Taro Leaf and Stylo Forage as Protein Sources for Pigs in Laos

Biomass Yield, Ensiling and Nutritive Value

Lampheuy Kaensombath
Faculty of Veterinary Medicine and Animal Science
Department of Animal Nutrition and Management
Uppsala

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Cover: Taro leaf or stylo forage, an alternative protein sources for pigs
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Taro Leaf and Stylo Forage as Protein Sources for Pigs in Laos: Biomass Yield, Ensiling and Nutritive Value

Abstract

Existing forage plants may have applications as alternative protein resources for pigs in smallholder farming systems. This thesis examined the effect of harvesting/defoliation interval on the yield and chemical composition of taro leaves and stylo forage and analysed appropriate ensiling methods for these materials. The effect of replacing soybean crude protein (CP) with ensiled taro leaf and stylo forage CP on growth performance and carcass traits of LY (Landrace x Yorkshire) and ML (Moo Lath) pigs was also examined.

Taro leaf and petiole dry matter (DM) yield increased with increased harvesting frequency in the two years studied, but there was no effect on tuber yield. The leaves contained 160-260 g CP kg^{-1} DM. Stylo leaf DM yield was unaffected by harvesting interval in the first year, while leaf DM yield was larger with the most frequent harvesting in the second year. The leaves contained 170-235 g CP kg^{-1} DM, which was much higher than in the stems or forage (leaves+stems).

Use of cassava root meal, sugar cane molasses and taro tuber meal as silage additives affected pH and the DM, ash and NDF content of stylo forage and taro leaf silage, and the NH_3-N content of stylo forage silage. Level of additive affected pH and DM, NH_3-N, CP, ash and NDF content in taro silage, but not NH_3-N, CP and NDF content in stylo forage silage. Increasing duration of ensiling reduced pH and DM content in stylo forage and taro leaf silage.

Dry matter intake (DMI) and CP intake (CPI) in growing LY and ML pigs were unaffected by increasing replacement (25 and 50%) of soybean CP by taro leaf silage CP in the diet, whilst for stylo forage silage DMI and CPI were highest when 25% of soybean CP was replaced. Average daily weight gain and feed conversion ratio (FCR), carcass weight, back fat thickness and dressing percentage were unaffected by increasing replacement of soybean CP with taro leaf or stylo forage CP in the diet. LY pigs had higher intake and better carcass traits than ML pigs.

The work confirmed that stylo forage and taro leaves can be used as protein sources in smallholder pig production systems without negative effects on the performance of growing LY and ML pigs.

Keywords: harvesting interval, taro leaf, stylo forage, yield, forage quality, taro leaves silage, stylo silage, growth performance, carcass traits

Author's address: Lampheuy Kaensombath, Department of Livestock and Fishery, National University of Laos. P.O. Box 7322, Vientiane, Laos
E-mail: lampheuyk@yahoo.com

Dedication

To my family with my respectful gratitude.

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List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Kaensombath, L. and Frankow-Lindberg, B.E. (2012). Effect of harvesting interval on biomass yield and chemical composition of taro (*Colocasia esculenta* (L.) Schott) for feeding pigs in Laos. *Field Crops Research* 128, 71-75.

II Kaensombath, L. and Frankow-Lindberg, B.E. (2012). Effect of defoliation on biomass yield and chemical composition of stylo 'CIAT 184' (*Stylosanthes guianensis* (Aubl.) Sw. var. guianensis). *Grassland Science* (In press).

III Kaensombath, L. and Lindberg, J.E. (2012). Effect of additives on ensiling of taro leaves (*Colocasia esculenta* (L.) Schott) and stylo CIAT 184 (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) forage as feed for pigs (Manuscript).

IV Kaensombath, L. and Lindberg, J.E. (2012). Effect of replacing soybean protein by taro leaf (*Colocasia esculenta* (L.) Schott) protein on growth performance of exotic (Landrace x Yorkshire) and native (Moo Lath) Lao pigs. *Tropical Animal Health and Production* (DOI: 10.1007/s11250-012-0172-7).

V Kaensombath, L., Neil, M. and Lindberg, J.E. (2012). Effect of replacing soybean protein by stylo (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) protein on growth performance of exotic (Landrace x Yorkshire) and native (Moo Lath) Lao pigs. *Tropical Animal Health and Production* (DOI 10.1007/s11250-012-0299-6).

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Abbreviations

ADF	Acid detergent fibre
ADG	Average daily weight gain
BW	Body weight
CIAT	International Center for Tropical Agriculture
CF	Crude fibre
CP	Crude protein
CPI	Crude protein intake
CR	Cassava root
DM	Dry matter
DMI	Dry matter intake
ES	Ensiled stylo forage
ET	Ensiled taro leaves
FCR	Feed conversion ratio
GDP	Gross domestic product
HCN	Hydrogen cyanide
LY	Crossbred Landrace x Yorkshire pigs
M	Sugar cane molasses
ME	Metabolisable energy
MEI	Metabolisable energy intake
ML	Moo Lath pig
NDF	Neutral detergent fibre
TR	Taro tuber

1 Introduction

Laos is a landlocked, mountainous country in South East Asia, with a total population of 6.4 million people (LSB, 2012). Around 75% are engaged in agricultural activities, and 66% live in rural areas and depend on farming and renewable natural resources for their livelihoods (FAO, 2012). In 2011, the agricultural sector accounted for 28% of GDP. The contribution of livestock and crops to agricultural GDP was 80% (LSB, 2012).

In addition to providing food, livestock plays an important role as a source of cash income and accumulation of capital for poor households in mountainous areas where shifting cultivation is practised. Pigs are commonly raised by smallholders, particularly in upland areas and in extensive systems with low capital inputs, and consequently the productivity is low. Rice bran, kitchen waste, maize, cassava, broken rice, vegetables and green plant material are the most common feedstuffs in these smallholder pig systems. The available feedstuffs mainly supply energy, while they are low in protein. Feedstuffs such as green plant materials are usually collected from the garden or from the wild. However, these plants are abundant in the rainy season, while feed shortages always occur in the dry season (Phengsavanh *et al.*, 2010; Thorne, 2005). Green plant materials are regarded as protein-rich feed sources. However, this is an increasingly scarce resource which results in lack of protein in pig diets and thus poor pig performance. To overcome this, one possibility could be to use cultivated low input crops (such as taro) and cultivated legume crops (such as stylo) as protein sources for improving pig diets in smallholder pig production systems.

Taro (*Colocasia esculenta* (L.) Schott) is grown for the edible corm as human food in Pacific Asia, as well as in Laos. It is the main home garden crop along with rice planting, but some farmers grow taro as a main crop for their family income and as a starch source (The National Biodiversity Strategy and Action Plan Project, 2003). It produces huge amounts of leaves during the vegetation period and a corm at the final harvest. The leaves and petioles are collected and are boiled with maize, rice bran, kitchen waste or cassava root before feeding pigs.

The forage legume Stylo CIAT 184 (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) was developed in Columbia for infertile soils in tropical climates, and can produce large quantities of good quality feed for cutting and grazing. It has been introduced into many countries in South East Asia, including Laos (Guodao *et al.*, 1997). It was promoted as a feed for both ruminants and pigs in the 1990s (Horn, 1998). In recent years, improving livestock production systems has been the highest priority for the Lao government in an attempt to alleviate poverty and reduce shifting cultivation. In this context, stylo forage is considered a suitable feed for supplementing village pigs, as manifested in many development projects and in advisory programmes in eight provinces of Laos (Stür *et al.*, 2010).

However, cultivated plants are only abundant in the rainy season (growing season), while there is usually a feed shortage in the dry season. Therefore, in order to ensure sufficient feed supply to the pigs throughout the year, without negative impacts on the major crop product (*e.g.* taro corm as human food), there is a need to find strategies that will allow optimal yield and quality, and that can be applied throughout the year.

2 Objectives

The general aim of this thesis was to study ways to improve the nutrition of growing pigs in smallholder farming systems in Laos using low-cost feed resources that are possible to cultivate on-farm.

Specific objectives were to:

- ✓ Investigate the effect of harvesting/defoliation interval on biomass yield and chemical composition of different plant parts of taro and stylo.
- ✓ Identify a simple method for ensiling taro leaves and stylo forage by using different levels of cassava root meal, taro tuber meal and sugar cane molasses.
- ✓ Evaluate the potential of protein from taro leaf and stylo forage silage to replace soybean protein in the diet of growing exotic and native Lao pigs.

2.1 Hypotheses

- Taro plants harvested frequently will produce greater leaf dry matter (DM) yield and smaller tuber yield than plants harvested less frequently.
- Stylo plants defoliated frequently will produce lower DM yield, but of a higher nutritional quality, than plants defoliated less frequently.
- Supplementation of pre-wilted plant biomass with 75 g cassava root meal or sugar cane molasses per kg will produce well-fermented silage of high nutritional quality.
- Up to 50% of soybean protein in the diet can be replaced by protein from taro leaf and stylo forage silage without negative impacts on growth performance and carcass traits in native Lao pigs, while a lower replacement rate is needed for exotic pigs in order to maintain growth performance and not impair carcass traits.

3 Background

3.1 Pig production in Laos

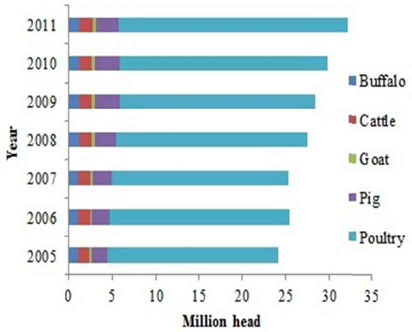

Figure 1. Population of livestock in Laos, 2005-2011 (LSB, 2012)

Livestock production is firmly based in the smallholder sector in Laos, with over 95% of all animals being raised by small farmers in both the Mekong corridor and on sloping land (Knips, 2004). Most pigs are raised in traditional smallholder production systems, but there is a trend for increasing pig production in commercial systems, close to densely populated areas, to meet the consumer demand for pork. Pork is the most popular meat consumed by people throughout the country. In 2004, pig meat production was estimated to be 40,919 ton, of which 30,230 ton (75%) originated from smallholders and 10,719 ton (25%) from commercial farms (MAF, 2005). Pig meat production increased to 47,000 ton in 2007, and is continuing to increase. As a result, the total pig numbers almost doubled (Fig 1) from 2007 to 2011 (FAO, 2012). Nearly 70% of the pigs are produced on small-scale farms (Huynh *et al.*, 2007).

Pig production in Laos can be classified into three main categories:

1. **Smallholder pig production,** which is common in remote areas. In these systems, several indigenous breeds (Moo Chit, Moo Lath, Moo Daeng and Moo Nonghaet), with mature weight 60-100 kg, are used (Vongthilath & Blacksell, 1999). Locally available feed sources from

villages, forests, along streams and gardens are used as pig feed. This production system is widespread in the north of Laos. The extensive management allows pigs to roam freely and scavenge for feed around houses and villages. In contrast, the smallholder pig producers in lowland areas keep weaned pigs for fattening in pens to supply the local market. The pigs are fed for 3-4 months until they reach slaughter weight at about 50 kg BW (Stur *et al.*, 2002).

2. **Semi-commercial pig production**, which is mostly found near population centres. In this production system, cross-breeds with imported breeds such as Landrace, Large White and Xingjin (from China) are commonly used (Wilson, 2007). The pigs are housed, and are fed with a mixture of locally available feedstuffs (rice bran, broken rice, cassava root and maize) and concentrate for 3-4 months to reach a marketable weight of 90-100 kg.

3. **Commercial pig production**, which is small compared with either smallholder or semi-commercial pig production. However, during the last 10 years the number of commercial pig farms has increased, particularly near the population centres in the Mekong corridor, due to high demand for pork. The pigs used are imported breeds, such as Large White, Landrace and Duroc. Feeding is based on concentrate and bagged commercial feed. Rice bran is used to supplement finishing pigs. Some commercial farms formulate and produce their own feed.

Considerable numbers of pigs are raised by smallholders using three different production systems: 1) free-scavenging, 2) semi-scavenging and 3) year-round confinement (Phengsavanh *et al.*, 2011).

Free-scavenging system: Typical for more remote and less accessible areas (inaccessible in rainy season and in dry season travel to the city market takes three hours by car). In this system, pigs are allowed to scavenge freely all year round. Additional feed is given occasionally. Pigs are kept in simple shelters, under dwellings, under rice storage sheds or under trees and farmers keep 2-4 sows plus piglets. They fatten pigs for special purposes, such as traditional festivals, weddings and cultural ceremonies.

Semi-scavenging system: Common in remote areas with cash crop cultivation. Pigs are only allowed to scavenge freely after the main crops have been harvested. During the free-scavenging period, farmers provide the pigs with a small amount of feed each day, while the main part has to be found by the pigs themselves. During the crop planting season, pigs are confined either in pens or enclosures near the village or close to crop production areas. During this period pig owners provide feed such as rice bran, maize and cassava, and green leaves which are available in the forest, on fallow areas, or along stream banks. This system is used for both piglet production and for fattening pigs.

Year-round confinement system: Common in areas close to the district centre. There are two types of confinement: pens and enclosure, and pigs are commonly kept confined throughout the year. The penning system is used to fatten pigs for sale, while the enclosure system is used to keep pigs away from the crops and improve village sanitation. In this system, farmers use exotic and crossbred pigs, feed concentrate to both piglets and growers and provide regular vaccination and de-worming. Pigs in enclosures are fed traditional feeds such as rice bran, maze, cassava and green plant material.

3.1.1 Main problems in smallholder pig production systems in Laos

The main problems in smallholder pig production systems in Laos are low growth rates, outbreaks of disease and high mortality of piglets. These problems are common in free-scavenging systems and in semi-scavenging systems. The management practices in these systems rely on traditional methods, with poor feeding and no vaccination against epidemic pig diseases. The feeding system varies depending on season. In the rainy season, which is the cultivation period, pigs are only fed once a day or are only fed when farmers do not work in the field. In the dry season, when crop harvesting has been completed, pigs are fed twice a day and the feed mainly contains agricultural by-products. Confinement in enclosures or pens allows better risk management. However, a good road that improves market access may also lead to exposure to epidemics of disease due to animal movement and uncontrolled visits from animal and meat traders (Chittavong *et al.*, 2012; Phengsavanh *et al.*, 2011).

3.2 Ensiling of forage

There are several methods to preserve forage for livestock. Ensiling is a cheap and simple method of controlled fermentation under anaerobic conditions in sealed containers that is used for preservation of high moisture crops in many regions of the world. There are two main purposes of the ensiling process, the first being to achieve anaerobic conditions by rapid filling of the silo and then sealing in order to prevent re-entry of air during storage. At any time during storage when oxygen comes into contact with the ensiled material, aerobic microbial activity occurs and the ensiled material will gradually deteriorate. The second purpose of ensiling is to encourage fermentation linked to microbial growth (*e.g.* lactic acid bacteria) by making use of naturally occurring sugars (mainly glucose and fructose) in the material to be ensiled, by addition of easily available carbohydrates or by addition of chemical additives (McDonald *et al.*, 2011). Wet crops should be pre-wilted prior to ensiling to increase DM content and thereby facilitate the ensiling process. Similarly, crops such as legumes which are low in water-soluble carbohydrates, and may have high buffering capacity, must be treated with effective additives before ensiling.

Tropical leaves, grasses and legume forages have successfully been preserved as silage (FAO, 2000). Cassava leaves (Ly *et al.*, 2010), sweet potato leaves (An *et al.*, 2005) and taro leaves (Chittavong *et al.*, 2008) have been preserved as silage, and have been used as pig feed. However, to obtain well-preserved silage, these forages need a water-soluble, carbohydrate-rich (*e.g.* molasses, starchy root) additive at an appropriate level and should preferably be pre-wilted in order to encourage the growth of fermenting bacteria.

3.3 Energy and protein requirements of pigs

The pig needs energy for maintenance, growth, gestation and lactation. The more the animal grows, the more energy is required to sustain this growth. The description of energy systems for pigs is complicated by the hierarchy of energy use in the animal and the complexity of diets and ingredients commonly used (NRC, 2012). The energy requirement of the pig is influenced by the pig itself (*e.g.* genetic strain, gender, health), the environment (*e.g.* temperature, wind speed, pen/housing materials, housing density), the diet and other factors (NRC, 1998). There is a lack of information on the optimal energy and protein requirement of both indigenous and exotic pigs raised in tropical climates. However, a few reports indicate that pigs raised in the tropics perform better when they are fed an energy level that is 10% lower than the NRC recommendations (Adesehinwa, 2008).

Generally, the protein supply in pig diets is formulated on the basis of crude protein (CP), which refers to the nitrogen content * 6.25 (NRC, 2012). Proteins are composed of amino acids, and a good quality protein should provide the 10 essential amino acids in proportions required for normal body functions of pigs. Amino acids are critical nutrients required by all classes of pigs for maintenance, growth, gestation and lactation. The quantitative requirements of amino acids in pigs varies with weight and physiological stage (Table 1). In general, the first limiting amino acid for pigs is lysine. In growing pigs, the lysine requirement gradually decreases with increasing age (BW) from 1.2% of

DM (at <20 kg BW) in young pigs to around of 0.7% of DM (at 100 kg BW) in older pigs (NRC, 1998).

Table 1. *Dietary amino acid requirements of growing-finishing pigs (NRC, 1998)*

	Body weight of pig (kg)			
	10-20	20-50	50-80	80-120
ME content of diets (MJ/kg DM)	13.6	13.6	13.6	13.6
CP (g/kg DM)	209	180	155	132
Essential amino acids (% in DM)				
Arginine	0.46	0.37	0.27	0.19
Histidine	0.36	0.3	0.24	0.19
Isoleucine	0.63	0.51	0.42	0.33
Leucine	1.12	0.90	0.71	0.54
Lysine	1.15	0.95	0.75	0.60
Methionine	0.30	0.25	0.20	0.16
Phenylalanine	0.68	0.55	0.44	0.34
Threonine	0.74	0.61	0.51	0.41
Tyrosine	0.21	0.17	0.14	0.11
Valine	0.79	0.64	0.52	0.40

3.3.1 Feedstuffs available in Laos

Feedstuffs used in smallholder systems for pigs include rice by-products (*e.g.* rice bran, broken rice and distiller's waste), planted feeds (*e.g.* maize and cassava), and various green plant materials. By-products and planted feeds mainly supply energy and green plant materials (*e.g.* sweet potato leaves, cassava leaves and taro leaves) mainly supply protein in pig diets. The composition of dietary components in selected locally available feedstuffs is presented in Table 2. In commercial complete feeds, the most common protein sources are fish meal and soybean meal. These feedstuffs provide high quality protein for pigs, but they are imported and are expensive. Due to their high price, such protein sources cannot be used by smallholder farmers.

Based on origin, the main feed ingredients that are used in smallholder pig production systems in Laos can be categorised into the following groups:

Rice by-products: Rice is the main staple crop in Laos. Rice by-products such as rice bran and broken rice are commonly used for feeding pigs. In 2011, Laos produced 3.6 million ton of rice, which, as a by-product, provided around 4 000 ton of rice bran. The use of rice bran is common in pig diets, in particular by smallholder pig producers. The diet may include from 60% up to 100% rice bran (Chittavong *et al.*, 2012; Phengsavanh *et al.*, 2010). Broken rice has a high energy content and a low fibre content, and is used as an energy source in pig diets. Broken rice is usually fed together with vegetables and leaves from cassava, yam, taro and sweet potato. All ingredients are boiled together in water, and are mixed with kitchen waste before being fed to pigs. Rice distiller's waste is the by-product from rice wine production, and is a good energy and protein source for pigs. However, this by-product is only available occasionally, and is used as a supplement for fattening pigs.

Planted feed: Maize and cassava roots are cash crops in Laos. Laos produced 1.1 million ton of maize and 323 000 ton of cassava roots in 2009. Sweet maize is commonly inter-cropped with dryland rice and is used for human consumption, while improved varieties of maize are planted in mono-crop stands and used as animal feed. The maize grain is boiled with water together with other feed ingredients before being fed to pigs. Maize is used as an energy feed source for growing-fattening pigs in smallholder farms.

Green plant material: Taro leaves, cassava leaves and sweet potato leaves are typical for this class of feed. The main characteristics of this group are a high fibre content (Table 2) and a relatively high content of crude protein (Chhay *et al.*, 2012; Leterme *et al.*, 2005; An, 2004). The feedstuffs are commonly used in rural areas as pig feed at household level, but not in commercial pig production or by the animal feed industry. The frequency of use of taro leaves by smallholder pig farmers in the North of Laos is reported to be 46% (Phengsavanh *et al.*, 2010). Taro leaf has a high content of CP and a high fibre level (Table 2), and the fresh taro leaf contains high levels of calcium oxalate (443-589 mg/100 g fresh weight) (Oscarsson & Savage, 2007). The calcium oxalate causes itching on the skin and mouth, and the content can be reduced by either boiling or by ensiling. The reduction in oxalic acid during ensiling has been reported to range from 79 to 86% (Chittavong *et al.*, 2008; Tiep *et al.*, 2006).

Traditionally, farmers plant sweet potato in their garden and harvest the vines for their pigs during the growing season and at harvesting of the sweet potato tubers. Sweet potato leaves have high nutritive value for pigs, and can be preserved by drying or ensiling (Ly *et al.*, 2010).

Cassava is considered an important cash crop for Lao farmers. Cassava is planted for root production and to provide human food and animal feed, and is cultivated on an area of 11,015 ha, with production of 233,420 ton (MAF, 2008). However, cassava plant parts contain hydrogen cyanide (HCN), which is toxic to animals and humans, and therefore cassava leaves are traditionally boiled before feeding to pigs. Several studies have reported that the HCN content in cassava can be reduced by sun-drying, ensiling or boiling (Hang *et al.*, 2006; Chinh & Ly, 2001; Phuc *et al.*, 1996). Ensiled or dried cassava leaves and sweet potato vines can replace protein from fish meal by up to 70%

in the diet of growing pigs without negative effects on performance (Ly *et al.*, 2010). This feeding strategy results in a reduction in feed costs.

Table 2. *Composition of feedstuffs available in Laos*

	Rice bran [A]	Broken rice [B]	Rice distiller' waste [C]	Maize meal [D]	Cassava root [E]	Cassava leaf [F]	Sweet potato leaf [G]	Taro leaf [H]
DM, g kg	882	869	91	864	362	294	180	139
g kg^{-1} DM								
CP	7.3	5.7	23.1	8.1	2.8	26.1	26.8	23.1
CF	20.4	2.8	-	2.2	3.0	10.5	12.8	13.0
NDF	29.2	-	15.4	10.4	9.3	43.9	28.5	29.8
ME (MJ/kg DM)	8.8	12.6	-	15.5	14.9	10.6	9.5	-
Essential amino acids (g 16 g^{-1} N) †								
Arginine	8.0	8.2	5.6	4.7	5.6	3.6	5.2	5.0
Histidine	2.6	2.0	-	2.9	2.0	1.5	2.2	1.9
Isoleucine	3.6	9.4	4.4	3.7	2.8	5.9	3.7	3.7
Leucine	7.1	4.9	8.0	12.5	5.8	3.5	8.6	7.5
Lysine	4.5	4.8	3.9	3.0	4.9	2.9	4.5	5.6
Methionine	2.2	2.3	2.0	2.1	2.3	0.8	1.5	1.8
Phenylalanine	4.6	5.8	5.3	4.9	3.5	3.9	7.1	4.7
Threonine	3.7	2.2	4.9	3.7	3.7	2.8	5.2	4.2
Tyrosine	1.8	-	-	4.2	2.3	-	4.1	1.3
Valine	5.3	4.3	6.0	5.0	4.0	3.1	5.6	4.8

[A] Taysayavong and Preston (2010); † Sauvant *et al.* (2004)
[B] Chittavong *et al.* (2008); † Chhay *et al.* (2012)
[C] Manh *et al.* (2009)
[D] Sauvant *et al.* (2004)
[E] (AFRIS); † Sauvant *et al.* (2004)
[F] Chhay *et al.* (2012)
[G] An (2004)
[H] Leterme *et al.* (2005)

3.4 Utilisation of forages in pig diets

Leaves and legume forages are usually added to pig diets in smallholder farming systems, and are the main protein feed sources used since most other feedstuffs available are high in energy, but low in protein. These plant materials are either fed fresh or are processed before feeding. In Vietnam, sweet potato vine silage has been successfully used as supplementation to the basal diet of pigs (Table 3). The daily allowance of sweet potato vine silage is in the range 0.5-1.8 kg depending on the BW of the pigs (Peters *et al.*, 2004). In Laos, there is no reported use of forage in pig diets. However, surveys on the frequency of feedstuff use by farmers in the North of Laos indicate that 46% of the farmers feed green plant material to their pigs (Phengsavanh *et al.*, 2010). The most common green plant materials used are leaves of taro (*Colocasia esculenta*), banana stems, thickhead (*Crassocephalum crepidiodes*) paper mulberry (*Broussonetia papyrifera*) and green amaranth (*Amaranthus viridis*) (Phengsavanh *et al.*, 2010). In addition, (Chittavong *et al.*, 2012) reported that elephant yam (*Amorphophallus paeoniifolius*) and taro leaves are used in cooked form, with up to 32 and 35% in the diet, respectively, in smallholder pig production systems in the central part of Laos. The green plant materials have high contents of CP, ranging from 12 to 35% of DM. However, these materials also have a high fibre content, with NDF ranging from 29 to 44% of DM (Table 2). Since most green plant materials have a high NDF content and low energy content, there is a risk of reduced feed intake, due to their bulkiness, if high levels are included in the diet.

Legume forage, particularly Stylo CIAT 184, has been promoted for many years through the extension project "Forage legumes for supplementing village pigs in Laos". Stylo CIAT 184 is well known to farmers in many provinces in Laos, and has been used as fresh forage for their livestock. Farmers have had clear benefits from using legume forage in feeding their livestock, with daily growth rates in native pigs of up to 207 g per day, which is twice the growth rate achieved with traditional feeding (Stür *et al.*, 2010). In addition, the farmers save time and labour in collecting the green feed and in feed preparation, as they can omit the cooking. However, this forage legume needs appropriate management in order to produce high yields and an acceptable nutritional quality to be used as pig feed.

Table 3. *Studies on the use of tropical leaves or forages in pig diets*

Forages	Processing	References
Cassava leaves	Ensiled/dried	Ly *et al.* (2011); Ly *et al.* (2010)
	Meal	Phuc (2000); Ravindran *et al.* (1987); Alhassan and Odoi (1982)
Sweet potato leaves	Ensiled	An *et al.* (2005)
Stylo forage	Fresh	Stür *et al.* (2010); Phengsavanh and Stür (2006)
Taro leaves	Ensiled	Hang and Preston (2009); Buntha *et al.* (2008)
	Boiled	Phengsavanh *et al.* (2010); Chittavong *et al.* (2012)

4 Summary of materials and methods

4.1 Experimental sites

All experiments described in Papers I-V were carried out at the experimental farm of the Faculty of Agriculture, National University of Laos (18º07´N 102º47´E, 172 m above sea level) located 40 km from the centre of Vientiane Capital, Laos. Forage production experiments (Papers I & II) were carried out from May to October 2007 and from May to November 2008, the ensiling experiment (Paper III) from August to November 2008, and the growth performance experiments (Papers IV & V) from September to December 2009.

4.2 Agronomy experiment (Papers I and II)

4.2.1 Land preparation, planting and management

Studies on biomass yield and chemical composition of different plant parts were performed on taro (*Colocasia esculenta* (L.) Schott) in Paper I and on Stylo CIAT 184 (*Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis*) in Paper II. Before soil preparation, the land was cleaned of weeds, which were subsequently burned on-site. In addition, hand weeding was done during the establishment phase and thereafter when necessary.

Taro (Paper I): The trials were carried out in a field of which 115.2 m^2 was used for planting and 72 m^2 was border area. The size of each experimental plot was 12.8 m^2 (4.0 m x 3.2 m), and the total number of plots was nine. All plants were cut at 20 cm above soil level nine weeks after planting.

Stylo (Paper II): A field of 72 m^2 was used for planting and 38.5 m^2 was border area. The soil was prepared by ploughing followed by harrowing in the first year of the study (2007). Stylo plants were transferred to the experimental plots after 20 days of growth. The size of each plot was 6 m^2 (4.0 m x 1.5 m), with 12 plots in total. Eight weeks after planting all plants were cut at 25 cm above soil level and thereafter the treatments were applied. The same plants were used in the second year (2008). Before the second year all plots were weeded by hand. The plants were cut at 25 cm above soil level and treatments were applied four weeks later.

4.2.2 Treatments, design, measurement and data collection

The treatments applied in Paper I were harvesting leaves and petioles at intervals of 4 [H4], 6 [H6] and 24 [H24] weeks, respectively. In Paper II, the treatments were three defoliation frequencies: four harvests [S4] (at 4-week intervals), three harvests [S3] (at 6-week intervals) and one harvest [S1] (at the end of the experimental period).

At each harvest of taro, a few young leaves were left for re-growth. Stylo plants were cut with a stubble height of 25 cm. The experimental layout was a completely randomised block design with three and four replicates per treatment for Papers I and II, respectively.

Dry matter yield of taro leaf and petiole was determined for each harvest occasion, and tuber yield was measured at the end of experimental period. Plant height (Paper II) was measured before each defoliation occasion on five randomly selected plants from each plot. Leaf and stem weights were recorded. Proportion of leaf to petiole/stem was calculated for each harvest occasion.

Samples of leaves, petioles, stems and forage (leaves + stems) were taken from each plot on each harvest occasion for analysis of dry matter (DM), crude protein (CP), crude fibre (CF), neutral detergent fibre (NDF), acid detergent fibre (ADF), and ash. A bulk sample composed of material from all harvests of each treatment was used for amino acid analysis of taro and stylo leaves.

4.3 Ensiling (Paper III)

4.3.1 Silage making

Stylo forage and taro leaves were collected from the first harvests in the second year of the field experiments. Forage and leaves were chopped into small pieces of 1 cm (length), and then wilted in order to reduce the moisture content. Cassava root meal (CR), sugar cane molasses (M) and taro tuber meal (TR) were used as silage additives at levels of 25, 50 and 75 g per kg^{-}pre-wilted forage. In addition, 5 g common salt (NaCl) was added in all treatments. Thereafter the material was mixed thoroughly and put into plastic bags, which were then sealed.

4.3.2 Experimental treatments, design and data collection

The experiment comprised two trials, trial 1 with taro leaves and trial 2 with stylo forage (Paper III). Each trial was arranged according to a completely randomised factorial design, with additives and level of additives as factors and with 10 treatments in total per trial.

Sampling time was at 0, 7, 14, 21, 56 and 84 days after ensiling. At each sampling time the pH and the physical characteristics (*e.g*. smell, colour) of the silage samples were immediately recorded. Fresh samples were collected for analysis of NH_3-N (except at 0 day) and DM, after which the samples were oven-dried at 60 ºC before analysis of CP, NDF and ash.

4.4 Pig performance (Papers IV and V)

4.4.1 Animals, diets and design

Castrated crossbred Landrace x Yorkshire (LY) and native Lao Moo Lath (ML) pigs were used in the experiments described in Papers IV and V. A total of 24 individually housed pigs, 12 of each breed, were used in each experiment. The average initial body weight (BW) was 15.2 kg for LY pigs and 9.1 kg for ML pigs in Paper IV, and 31.0 kg for LY pigs and 9.0 kg for ML pigs in Paper V. The experiments lasted for 105 days in Paper IV and for 98 days in Paper V.

The control diet was composed of rice bran, cassava root meal, maize meal, vitamin premix and soybean meal as the main crude protein (CP) source. In the silage diets, soybean meal and cassava root meal was replaced with ensiled taro leaves (ET, Paper IV) and ensiled stylo forage (ES, Paper V) to comprise 25% and 50% of the CP in the diet, respectively. The diets were formulated to have the same CP content and to meet nutritional requirements for growing and finishing pigs according to NRC (1998).

The taro and stylo silages were prepared from fresh material collected from the same field, then chopped (1-2 cm length), and wilted for 4-8 hours before being ensiled. For this, 5 g common salt (NaCl) and 75 g or 50 g sugar cane molasses were added per kg wilted taro leaves or stylo forage and mixed thoroughly before pressing and sealing in plastic containers.

For the silage diets, the taro and stylo silage were mixed with the other dietary ingredients at each feeding. Pigs were fed twice daily at 4% DM of BW and had free access to drinking water.

The experiments were arranged according to a completely randomised factorial design, with diet (three levels of silages) and breed (LY and ML) as factors, giving four replicates per treatment.

4.4.2 Measurements

Feed offered and refused was recorded daily and pigs were weighed every 15 days. At the end of experiment all pigs (Paper IV) and three ML and two LY pigs of each dietary treatment (Paper V) were slaughtered after 12 h of feed withdrawal by captive bolt and exsanguination. The carcass traits and organ weights were measured

4.5 Chemical analysis

Leaves, petioles, stems, forages, silages and feed ingredients, feed offer and feed refusal samples were analysed for DM using microwave radiation (Undersander *et al.*, 1993). The content of CP, CF and ash was determined according to AOAC (1990). NDF was analysed according to Van Soest *et al.* (1991) and ADF according to Undersander *et al.* (1993). A bulk sample composed of material from all harvests (Papers I & II) of each treatment in 2007 and a bulk sample of feed ingredients (Papers IV & V) was used for determination of amino acid content according to Spackman *et al.* (1958).

4.6 Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Minitab software version 15.1 (Minitab, 2007) for Paper I and version 16.1 (Minitab, 2010) for Papers II-V. When the F test was significant ($P<0.05$), Tukey's pair-wise test for comparison was used to determine differences between means of treatments for Papers I & II, levels of additives in silages for Paper III, and dietary treatments, pig breeds and interaction between diets and pig breeds for Papers IV & V.

5 Summary of results

5.1 Biomass yield and chemical composition of taro and stylo

The taro plants always had 5-7 green leaves. The size of the leaves was larger during the peak of the rainy season (July-August) and the number of leaves produced was 2 per week. Leaf proportion did not differ between treatments and was on average 52% in 2007 and 62% in 2008.

Leaf and petiole DM yields were larger when the taro plants were harvested at 4- and 6-week intervals, whilst one harvest at the end of the experimental period gave the smallest yield. Total leaf DM yield was 2146, 1654 and 364 kg ha^{-1} in 2007 and 1483, 1346 and 691 kg ha^{-1} in 2008 for treatments H4, H6 and H24, respectively. However, root production was not affected by the treatments and was on average 3667 and 2732 kg ha^{-1} in 2007 and 2008, respectively.

Leaves had higher CP and NDF contents than petioles, while the difference in CF, ADF and ash content was smaller. Treatment H24 had a significantly larger content of CP and NDF compared with treatments H4 and H6. Total essential amino acid content of taro leaves ranged from 40 to 45 g 16 g^{-1} nitrogen.

Stylo leaf DM yield was unaffected by defoliation treatments in 2007 (6-10 ton ha^{-1}). In 2008 treatments S4 and S3 had larger leaf DM yields (by on average 4 ton ha^{-1}) than treatment S1. Stem DM yield in treatment S1 was largest, while in 2008 there were no significant difference between treatments. Leaf proportion did not differ significantly between treatments S4 and S3 and was on average 55 and 60% in 2007 and 2008, respectively, while treatment S1 had a significantly lower leaf proportion in both seasons.

Stylo leaves had a higher CP content than stems, while CF, NDF and ADF contents were lower (Table 4). The CP content was highest in both leaves and stems from treatments S4 and S3 compared with treatment S1, while the NDF content showed the opposite pattern. The ash content of leaves and stem was lower in treatment S1 compared with treatments S4 and S3. Defoliation treatments had no effect on the NDF content in stylo forage, while treatments S4 and S3 had a significantly higher CP content. The CF and ADF contents were lowest in treatment S4. Total essential amino acid content of leaves ranged from 45 to 50 g 16 g^{-1} N and from 40 to 42 g 16 g^{-1} N in the stylo forage from treatments S4 and S3, respectively.

Table 4. *Chemical composition of taro leaf, petiole and stylo leaf, stem and forage (leaf + stem), g kg^{-1} DM*

	Plant parts	CP	CF	NDF	ADF	Ash
Paper I,	Leaf	179-262	169-206	532-648	191-416	110-145
taro	Petiole	39-82	195-229	353-451	254-314	153-171
Paper II,	Leaf	170-235	179-206	510-570	296-372	69-89
Stylo	Stem	73-108	434-446	686-722	547-607	48-91
	Forage	85-182	268-332	583-621	494-580	48-89

5.2 Ensiling of forage and leaves

After 7 days of ensiling, stylo forage had turned brown and taro leaves had a yellow colour (Paper III). At 56 days of ensiling, the silage colour had become darker for stylo and yellow brown for taro leaves. Both silages had a distinct silage odour at 7 days of ensiling, which became stronger at 14 days onwards. The silage odour was stronger with cane sugar molasses (M) as additive than with cassava root meal (CR) and taro tuber meal (TR).

Silage additive sources affected DM, pH, ash and NDF content of stylo and taro silages and NH_3-N content of stylo silage, while the CP content was unaffected (Table 5). The lowest DM content and pH were recorded when M was used as the additive in both stylo and taro silage. Ash content was highest in both stylo and taro silage with M as the additive, while NDF content was lowest in both stylo and taro silage with M as the additive.

Level of additive had an effect on DM, pH, NH_3-N, CP, ash and NDF in taro silage but not on NH_3-N, CP and NDF in stylo silage. Increasing additive level resulted in significantly increased DM content and reduced pH and ash content for both stylo and taro silage, and reduced NH_3-N, CP and NDF content for taro silage.

Increasing duration of ensiling resulted in a reduction in DM content and pH in both stylo and taro silage, while NH_3-N and NDF content increased in stylo silage. The NH_3-N content in taro silage showed an irregular pattern with duration of ensiling, while the NDF content of taro silage was reduced.

Table 5. *Summary of the impact of additive source, level of additive (g kg $^{-1}$ pre-wilted matter) and duration of ensiling (days) on dry matter (DM, g kg $^{-1}$), pH, ammonia-nitrogen (NH_3-N, g kg $^{-1}$ total N), crude protein (CP, g kg $^{-1}$ DM), ash (g kg $^{-1}$ DM), neutral detergent fibre (NDF, g kg $^{-1}$ DM) in stylo silage and taro silage*

	DM	pH	NH3-N	CP	Ash	NDF
Stylo forage silage						
Additive	273-287	5.2-5.7	62-69	166-169	84-89	510-533
Level of additive	258-301	5.4-5.6	64-67	165-269	81-91	511-531
Time of ensiling	271-306	5.2-6.2	60-77	164-172	85-87	499-542
Taro leaf silage						
Additive	160-173	5.1-5.4	99-108	182-185	167-179	356-382
Level of additive	138-192	5.2-5.5	92-116	167-199	156-188	306-410
Time of ensiling	157-177	4.9-6.4	91-118	177-184	168-174	344-399

5.3 Effect of replacing soybean protein with silage protein on feed intake, growth performance and carcass traits

The results in Papers IV and V showed that taro and stylo silage CP can replace the CP from soybean meal by up to 50% in the diet of growing Lao LY and ML pigs without negative effects on growth performance and carcass traits. Pig DM intake (DMI) and CP intake (CPI) were highest with diet ES25 in Paper V, while DMI and CPI were unaffected by increasing replacement of soybean CP in Paper IV. Average daily weight gain (ADG) and feed conversion ratio (FCR) were unaffected by increasing replacement of soybean CP in the diet, while calculated metabolisable energy intake was affected. Carcass weight, back fat thickness and dressing percentage were not affected by soybean CP replacement, while organ weight was affected, except for the spleen in Papers IV & V. In Paper IV, the weight of lung, liver, heart, kidney, intestine and stomach increased when soybean CP was replaced with ensiled taro leaf CP. In Paper V, lung and large intestine weight was significantly increased when soybean CP was replaced with ensiled stylo forage CP, and the weight of the stomach was highest with diet ES25. LY pigs had higher DMI, CPI, and ADG than ML pigs. LY pigs had higher carcass weight, lower back fat thickness and higher organ weight than ML pigs when soybean CP was replaced in the diet. In Paper V, there were interactions between diet and breed on final BW in the growing period, but not in the finishing period. There were also interactions between diet and breed on ADG in the finishing period, but not in the growing period or overall, and finally on FCR in the growing and finishing periods and overall.

Table 6. *Summary of effects of silage protein on nutrient intake (g kg $BW^{0.75}$), growth performance (g/day) and dressing percentage (%) of LY and ML pigs*

	Daily intake (g kg $BW^{0.75}$)					
	DMI	CPI	MEI	ADG	FCR	Dressing %
Paper IV Taro leaf silage	107-110	16.3-16.8	1.3-1.4	280-302	3.8	80-83
Paper V Stylo forage silage	89-100	13.1-14.9	1.0-1.2	331-356	3.6-3.9	85-87

DMI=dry matter intake; CPI=crude protein intake; MEI=metabolisable energy intake; ADG=average daily weight gain; FCR=feed conversion ratio;

6 General discussion

6.1 Effect of harvesting/defoliation interval on biomass yield and chemical composition of taro and stylo

The management of forage crops is crucial to obtain both high yield and high nutritional quality. However, despite the importance of taro as food for humans and the potential of taro and stylo as feed for livestock on smallholder farms in Laos, there is lack of data on suitable management of both cultivated taro and stylo.

6.1.1 Yield

Paper I showed that different harvesting intervals had an effect on leaf and petiole DM yield in taro, but no effect on tuber DM production in either year of the study. Frequent harvesting intervals yielded larger leaf and petiole biomass DM than less frequent harvesting intervals in both years. This can be explained by the high leaf turnover rate recorded in the present study, which was higher than rates reported by Johnston *et al.* (1997) and Sivan (1979). Moreover, Sivan (1979) reported that leaf turnover was different among cultivars, and that cultivars with high leaf turnover had larger leaf and petiole DM yields. To obtain a high biomass yield the soil should be fertilised with manure (Paper I). Applications of nitrogen fertiliser at levels of 200-400 kg ha^{-1} can increase aboveground biomass of taro more than two-fold (Hartemink *et al.*, 2000). Paper I showed that taro is well suited for both leaf and tuber production. This is in contrast to results on sweet potato, which showed that its tuber yield declined with frequent harvests of leaves (An *et al.*, 2003).

In Paper II, the production of stylo leaf differed between years and among treatments in the second harvest year. In the first year (2007), there was no difference in leaf DM yield among defoliation treatments, but stem yield was almost three-fold larger with a single harvest compared with frequent harvesting. In the second year, stem DM yield was unaffected by defoliation treatment, whereas leaf DM yield was least with a single harvest. The data in Paper II suggest that stylo should be regularly defoliated throughout the year in order to maintain the growing point close to the ground for re-growth (Cook *et al.*, 2005) and to obtain a quantity and quality of forage that is suitable for feeding pigs. Moreover, in order to maintain high yield and nutritional quality, manure and phosphorus fertiliser should be applied regularly.

6.1.2 Chemical composition

The chemical composition of taro leaves differed from that of petioles (Paper I), in agreement with previous findings (Chay-Prove & Coebel, 2004). The CP content of taro leaves was much higher than that of petioles (Paper I), again in agreement with previous studies (Pheng *et al.*, 2007; O'Hair *et al.*, 1982). Leaf CP content was highest in the treatments with the least frequent harvest interval, followed by those with the most frequent harvest intervals. These treatments produced leaves with the most suitable levels of protein for growing pigs. However, the biomass yield was lowest in the least frequent defoliation treatment. Thus, a 4-week harvesting interval gave optimum biomass yield with a high CP content.

In Paper II, the defoliation frequency had an effect on CP content of both leaf and stem, and the CP content of the leaf was always higher than of the stem, as reported previously (Adjei & Fianu, 1985; Gardener *et al.*, 1982). However, separation of leaves and stems is not practical and thus the quality of the forage (leaf + stem) is the most important trait. In Paper II, defoliation at 4-week intervals was the most suitable management regime in order to achieve a good quantity of high quality forage for pigs. The CP content of stylo forage in the frequently defoliated treatments was higher than that of stylo forage harvested at 125 days after sowing (Liu *et al.*, 2011). Thus, the quality of stylo forage is closely related to the defoliation management. With regular defoliation at 4- to 6-week intervals, a leaf proportion of up to 60% of the biomass can be maintained.

6.2 Ensiling taro leaves and stylo forage

Several tropical forages and leaves have been successfully preserved by sun-drying for use as animal feed. However, sun-drying is not an option during the rainy season in the tropics, which is the period of the year when potentially useful forages and leaves are abundantly available. During the wet season, the ensiling technique can be used to preserve material with a high moisture content through controlled lactic acid fermentation under anaerobic conditions (McDonald *et al.*, 1981).

In all experiments (Papers III, IV & V), pre-wilted stylo forage and taro leaves were successfully preserved as silage. However, the fermentation process was slow in the treatments without additives, which was manifested by a high pH value in the silage without additive in Paper III. Ensiling without a carbohydrate-rich additive resulted in high pH values, which indicates that the fermentation process was not sufficient (Paper III). This can be explained by the low natural content of water-soluble carbohydrates in both stylo forage and taro leaves (Liu *et al.*, 2011; Bradbury & Holloway, 1988). In addition, the DM content was low in the pre-wilted taro leaves (around 15%) and the buffering capacity is high in stylo forage (Liu *et al.*, 2011), which makes it more difficult to initiate an efficient fermentation process in the material (McDonald *et al.*, 2011; McDonald *et al.*, 1981). Bradbury and Holloway (1988) reported that taro leaves contain about 9.2 g sugars and 0.7 g starch per kg DM and according to Liu *et al.* (2011), stylo forage contains 20.3-30.4 g water-soluble carbohydrates per kg DM. In addition, stylo forage has a high buffering capacity (320.0-427.3 mE per kg DM), which adds to the problem of making a stable silage of high quality (Liu *et al.*, 2011). Wilting is recommended for high moisture forages and leaves, and for crops with high buffering capacity (Liu *et al.*, 2011; Nelson & Bozich, 1996), in order to increase DM content before making silage. However, it may be difficult to reach the target DM content within a reasonable time during periods of high relative air humidity. Earlier studies have demonstrated that wilting of forages and leaves before making silage results in successful ensiling of grasses (Vendramini *et al.*, 2010), legume forages (Liu *et al.*, 2011; Nelson & Bozich, 1996) and leaves from tropical plants (*e.g.* cassava, sweet potato, taro) (Chittavong *et al.*, 2008; An & Lindberg, 2004; Phuc, 2000). An increased DM content in the material will minimise clostridial and enterobacterial activities in the silage, and benefit the growth of lactic acid bacteria (LAB) (McDonald *et al.*, 2011; McDonald *et al.*, 1981).

Cassava root meal, sugar cane molasses and taro tuber are locally available in Laos, and can be obtained at a low price. They are all carbohydrate-rich feedstuffs, but they differ in composition of the carbohydrate fraction. While sugar cane molasses is characterised by a high content of water-soluble sugars (mainly as sucrose) and contains no starch, both cassava root meal and taro tuber meal are characterised by a high content of starch and low content of water-soluble sugars (Bradbury & Holloway, 1988). They are all potential sources of energy for growth of LAB, but with more easily available carbohydrates in sugar cane molasses than in cassava root and taro tuber meal.

This was also reflected in a more rapid drop in pH at day 7 when sugar cane molasses was used as additive at all levels of inclusion (Paper III). In contrast, the drop in pH at day 7 was much less pronounced with cassava root meal and taro tuber meal as additives at all levels of inclusion. However, the data on pH in stylo silage indicated that the availability of carbohydrates for fermentation was higher in cassava root meal than in taro tuber meal (Paper III). This could be related to more available sugars in cassava root meal than in taro tuber meal (Bradbury & Holloway, 1988).

The NH_3-N content (g kg^{-1} total N) was on average 65 g in stylo silage and 101 g in taro leaf silage (Paper III). The lower value for stylo silage indicates good quality and compares favourably with values reported for well-preserved temperate forage silage (McDonald *et al.*, 2011; McDonald *et al.*, 1981), cassava leaf silage (Phuc, 2000) and sweet potato leaf silage (An & Lindberg, 2004). The average NH_3-N value for taro leaf silage (Paper III) was also within the range (8-12 g) for acceptable silage quality (McDonald *et al.*, 1991). However, the NH_3-N content of taro leaf silage (Paper III) was higher than reported for cassava leaf silage (Phuc, 2000) and sweet potato leaf silage (An & Lindberg, 2004). This indicates that ensiling of taro leaves may require other measures to obtain silage with lower NH_3-N content.

6.3 Effect of taro and stylo silage on growth performance and carcass traits of Lao pigs

6.3.1 Feed intake

Crude protein from taro (Paper IV) and from stylo silage (Paper V) was able to replace up to 50% of CP from soybean meal in the diet without negative effects on growth performance and carcass traits of growing LY and ML pigs. However, increasing inclusion of ET and ES in the diet resulted in a reduction in the ME content.

Replacing soybean CP with CP from ensiled taro leaves had no effect on DMI (Paper IV), which was in agreement with results reported by Hang and Preston (2009) and Rodriguez *et al.* (2006). Feeding ensiled cassava leaves and sweet potato vines does not affect DMI of crossbred pigs (Ly *et al.*, 2011; Ly *et al.*, 2010). In contrast, replacing soybean CP with CP from stylo forage silage increased DMI (Paper V). Similarly, inclusion of fresh stylo forage increases DMI of pigs (Khoutsavang, 2005; Keoboualapheth & Mikled, 2003). The increase in DMI in Paper V can be explained by a lower ME content in the stylo forage silage than in the taro leaf silage used in Paper IV, which induced a higher DMI to maintain the ME intake. This reduction in ME content was partially compensated for by an increase in DMI. The pigs fed diet ES25 (25%

of the CP in soybean meal replaced with CP from stylo forage silage) managed to compensate for the lower ME content in the silage by consuming more DM (Paper V). However, the pigs fed diet ES50 (50% of the CP in soybean meal replaced with CP from stylo forage silage) were not able to compensate for the lower ME by consuming more, probably due to the bulkiness of the feed. There was a marked increase in DMI, CPI and MEI in ML pigs in the growing period on diet ES25 compared with the other diets (diets ES0 and ES50). DMI increased on diets ES25 and ES50 compared with diet ES0 in LY pigs, resulting in the highest CPI and MEI on diet ES25 in the finishing period. In ML pigs, the DMI followed the same pattern over the experimental period, resulting in a lower CPI and MEI on diet ES50. These breed-related differences in feed intake had implications for the growth performance of LY and ML pigs. However, the reason for the difference in response in feed intake between breeds is unclear.

6.3.2 Growth performance

In general, the growth performance of the pigs in Papers IV & V was rather low compared with earlier studies (Ngoc, 2012; Keonouchanh *et al.*, 2008; Len *et al.*, 2008; Keoboualapheth & Mikled, 2003). Poor growth potential may explain the lack of response to replacement of soybean CP in the diet with CP from taro leaf silage and stylo forage silage, as the requirement for essential amino acids can be expected to be low (NRC, 1998). It has been reported that existing pig breeds in Laos have poor genetic growth potential compared with other breeds (Wilson, 2007). However, the ML pigs fed ensiled taro leaves (Paper IV) and ensiled stylo forage (Paper V) had two- to three-fold higher ADG than ML pigs in the North of Laos, raised under traditional conditions and fed by-products, planted feed and green plant material (Phengsavanh *et al.*, 2010) and pigs fed rice bran, water spinach and rice distiller's by-product (Taysayavong & Preston, 2010).

Overall, growth performance of LY pigs in Papers IV & V was higher than of ML pigs. However, the observed ADG of LY pigs was rather low compared with other data on crossbred pigs on a similar feeding regime in Laos and in the region (Ly *et al.*, 2010; Toan & Preston, 2010; Rodriguez *et al.*, 2006; An *et al.*, 2005). LY pigs have a high genetic growth rate potential among the crossbred genotypes when fed a nutrient-sufficient diet (Gu *et al.*, 1991). This applies at any age and under different environmental conditions (Becerril *et al.*, 2009). The poor growth of Lao LY pigs in Papers IV & V could be related to limited digestive capacity, as shown in other exotic pig breeds when fed stylo forage or taro leaves (Stür *et al.*, 2010; Rodriguez *et al.*, 2009).

The low growth rate of ML pigs can be related to lower genetic capacity, similar to that reported for Vietnamese local pigs (Tu, 2010). However, ML pigs may have a higher capacity than LY pigs to utilise ensiled stylo forage and taro leaves. Len *et al.* (2009) reported that local Vietnamese (Mong Cai) pigs had better developed digestive capacity than exotic (LY) pigs and digested plant fibre better than exotic pigs.

Composition of the diet (*e.g.* essential amino acids, energy, fibre level) is a major factor influencing the performance of pigs. Taro leaves and stylo forage have a lower content of essential amino acids (lysine) and energy than soybean meal, while they contain more fibre (NDF). Thus, replacing soybean meal CP with CP from taro leaf and stylo forage silage decreases the content of essential amino acids in the diet, while it increases the fibre (NDF) content. Here, increased fibre level in the diet linearly decreased the DMI and MEI, which resulted in reduced ADG. Similar results have been reported for exotic and native pigs in Vietnam (Ngoc, 2012).

6.3.3 Carcass traits and organ weights

In Papers IV & V, the exotic crossbred LY pigs had higher carcass weight than the native ML pigs, which was similar to findings by Jiang *et al.* (2011) and Len *et al.* (2008). This is related to the greater mature BW of exotic pig breeds than of native pig breeds.

Dressing percentage was on average 4-% units higher in LY than in ML pigs (Papers IV & V). This can be explained by different genetic potential for lean meat deposition between the two breed types and is reflected in higher fat content in the carcass of native pig breeds in China and South East Asia than in exotic pig breeds (Affentranger *et al.*, 1996).

In general, visceral organ and digestive tract weights (Papers IV & V) were numerically higher in LY than in ML pigs, while their proportions of the empty body weight were comparable between breed types. Increasing visceral organ and digestive tract weight with inclusion of ensiled stylo forage (Paper V) and taro leaves (Paper IV) in the diet could be explained by the increasing fibre content in the diet, confirming earlier studies (Ngoc, 2012; Len *et al.*, 2009; Nyachoti *et al.*, 2000). In addition, the increased intake of calcium oxalate from ensiled taro leaves may have contributed to higher liver and kidney weights (Paper IV). Chai *et al.* (2004) and Liebman *et al.* (1999) reported that in humans a small proportion of ingested oxalate is absorbed (8-13% of ingested) and excreted in urine. Moreover, calcium oxalate is deposited in the kidneys as crystals, and may be deposited in the liver and other soft tissues as a non-crystalline complex of calcium oxalate and lipid (Zarembski & Hodgkinson, 1967).

7 Conclusions and implications

7.1 Conclusions

- Harvesting taro leaves did not affect tuber yield. There were only small differences in chemical composition of the leaves between different harvesting interval treatments. Therefore, taro leaves can be harvested from plants grown for tubers any time during the season and used as animal feed.
- Stylo CIAT 184 harvested at 4- to 6-week intervals gave a high yield of biomass of high nutritional quality suitable for use as a protein supplement for growing pigs in rural areas of Laos.
- Pre-wilted cultivated stylo forage and taro leaves can be preserved as silage by using locally available carbohydrate-rich feed sources as silage additives. Addition of sugar cane molasses, at a level of 50 g per kg pre-wilted matter, resulted in better silage quality than addition of cassava root meal and taro tuber meal.
- Stylo forage and taro leaf silage crude protein can replace up to 50% of crude protein from soybean meal in the diet of growing Landrace x Yorkshire and Moo Lath pigs in Laos without negatively affecting growth performance and carcass traits.

7.2 Implications and future research

The findings presented in this thesis can be applied to optimise the production and use of existing forages and leaves as alternative protein sources in smallholder pig production. The experiments showed that cultivated stylo provides an adequate quantity of good-quality forage in terms of nutritional value, especially crude protein. A taro crop can provide feed for animals and food for humans, as leaves can be harvested at any time during the rainy season without affecting tuber production.

Ensiling technology can be applied at farm level and should be introduced to farmers to provide a cheap and easy method to preserve abundant forage and leaves in the rainy season. Introducing the ensiling technique could be a way to improve the nutritional quality of pig feed and provide sufficient feed for small-scale pig producers during periods of feed shortage in the dry season. Using ensiled stylo forage and taro leaves can improve the performance of pigs, particularly native Lao (Moo Lath) pigs, and thereby improve the economy of resource-poor farmers.

Further studies should be performed on the digestibility of ensiled forages and leaves in order to fully evaluate the nutritional properties and assess their potential as feed sources for both exotic and native pigs. In addition, growth performance studies using forages and leaves in different forms, with and without addition of synthetic essential amino acids, in existing pig breeds should be prioritised in future research in order to evaluate the potential and to identify limitations of existing feedstuffs in Laos.

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