the beginning of the experiment and 74.3 ± 8.0 kg at the end were used. On arrival, the pigs were kept and observed for one 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 2 pigs (average weight: 50.0 ± 1.2 kg). Each group was 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 DM basis or the basal diet fed at 3.2 % of body weight on DM basis (80 % of the allowance of the control groups) completed with fresh leaves of one of the 3 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-days periods for further chemical analyses as explained above. The refusals underwent the same treatment. Since the experiment lasted for 90 d, there were a total of 9 samples for the basal diet and for each of the forage species. 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 had been disinfected and repainted with lime two 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 d until the end of the experiment. After 90 d, all pigs were slaughtered after an overnight fasting and the empty carcasses and major organs were weighed. Back fat was measured at the P2 position, 65mm away from the midline, at the level of the last rib.

Table 28. Proximal composition of tropical forage legumes and essential amino acid contents of the basal diet and the forage legumes fed to the pigs (g/kg DM) (N=9 except for amino acids where N=6)

	Control diet	Psophocarpus scandens		Stylosanthes guianensis		Vigna unguiculata	
		Mean±SD[1]	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max
Dry matter of fresh forage		201±23		216±25		156±16	
Ash	69±3	95±9		92±11		131±31	
Crude protein (N x 6,25)	192±7	230±18	194-252	194±24	150-226	212±29	172-263
Neutral detergent fibre	228±19	473±28	431-524	507±64	419-596	359±61	259-446
Acid detergent fibre	60±2	316±27	271-354	347±59	234-460	252±58	155-311
Acid detergent lignin	17±1	70±10	55-82	64±13	48-80	51±14	23-65
Gross energy (kcal/kg DM)	4455±18	4457±91	4263-4557	4335±54	4224-4408	4233±95	4206-4472
Essential amino acids (g/Kg DM)							
Arginine	12.3±0.9	10.3±0.7		9.6±0.8		12.6±0.7	
Histidine	5.0±0.3	4.3±0.1		3.8±0.4		4.4±0.4	
Isoleucine	7.3±0.6	8.8±0.4		7.8±0.9		10.0±0.9	
Leucine	14.1±0.9	14.2±0.6		13.0±0.9		16.5±0.9	
Lysine	7.7±0.6	9.4±0.6		8.1±0.7		9.7±0.9	
Methionine	3.4±0.3	3.5±0.4		3.2±0.2		4.2±	
Phenylalanine	8.7±0.5	9.4±0.5		8.8±0.8		10.9±0.9	
Threonine	7.8±0.5	10.1±0.4		8.5±0.9		10.5±0.9	
Tyrosine	4.9±0.3	5.0±0.3		4.6±0.5		5.5±0.7	

[1]Standard deviation

The production costs of diet for pigs whose diet was supplemented with forage was calculated by adding the cost of the commercial diet to the production costs (agricultural inputs, labour and mechanization, Table 31) of the forage actually consumed by pigs. The feed cost per kilogram of gain weight was then calculated by the ratio of the feed cost of the average feed consumed during the whole period of the experiment on the average daily gain. The economic value of carcasses was calculated per kg of body weight irrespective of their conformation.

2. Chemical analyses

Dry forage legumes (60°C for 48h) and basal diet samples were ground to pass a 1 mm mesh screen in a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark) and analysed for their content in dry matter by drying at 105 °C for 24 h (method 967.03; AOAC, 1990), in ash by burning at 550 °C for 8 h (method 923.03; AOAC, 1990), in N according to the Kjeldahl method and calculating the crude protein (CP) content (N × 6.25; method 981.10; AOAC, 1990), in gross energy by means of an adiabatic oxygen bomb calorimeter (1241 Adiabatic Calorimeter, PARR Instrument Co., Illinois, USA), and in 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, in acid detergent lignin (ADL) according to Van Soest et al. (1991) using an ANKOM-Fiber Analyzer (ANKOM-Technology, Fairport, NY), and in amino acids by HPLC (Alliance 2690, Waters) after hydrolysis with a mixture of 6 mol HCl/l containing 1 g phenol/l at 110 °C for 24 h and derivatization with the AccQ-Fluor reagent Kit (Waters, USA). Methionine and cystine underwent performic oxidation before hydrolysis.

3. Statistical analysis

Data were subjected to an analysis of the variance using the MIXED procedure of the SAS 9.2 software (SAS Inc., Cary, NC) with the individual pig as experimental unit for carcass composition and organ weights and the group of 2 pigs for growth performance parameters and costs calculation. 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.

4. Results

1. Feed intake

Forage legume intake was less than the 20% expected from the reduction in basal diet allowance and it resulted in a reduction in dry matter intake (DMI) ($P < 0.001$). However, the Stylosanthes-based diet had a higher DMI than the Vigna- and Psophocarpus-based diets (Table 30). Moreover, the difference between Stylosanthes and the control was not significant when expressed per kg of metabolic weight, 108 and 110 kg DM/kg$^{0.75}$ respectively, and the intake in those diets were higher than for the 2 other forage-based diets (Vigna and Psophocarpus). Finally, when considering forage intake alone, it was highest with Stylosanthes (321 kg/d) as opposed to Vigna (232 kg/d) and Psophocarpus (214 kg/d). The DMI was related to the DM of the forage ($R^2 = 0.74$, $P < 0.05$).

Table 29. Effects of reducing feed allowance in corn-soybean meal diet and supplementing with tropical forage legumes on growth performance, daily feed intake and feed conversion ratio (FCR) in pigs

	Control[1]	*Psophocarpus scandens*	*Stylosanthes guianensis*	*Vigna unguiculata*	*P values*	*SEM*[2]
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 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*
Feed cost ($US/kg gain)	*1.462*	*1.390*	*1.408*	*1.381*	*0.157*	*0.01*

[1]Values within row with differing superscript letters are significantly different (P<0.05)
[2]SEM, standard error of the means

2. Growth performance

The average daily gain (ADG) ranged from 515 to 597 g/day and feed conversion ratio (FCR) from 3.52 to 3.67. The reduction (20%) of the basal diet with *ad libitum* supplementation of forage reduced the average daily gain (ADG), while FCR remained unaffected. However, the way it reduced the weight gain differed between forage species. The ADG was higher ($P < 0.05$) in control pigs than those on the Psophocarpus- and Vigna-based diets (Table 29), while no difference was found between control pigs and those fed the

Stylosanthes-based diet. Nevertheless, differences in ADG between forage species were not significant.

3. Carcass composition and organ weights

The pigs supplemented with fresh forage legumes had lower hot carcass weights (P<0.05), while the dressing percentage ranged from 72.7 to 75.1% (Table 30) and was unaffected (P = 0.19). However, no differences were found between forage species.

Table 30. Effects of reducing feed allowance in corn-soybean meal diet and supplementing with tropical forage legumes on carcass composition and organ weight in pigs

	Basal diet[1]	*Psophocarpus scandens*	*Stylosanthes guianensis*	*Vigna unguiculata*	*P values*	*SEM*[2]
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	*1395*	*1306*	*1382*	*1401*	*0.650*	*29.1*
Lung	*706*	*752*	*725*	*801*	*0.361*	*23.6*
Kidney	*299*[a]	*238*[c]	*251*[bc]	*276*[ab]	*0.001*	*7.0*
Kidney (g/kg carcass weight)	*5.0*	*4.3*	*4.5*	*4.9*	*0.125*	*0.12*

[1]For one column, means followed by different letters differ (P<0.05)
[2]SEM, standard error of the means

Among organ weights, the stomach varied from 640 to 756 g and differed (P<0.05) between treatments (Table 30). Control pigs had lower stomach weights than those on forage. The Stylosanthes-based diet tended to result in a heavier stomach than the Vigna-based diet. Other organs were unaffected by the treatments.

Table 31. Cost of production of forage species

Items	*Psophocarpus scandens*	*Stylosanthes guianensis*	*Vigna unguiculata*
Seeds ($ USD/ha)	*80*	*80*	*28*
Plowing and harrowing (tractor) ($ USD/ha)	*160*	*160*	*160*
Seedlings (10 man-days) ($ USD/ha)	*100*	*100*	*100*
Weeding (20 man-days) ($ USD/ha)	*200*	*200*	*200*
Havest (10 man-days) ($ USD/ha)	*100*	*100*	*100*
Cost of production ($ USD/ha)	*640*	*640*	*588*
Yield (kg DM/ha)	*7471*[1]	*6267*[1]	*6043*
Yield in edible parts (kg DM/ha)	*3716*	*3734*	*3071*
Cost of production of edible parts (USD/kg DM)	*0.186*	*0.185*	*0.208*

[1]Yield of two crops (first crop and yield of regrowth after the first haverst)

The cost of production is almost the same for all forage species. The item of expenditure which differed is the price of the seeds. The cost of production per kg of edible dry matter for feeding pigs seems slightly higher for Vigna despite its lower seed cost

5. Discussion

Pigs were not able to fully compensate the 20% reduction in basal diet feeding allowance using forage legumes. It resulted in lower DMI and, as a consequence, lower nutrient intake, which, in turn, resulted in lower growth performance and lower slaughter hot carcass weight. The low DMI in this study is related to the high water and high fibre content of the forage-based diet compared to the control diet (Table 29). Moreover, the high water-holding capacity of some dietary fiber 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 before the nutritional requirements are met and, thereby, prevent animals from continuing to eat. 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. The absolute capacity for bulk is related to live weight by a quadratic function (Whittemore et al., 2003). A study with pigs fed Stylosanthes and *Aeschynomene histrix*-based diets showed a similar decrease in DMI when forage (13, 21 and 37%) was included in the pig diet (Phengsavanh and Lindberg, 2013). However, Keoboualapheth and Mikled (2003) reported an increase in individual feed intake from 942 to 1309 g DM/d when pigs fed a protein deficient corn and rice bran-based diets were supplemented with fresh Stylosanthes. The intake in Stylosanthes represented less than 12% of the total intake, showing that supplemented pigs were prone to eat more of the protein deficient basal diet and not only the extra forage. However, in the present experiment, the average daily forage DMI intakes were 214 g, 321 g and 232 g DM (Table 29) respectively, reaching 11.5, 16.2 and 12.3% of the average daily DMI for Psophocarpus, Stylosanthes and Vigna, 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. However, this higher consumption compared to Vigna should be considered as relative because the latter had a DM content of 19% lower than Stylosanthes (Table 28), which may have influenced its DMI. The DMI of forage resources can be improved by processing methods 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; Martens et al., 2013). In a study by Sarria et al. (2010), Vigna leaf meal was incorporated up to 32.9% of DM, in replacement of wheat bran, allowing a reduction of soybean meal thanks to the protein provided by Vigna. No difference in weight gain, daily feed intake and final weight between treatments was observed. It is clear from that study that processing of fresh Vigna to leaf meal encourages DMI with a positive effect on growth performance.

Thus, to produce high quantity of high quality forage, the agronomic conditions and the potential yield of biomass of the species should be considered, but also other parameters that may affect feed intake such as fibre content, which depends on the forage maturity and the proportion of leaves to stalks (Buxton and Redfearn, 1997).

While the final weight and ADG were not different between control pigs and pigs supplemented with Stylosanthes, the carcass was heavier for pigs eating the control diet. This means that the live weight of pigs fed Stylosanthes was strongly counterbalanced by their digestive tract contents, which were heavier than those on the basal diet, probably due to the high WHC of its fibre content (7.5 g H_2O/g DM) as opposed to Vigna (5.9 g H_2O /g DM) (Kambashi et al., submitted). 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. Although no difference in DMI expressed per kg of metabolic weight was found between the control and Stylosanthes diet, the latter showed a lower hot carcass weight. These results are consistent with those of Phengsavanh and Lindberg (2013) who found a decreased growth rate and DMI with increased legume leaf meal; but they are inconsistent with the results of Kaensombath and Lindberg (2013) and Kaensombath et al. (2013) who found no effect on growth performance and DMI in pigs fed ensiled *Colocasia esculenta* and Stylosanthes-based diets containing up to 325g NDF/kg DM. This discrepancy can possibly be explained by the already high NDF content of the commercial diet (228 g NDF/kg DM) in this study.

In contrast with growth performance, carcass quality and dressing percentage was not influenced by the inclusion of forage. However, pigs fed forage based-diet had heavier stomachs than those on control diets. The present result is consistent with those of earlier studies (Len et al., 2009; Ngoc et al., 2013) where stomach weight was affected by increasing fibre level. Pigs fed Stylosanthes tended to have a high stomach weight (P=0.054) probably due to its high fibre content.

Moreover, the low growth performance of pigs fed forage originates from the fact that those diets were compared with a commercial balanced diet in pigs with a high growth potential but also high nutritional requirement. Earlier studies have shown that the use of forage legumes significantly improved growth when pigs are fed an unbalanced and fibre-rich diet, generally made of crop residues and by-products available on the farm (Keoboualapheth and Mikled, 2003; Phengsavanh and Lindberg, 2013).

The inclusion of forage had no effect on feed cost per kilogram gain between diets. Feed costs were reduced to 4.0, 4.9 and 5.2% (0.058, 0.072 and 0.076 $US/kg weight gain) when pigs were fed forage legumes based diet (Table 29). The lower effect of forage on feed cost is partially due to its low consumption conversely to what had been expected. Nevertheless, on smallholders’farms, the cost of forage production would be lower than that obtained in this study for several reasons: (i) forage legumes are grown either in association with other crops or cover crops, which would reduce costs for the preparation of soil, (ii) family labour is used and would be unemployed if is was not to work on the family farm.

Feeding forage legumes to pigs in replacement to a reduction of 20% of feed allowance of a well-balanced basal diet 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. However, due to lower production costs, the use of forage legumes to pigs makes sense for smallholder pig producers with limited access to commercial concentrate feeds or working with local breeds with lower nutritive requirements.

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CHAPTER VI

General discussion

This thesis addressed the relevancy of the use of local forage resources by pig smallholders in the provinces of Bas-Congo and Kinshasa, in the western part of the Democratic Republic of the Congo. The survey was conducted to characterise the actual system used to rear pigs. This survey highlighted the reasons why smallholders use forage in the diets of their animals.

In the investigated areas, pigs are held primarily by farmers that possess a small herd (18 pigs and 3 sows per farm, on average). These farms are largely oriented towards the market, primarily to provide cash for the farmer, and then to support the family's needs for animal products. This is very similar to other situations in Africa (Ajala et al., 2007; Kagira et al., 2010), and it should represent an asset, since market-oriented producers are more likely to be receptive to system changes that prove useful in increasing profitability.

Nonetheless, biosafety and sanitary conditions in the investigated pigs' farms were also identified as major constraints to sustainable production and profitability. The studied area is an endemic area for many diseases, including the African swine fever (ASF). These deseases increase the risk taken by farmers when investing in pig production (Costard et al., 2009; Fasina et al., 2012). Tighter health regulations and health surveillance systems are absolute necessities, in addition to a better training for the farmers regarding farm hygiene and biosafety measures, in order to allow a wider development of pig production in those provinces. Improved hygiene would also benefit the pigs' individual performances, since Renaudeau et al. (2009) reported that poor hygienic conditions make pigs less productive and more susceptible to diseases.

Besides sanitary conditions, the other major constraint identified during the survey is related to the slow growth and high mortality rates (Table 8) caused by unbalanced diets and the poor genetic background of the animals. Therefore, it seems justified to investigate feeding practices that could improve the nutritional status of the animals, even if improvement genetics should also come along. However, such action towards genetics requires increasing as suggested before the confidence in biosafety for the herd of the farmers who will have to invest in improved boars and sows and want to seehis efforts ruined by an ASF epidemic.

The suspected poor feeding status of the animals observed in the surveyed farms is consistent with the low number of farmers (4%) who can afford to feed their animals commercial diets (Table 16). As is often the case in developing countries, most of the farmers use feedstuffs that are available on and around the farm, including a wide range of forage plants, because commercial diets and agro-industrial by-products are either inaccessible or too expensive, and are often both. When available, some by-products provide energy and are low in protein, except for brewer's grains, which are of poor nutritive value for pigs, making an unbalanced diet that results in poor growth performance and high piglet mortality rates (Phengsavanh, 2013).

The choice of forage species is a key issue to ensure their rational use to feed pigs. The 20 most commonly used forage species, as determined by the survey, were investigated using an *in vitro* model of the pig gastrointestinal tract. This work showed that some species (*Amaranthus hybridus*, *Ipomoea batatas*, *Manihot esculenta*, *Moringa oleifera*, *Psophocarpus scandens* and *Vigna unguiculata*) seem quite interesting and farmers were right to in the use of the species.

Other species badly scored (grasses, as well as *Acacia mangium*, *Eichhornia crassipes* and *Cajanus cajan*). It should be interesting to uncover the reasons that drive farmers to use those species in the pigs' diets, despite the forage poor nutritive values.

In vitro models are used in order to provide a useful alternative to *in vivo* models, by rapidly screening large numbers of ingredients (Hur et al., 2011). However, as explained in Chapter 3, many factors interfering with the intake and the digestive processes are not considered with the chosen *in vitro* model. Therefore, if a species scored badly *in vitro,* it is likely to be as bad when fed to pigs. However, the opposite is not true, and definite conclusions cannot be drawn regarding the forage species that have apparent good nutritive attributes when using *in vitro* the model.

Among the interfering factors is the impact of bulkiness and viscosity on digestive enzymes and transit time (Ferrua & Singh, 2010). For example, in humans, altering the lumen viscosity can significantly reduce the glucose from starch hydrolysis that becomes available for absorption (Tharakan et al., 2010). Another factor is the impact of some secondary metabolites, such as tannins, on the *in vivo* increase of endogenous losses in animals, including mineral losses by chelation, resulting in a lower level of minerals available for absorption (Acamovic & Brooker, 2005; Gaffney et al., 2004; Stukelj et al., 2010).

Because of the above-mentioned drawbacks of the *in vitro* approach, three *in vivo* experiments were conducted in an attempt to classify the effectiveness of the most promising forage species to partly substitute for part of the concentrated feed ingredients, as well to reduce production costs.

The nutritive value of forage species measured *in vivo* was not as high as predicted when using the *in vitro* method. The calculation of the nutritive value of the forage as determined by the extrapolation of the value obtained when the forage was incorporated into a basal well-balanced diet at a rate of 12.5 and 25% differed according to the inclusion rate (Table 32). This is due to a suspected quadratic function of digestibility parameters with the forage inclusion, but the quadratic relationship could not be formally proven, since only three levels of incorporation of the forage were tested (0, 12.5, 25%).

Nevertheless, the ranking of the forage species was similar to taht obtained using the *in vitro* method. With the exception of *P. phaseoloides,* for which the coefficient of the *in vitro* N digestibility was higher than with *P. scandens* and *S. guianensis* (Table 32), the rank order of digestibility remained the same, with *V. unguiculata* being the most digestible species. *P. phaseoloides* was the least consumed species, while also being one with both high fibre content and high water holding capacity.

Table 32. Trend digestibility of forage species measured in vitro and extrapolated in vivo models

	Psophocarpus scandens			*Pueraria Phaseoloides*			*Stylosanthes guianensis*			*Vigna unguiculata*		
	In vitro[1]	*In vivo*[2]		*In vitro*	*In vivo*		*In vitro*	*In vivo*		*In vitro*	*In vivo*	
Inclusion rate (%)		*12.5*	*25*		*12.5*	*25*		*12.5*	*25*		*12.5*	*25*
Digestibility (%)												
Nitrogen	*0.69*	*0.50*	*0.40*	*0.75*	*0.37*	*0.34*	*0.67*	*0.55*	*0.37*	*0.81*	*0.60*	*0.48*
Energy	*0.58*	*0.41*	*0.29*	*0.54*	*0.24*	*0.22*	*0.58*	*0.37*	*0.23*	*0.66*	*0.47*	*0.35*

[1]The *in vitro* nitrogen coefficient is calculated from the enzymatic hydrolysis, while the energy coefficient includes the enzymatic hydrolysis and energy from short-chain fatty acids.
[2]Fecal apparent digestibility calculated by the substitution method

To use forage in the diets of pigs, it is necessary to select species with high protein content. However, emphasis should also be placed on the fiber content. The high fiber content affects the intake and digestibility, both factors determining the nutritional value, by its physicals properties. Fiber with high WHC leads to high bulkiness inside the digestive tract of the pig, due to the swelling of the fibre component (Bach Knudsen, 2001). This bulkiness reduces the feed intake through reduced emptying rate of the stomach (Leterme et al., 2006). Fibre fractions increase the chyme and digesta passage rate, reducing the accessibility and time of action of digestive enzymes and reducing global digestibility (Partanen et al., 2007). Therefore, the fiber content of the other ingredients of the diet should be taken into account in determining the incorporation rate of forage in the diet. For example, a higher incorporation rate may be used in a diet based on cassava root which is both low in protein and fibre. Cassava root was showed in the survey (Chapter 2) to be widely available in most areas of Western DRC.

In Chapter 4, we have assumed that the decrease in digestibility was due to high fiber content of basal diet. As consequence, this diet had a low digestible energy content. Fibre strongly interferes with protein digestibility. Proteins can be bound to the NDF fraction preventing them from being hydrolysed by the digestive enzymes of the pigs. This NDF-bound protein fraction is higher in dicotyledons than grasses (Bindelle *et al*., 2005). However, high fermentable fibre content of some forage species decreases the fecal apparent digestibility of N through a shift of N excretion from urinary-N (urea) to fecal-N (bacterial protein) without systematically altering the protein value of the diet (Bindelle *et al.*, 2009). The results displayed in Table 23 show that up to 36% to 46% of the N, for *P. phaseoloides* and *P. scandens*, respectively, was bound to the NDF fraction, negatively affecting protein digestibility. This explains the low protein digestibility of these species.

The hay-making treatment applied to the forage in the first two *in vivo* experiments (Chapter 4), including the voluntary intake and the digestibility measurement, also influenced the composition of the forage, lowering its digestibility. In the growth experiment, (Chapter 5) changes appeared in the protein and fibre content of the same species over time. Protein content varied from 207–277 g/kg DM, 150–226 g/kg DM and 172–272 g/kg DM, while the NDF content varied from 43–578 g/kg DM, 419–596 g/kg DM and 259–446 g/kg DM for *P. scandens*, *S. guanensis* and *V. unguiculata*, respectively, despite the fact that the seeds were from the same batch and sowed in similar fields. This drift in composition originates not from the harvesting methods and post-harvest treatments used, but rather from the maturity of the plant itself at the time of harvest.

Samples used in the *in vitro* screening experiment were collected in small quantities and treated with the maximum level of care. Forage species for the experiments testing voluntary intake and digestibility were harvested in mass quantity and dried in open air. Drying can induce a change in the leaf: the stem ratio and the chemical composition, as compared to the initial product, due among others to the loss of leaves. For the experiment testing growth performance, fresh forage was used. The specimens were harvested regularly over an extended period of time (from 1–3 months), inducing different maturity levels of the collected plants, resulting in an increase in the fibre content and a decrease in the protein content over time (Table 28), as reported elsewhere (Melvin & Marya, 2001; Sudekum et al., 2006).

Moreover, when large amounts of forage are harvested, it is difficult to maintain a high leaf/stems ratio. It is also difficult to harvest only tender leaves, stems or shoots. The use of fresh forage is not ideal either due to a higher water content, in addition to anti-nutritional factor contents that affect the feeding value (Leterme et al., 2005; Régnier, 2011). It is therefore important develop the practical feeding methods that could be recommended to farmers in order to optimise the balance between feed intake, nutritive value and operation costs.

Forage should be harvested at the right time in order to yield a high biomass with low fibre and high protein contents. The forage should also be processed in a manner that leads to a decrease in water and anti-nutritional compounds (Hare et al., 2007; Phengsavanh & Frankow-Lindberg, 2013). In addition, processing forage can increase its quality, providing a stable nutritional value over an extended period of time, helping farmers to cope with periods of shortage. Preserving forage usually increases its feeding value and voluntary intake when anti-nutritive compounds are present (Martens et al., 2013; Nguyen et al., 2012).

In Chapter 4, we used hay, but silage is probably a better alternative, as it requires less energy to make and is not dependent on weather conditions in the tropical humid climate of the DRC, where rains are abundant during ideal periods for forage crops. However, as already mentioned when discussing improvements in sanitary conditions, making silage requires farmers to be trained to yield a final product that has a good nutritive value for pigs.

In addition to these considerations regarding plant material quality, the most striking conclusion from the *in vivo* experiment is that despite a reduction in dry matter intake and digestibility that impaired growth performance, the feed conversion ratio was not affected. However, the production cost per kilogram of live weight was not significantly reduced either, due to the fact that the costs of forage cultivation and harvesting were supported by forage alone. Nevertheless, if forage legumes are fully integrated into the agricultural system based on optimised fallows, a multi-year forage production, including the rotation and association with food crops, could be associated with reduced costs could occur.

In the western provinces of the DRC, where smallholders commonly plant corn and cassava, forage legumes can be added into the crop rotation or as part of an inter-cropping system. The integration of forage legumes into cropping cycles will have the potential to increase yields of subsequent crops through the increase in plant available nitrogen (N) in the soil (Odunze et al., 2004). For forage, soil could either be partially prepared or not prepared at all, and the nitrogen fixed by legumes will support both animal production and food crops. In addition, if forage consists of the by-products of food crops, such as cassava and sweet potato, the production costs would be even lower because they would consist solely of harvesting and storage costs.

Moreover, the growth experiment (Chapter 5) was performed by partly substituting a well-balanced diet with forage, and since farmers seldom use such commercial feeds (Chapter 2), the impact of adding the most appropriate forage species to cassava peels or brewer’s grains diets could produce results that further favoured the use of those forage species, even above what was concluded from the growth experiment in Chapter 5.

Furthermore, the most interesting forage plants fed to pigs, especially legumes, are rich in protein. Offered *ad libitum,* this could lead to an excessive intake of protein. Compared to animal protein, plant proteins have a lower digestibility, partially due to some parts of proteins that are trapped within the fibre matrix. These trapped proteins escape digestion in the small intestine, and are fermented in the caecum and the colon instead. Anaerobic degradation of undigested protein in the large intestine by the resident microbiota produces toxic metabolites, such as ammonia, amines, phenols and sulphides, which are detrimental for the host animal’s health (Davis & Milner, 2009; Manning & Gibson, 2004) and support the growth of potential pathogens.

This mechanism is one of the causes for the occurrence of weaning diarrhoea in piglets (Molist et al., 2014) and accounts for a reduced health status. However, in contrast with more conventional protein-rich ingredients, forage plants that are rich in protein come with fermentable fibre too. This fermentable fibre reduces the intestinal fermentation of protein as a source of energy for bacteria, since the amino acids are used to anabolise the bacterial protein during bacteria’s growth, using fibre as an energy source (Bindelle et al., 2009).

Furthermore, short-chain fatty acids, resulting from fibre fermentation, are a source of energy for the animal, but also act as anti-microbial compounds. Butyrate is the most important energy source for colonocytes and plays a major role in both proliferation and differentiation. Bartram et al. (1993) hypothesised that the toxic effects of ammonium were counteracted by the differentiating effects of butyrate. In addition, it was reported that butyrate inhibits colonic carcinogenesis and inflammation, reduces oxidative stress and reinforces the colonic defence barrier (Hamer et al., 2008; Vermorel et al., 2008; Windey et al., 2012).

Forage plants, such as *I. batatas, M. esculenta, P. scandens, M. oleifera, S. guianensis, V. unguiculata,* which, in addition to their high protein content and high dry matter digestibility, showed a rapid fermentation (10.9–16.7 ml/h) with high productivity of SCFA (342–405 mg/g), seemed to display a valuable profile for both growth performance and intestinal health. However, considering the profile of the protein balance of the forages species (Table 22), and their deficiency in some essential amino acids for pigs, a synthetic amino acid supplementation, when accessible to farmers, would be an important alternative when an increase in the growth performance of pigs fed on forage is desired.

Finally, forage seems to be an interesting ingredient for gestating and lactating sows. Indeed, when sows are fed a high fiber diet, the frequency of posture changes is decreased during pregnancy and lying time is more important (Ramonet et al., 1999). In the rearing conditions, especially in tropical pig smallholder, where pigties are not equipped with a protective device for young piglets, such a decrease in the frequency of changes of position of sows may help reduce the number of piglets crushed in early lactation which was shown to be a problem in the survey (Chapter 2). Loisel et al. (2013) found higher consumptions of colostrum and lower mortalities in litters from sows fed a rich fiber diet compared piglets from sows in a diet with low fiber. These authors hypothetized that these effects could be related to greater vitality of piglets and sow behavior at parturition. Other results showed an increase in the weight gain of piglets during the first week of life when fiber was incorporated in sow diets. It is also possible that the effect of the fiber depends on length of time sows are fed such a diet, its source and its physico-chemical properties (Guillemet et al. 2007, Oliviero et al. 2009)

In conclusion, although forage species reduced the nutritive value of well balanced diets and the growth of animals, the investigated legumes did not impact negatively the economical balance of concentrate-fed pigs when forage accounted for about 10 % of the diet. However, considering pig feeding system and feed ingredients used by pig smallholders in the provinces of Bas-Congo and Kinshasa in the Western part of the Democratic Republic of the Congo, some forage species are hypothetized to improve performances of animals fed ill-balanced diets as usually practiced.

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