Nutritional Status of Local Pigs in Central Lao PDR

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Cover: Local pigs in free-scavenging and penning systems in central Lao PDR (photo: Malavanh Chittavong, 2010)

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Abstract

The feeding regime, health status, feed allowance, body weight and mineral status of local pigs kept by smallholder farmers in Lao PDR were assessed. The long-term effect of supplemental salt (NaCl) on voluntary feed and water intake, growth, sodium (Na) and potassium (K) balance was evaluated in local pigs, and faecal K/Na ratio was assessed as a marker of Na intake in pigs.

A field study of management of local pigs kept by smallholder farmers was carried out in three districts (Borrikun, Khamkeuth and Pakkading) of central Lao PDR, where pig keeping is mainly women's work. The main feed ingredients used in the region are rice bran and cassava root, with agricultural by-products and green plants used as supplements to varying degrees. Daily crude protein and calcium (Ca) allowances to sows, piglets and growing pigs in all districts were lower than the recommended levels, as was Na allowance to growing pigs in Borrikun and Khamkeuth and to lactating sows in all districts. Phosphorus (P) allowance to growing pigs in Pakkading and sows in Borrikun and Pakkading was lower than recommended, but K allowance to both growing pigs and sows was higher. Piglet mortality was around 20%. Feed supplementation had no effect on the body weight of pigs raised by smallholder farmers, but affected plasma iCa concentration. Ionised Ca level was outside the normal range for all pigs. There was a tendency for higher faecal K/Na ratio in sows not supplemented with Na.

In two experiments examining the effect of high and low levels of NaCl in the diet of native Moo Lath pigs, dietary Na content affected feed and water intake, Na and water retention. Low dietary Na level (0.6 g/kg DM) reduced intake, retention and weight gain, while high intake (3.0 g/kg DM) increased intake, retention, extracellular volume and weight gain, without increasing N and K retention. A dietary Na content of 1.2 g/kg dry matter proved sufficient to support a positive Na balance and growth in these pigs. Individual faecal K/Na ratio was a rough indicator of Na intake.

Overall, the studies showed that the protein, Ca and Na supply to local pigs in central Lao PDR appears to be below requirements. Thus farmers should aim to include more green plant materials and NaCl in the feed allowance.

Keywords: Local pig, feeding management, protein, minerals, mortality, growth, faeces aldosterone, plasma protein, osmolality.

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Dedication

To my parents, sisters and brother

Contents

List of Publications

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

I Chittavong, M., Lindberg, J.E. & Jansson, A. (2012). Feeding regime and management of local Lao pigs in Central Lao PDR. *Tropical Animal Health and Production* 41(DOI 10.1007/s11250-012-0249-3), 1-7.

II Chittavong, M., Lindberg, J.E. & Jansson, A. (2012). A field study on feed supplementation, body weight and selected blood parameters in local pigs in Laos. *Tropical Animal Health and Production* 41(DOI 10.1007/s11250-012-0249-3), 1-6.

III Chittavong, M., Jansson, A. & Lindberg, J.E. (2012). Effects of high dietary sodium content on performance and sodium and potassium balance in growing pigs (Submitted).

IV Jansson, A., Chittavong, M. & Lindberg, J.E. (2012). Effects of dietary NaCl content on sodium, potassium and nitrogen balance, weight gain and plasma aldosterone concentration in growing pigs (Manuscript).

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Abbreviations

BW	Body weight
Ca	Calcium
CF	Crude fibre
CP	Crude protein
DM	Dry matter
DNA	Deoxyribo nucleic acid
FCR	Feed conversion ratio
HCN	Hydrogen cyanide
iCa	Ionised calcium
K	Potassium
Lao PDR	Lao People's Democratic Republic
ME	Metabolisable energy
Na	Sodium
NaCl	Sodium chloride
NAFRI	National Agriculture and Forestry Research Institute
NE	Net energy
P	Phosphorus
RNA	Ribo nucleic acid
SEM	Standard error of mean
SID	Standardised ileal digestible

1 Introduction

Lao People's Democratic Republic (Lao PDR) is a landlocked country located in South-east Asia with a population of around 6.3 million people. Overall population density is 27 people per square kilometre (LSB, 2011). More than 50% of the gross domestic product is derived from crops, livestock, fisheries and forestry. Over 73% of the population is living in rural areas (UNDP, 2009). They are engaged in the agriculture sector, where the main activity is irrigated and rain-fed rice production and production of annual crops such as maize, cassava and legumes (LSB, 2011; Devendra & Thomas, 2002). Livestock is an integral part of farming systems, providing animal products, as well as opportunities for saving, insurance, asset accumulation and maintaining social customs (Blacksell *et al.*, 2006; Stür *et al.*, 2002).

Pigs are widely kept by smallholder farmers in 17 provinces in Lao PDR. The total number of pigs is approximately 2.7 million (LSB, 2011), with 88% of these being produced by smallholder farmers (Conlan *et al.*, 2008). In the north of Lao PDR pigs are more abundant than in the centre and south of the country (LSB, 2011). However, farmers in Borikhamxay, a province in central Lao PDR, also keep 64,000 head of pigs (LSB, 2011). Around 80-90% of all pigs in this province are raised by smallholder farmers and 47% of agricultural holdings raise pigs (MAF, 2002). Most farmers in Borikhamxay province are engaged in lowland rice production. The main constraints for these farmers are limited planting areas and lack of water to supply rice fields in the dry season, leading to a lack of rice for human consumption. To cope with this situation, farmers keep livestock as a form of capital that can be used during periods of food shortage. Therefore, livestock production in Lao PDR is characterised as being a smallholder farming practice, with more than 95% of the products from livestock and fisheries being produced by smallholder farms (Government Report, 2010). The main animals kept are cattle, buffaloes, pigs and poultry. To alleviate poverty, the Lao government has given the highest priority in its rural development strategy to improving livestock production systems (Government Report, 2004).

Most pigs in rural areas of Lao PDR are raised in traditional, low input, free and semi-free scavenging systems, where pigs are allowed to scavenge freely for feed all the year round or after the main crops have been harvested (Phengsavanh *et al.*, 2011). Farmers give only small amounts of additional feed to these scavenging pigs (Phengsavanh, 2006). The main feed resources are agricultural by-products and vegetables, and weeds that grow in forests, along the banks of streams and in cropping areas. These feed resources are vulnerable to seasonal weather changes and in the dry season feed is always in short supply. Thus, one of the main limitations to pig production in these smallholder production systems is a shortage of feed. Apart from this feed shortage, infectious diseases are also a problem that limits productivity (Conlan *et al.*, 2008; Phengsavanh, 2006; Thorne, 2005).

Objectives of the thesis:

The main objectives of the work described in this thesis were to:

- Describe feed intake, particularly protein and mineral intake, feeding systems and piglet health in smallholder systems in central Lao PDR.
- Investigate feed allowances, body weight, haematocrit, haemoglobin, plasma iCa, Na, K, pH and glucose concentration and faecal K/Na ratio in local pigs kept by smallholder farmers in Lao PDR.
- Investigate the long-term effect of supplemental NaCl on voluntary feed and water intake, growth, Na and K balance in local pigs.
- Assess the Na requirements of growing pigs using growth and balance studies together with measurements of plasma osmolality, protein and aldosterone concentration.
- Evaluate the use of faecal K/Na ratio as a marker of Na intake in pigs.

Hypothesis of the studies:

- Local pigs are underfed and body weight is higher in pigs receiving supplementary feed.
- The blood profile of pigs subjected to a very poor diet is outside the normal range.
- Supplemental sodium in the diet improves growth performance in local pigs.
- Local pigs with free access to saline-free water can tolerate a high level of sodium in the diet.

2 Background

2.1 Pig production in Lao PDR

In Lao PDR, 96% of the pig production is carried out by smallholder farmers and there are only a few commercial pig farms in operation (Vongthilath & Blacksell, 1999). Around 64% of smallholder farmers raise pigs for home consumption and sale, and for cultural events by some ethnic groups. Sale of livestock is the main income for farmers when cash is needed for buying food and medication and paying tuition fees for children (Blacksell *et al.*, 2006; Phengsavanh, 2006; Stür *et al.*, 2002; Vongthilath & Blacksell, 1999).

Smallholder farmers raise pigs of local breeds, such as Moo Lath, Moo Chid and Moo Hmong, in production systems based on free-scavenging, semi-scavenging and penning (Phengsavanh *et al.*, 2011; Vongthilath & Blacksell, 1999). However, free-scavenging is the most common system used and in combination with poor management and animal healthcare, it can lead to ineffective disease control (Kagira *et al.*, 2010). The main constraints for small-scale pig production in Lao PDR are feed shortages and infectious diseases such as classical swine fever (CSF) (Conlan *et al.*, 2008; Osbjer, 2006; Phengsavanh, 2006). There are annual outbreaks of CSF, with high morbidity and mortality (Blacksell *et al.*, 2006). Overall, less than 10% of pigs raised by smallholder farmer are vaccinated to prevent CSF (Conlan *et al.*, 2008). The main factor affecting pig vaccination is the difficulty in delivering vaccine from the district level to the villages. In addition, there is a lack of an effective cold chain and vaccine stability is therefore inadequate (Conlan *et al.*, 2008). In 2002, there were 38 outbreaks of CSF in Borrikun district and four outbreaks of CSF in Pakkading district. The number of farmers raising pigs in these districts has decreased by between 26 and 40% in recent years (Conlan *et al.*, 2008). It has been reported that 70-80% of the pigs in rural areas in the northern part of Lao PDR died in an outbreak of CSF (Phengsavanh, 2006).

Feed resources for smallholder farms are based on planted crops, agricultural by-products, vegetables that are available in the villages, distiller's waste and household scraps (Phengsavanh *et al.*, 2010; Osbjer, 2006). Several energy-rich feedstuffs (rice bran, maize and cassava root) are produced by smallholder farmers (LSB, 2011). However, limited access to suitable feed stuffs results in imbalances of nutrients such as amino acids, minerals and vitamins in the diet, which is a major problem for smallholder pig production (Phengsavanh, 2008; Thorne, 2005). This results in low daily gain (135 g/day) in rural areas (Phengsavanh *et al.*, 2010). Fish meal and soybean meal are very good sources of protein for pigs, but they are expensive as they are not produced in Lao PDR. Due to high prices, smallholder farmers cannot afford to buy these feedstuffs. Commercial feed mixed with cassava root meal or maize meal is used by semi-intensive pig farms, but they only account for about 1% of pig production. These farms are situated close to cities and this type of production system is not economically feasible for smallholder pig production due to high feeding costs (Vongthilath & Blacksell, 1999).

2.2 Potential feed resources for pigs in Lao PDR

In Lao PDR, the feeding of livestock on smallholder farms is based on agricultural production (maize (*Zea mays*) and cassava (*Manihot esculenta*)), agricultural by-products (rice bran, broken rice) and green plant materials (*e.g.* taro (*Colocasia esculenta*), thick head (*Crassocephalum crepidioides*), paper mulberry *(Morus papyrifera*), green amaranth (*Amaranthus viridis*), pumpkin tops, sweet potato leaves), distiller's waste and household scraps (Phengsavanh *et al*., 2010).

Rice (*Oryza sativa*) is the single most important crop in Lao PDR, with a total planted area of 855,114 hectares (LSB, 2011; Schiller *et al.*, 2001). The total annual production of rice is more than 3 million tons (LSB, 2011). By-products from rice production, such as broken rice and rice bran, are widely used for feeding pigs and poultry. Rice bran is a good source of energy and water-soluble vitamins, especially B vitamins (Blair, 2007). It contains (per kg dry matter, DM) about 120-145 g crude protein, 110-180 g crude fat (McDonald *et al.*, 2011), 140 g crude fibre (Miller *et al.*, 1991), 2.2 g calcium and 21.6 g phosphorus (NRC, 2012). At high ambient temperature, the fat is rapidly oxidised and becomes rancid, which results in unpleasant taste and odour, and reduced palatability (Blair, 2007; Miller *et al.*, 1991). It is recommended that rice bran should not be used at inclusion levels higher than 300-400 g/kg total diet for growing pigs (Blair, 2007).

Maize is the second most important crop after rice for smallholder farmers (LSB, 2011). The total planted area is around 200,000 hectares and more than 1 million tons of maize are produced annually (LSB, 2011). Maize is used for human consumption and also for feeding animals such as pigs and poultry (Phengsavanh *et al*., 2010). The use of maize, especially yellow maize, should be restricted in pig diets because it can affect the carcass quality, resulting in too soft or too yellow carcass fat (McDonald *et al.*, 2011; Blair, 2007). Maize is an excellent source of energy, but has a low content of protein, fibre, vitamins and minerals, such as calcium. Maize contains (per kg DM) around 40-60 g crude fat, 90-140 g crude protein, 0.2 g calcium and 2-3 g phosphorus. However, some essential amino acids (EAA) such as lysine, threonine, isoleucine and tryptophan are limiting in maize (McDonald *et al*., 2011; Blair, 2007).

In the northern part of Lao PDR, where the rice planting area is limited (especially in Hmong and Khmu villages), rice production is occasionally insufficient for home consumption. Therefore, cultivation of cassava is a means of providing an alternative food crop that can partly compensate for low rice yield. In addition to be used for human consumption, cassava is also used for feeding pigs (Phengsavanh, 2006). The total planted area of cassava in smallholder farms in Lao PDR is 10,375 hectares, with an annual production of 152,590 tons (FAO, 2011). The cassava root is a very good source of carbohydrate, with a low content (43 g/kgDM) of fibre and also with a low content (35 g/kg DM) of crude protein. A major limiting factor as regards fresh cassava roots is the content of hydrocyanic acids (HCN). However, sun drying, boiling and ensiling can markedly reduce content HCN in both the root and leaves of cassava (McDonald *et al*., 2011).

2.3 Nutrient requirements of pigs

2.3.1 Dietary requirement of protein and amino acids in pigs

The most important single factor affecting the growth performance of pigs is the dietary balance of protein and amino acids (AA). If the requirements for protein and AA are not fulfilled, the growth performance and health can be negatively affected (NRC, 2012; Kerr *et al.*, 1995). Moreover, excess AA can also be deleterious for performance and health (Buttery & D'Mello, 1994) by causing a high rate of protein turnover, increased muscle respiration and increased visceral organ mass. Production of urea leads to heat production (Xue *et al.*, 1997). Daily gain and feed efficiency of growing exotic pigs are reported to be reduced with a reduction in the dietary crude protein (CP) content from 19 to 15% without AA supplementation (Kerr *et al.*, 1995).

However, a diet with a good AA balance but with low CP content can result in better growth performance than a diet with a high content of CP but with imbalanced AA profile (Kerr *et al.*, 2003). If the diet is supplemented with limiting EAA, the content of protein can be further reduced (Kerr & Easter, 1995). An adequate dietary intake of EAA will depend on the feed ingredients contained in the diet (McDonald *et al.*, 2011).

Nine EAA (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) cannot be synthesised by the pig and must therefore be supplied in the diet (NRC, 2012; McDonald *et al.*, 2011; Cheeke & Dierenfeld, 2010). The protein and EAA requirements of weanling pigs and growing-finishing, gestating and lactating sows as suggested by NRC (2012) are shown in Table 1.

Table 1. *Recommended dietary content of net (NE), digestible (DE) and metabolisable (ME) energy (kcal/kg), minerals (%), digestible essential amino acids (%) and digestible crude protein (CP) of growing pigs, gilts and sows fed ad-libitum (90% dry matter)*

	Growing pigs (kg)				Gilts(kg)		Gestating sow	Lactating sow
	7-11	11-25	25-50	50-75	50-75	75-100	140	175
NE content a	2,448	2,412	2,475	2,475	2,475	2,475	2,518	2,518
DE content a	3,542	3,490	3,402	3,402	3,402	3,402	3,388	3,388
ME contenta	3,400	3,350	3,300	3,300	3,300	3,300	3,300	3,300
Body weight gain (g/day)	335	585	758	900	866	897	578	190#
Body protein deposition (g/day)	-	-	128	147	145	144	-	-
Mineral (%)								
Total calcium	0.80	0.70	0.66	0.59	0.61	0.56	0.61	0.63
Total phosphorus	0.65	0.60	0.56	0.52	0.53	0.49	0.49	0.56
Sodium	0.35	0.28	0.10	0.10	-	-	0.15	0.20
Chloride	0.45	0.32	0.08	0.08	-	-	0.12	0.16
Potassium	0.28	0.26	0.23	0.19	-	-	0.20	0.20
SID amino acids (%)b								
Arginine	0.61	0.56	0.45	0.39	0.40	0.35	0.28	0.43
Histidine	0.46	0.42	0.34	0.29	0.30	0.26	0.18	0.30
Isoleucine	0.69	0.63	0.51	0.45	0.46	0.41	0.30	0.41
Leucine	1.35	1.23	0.99	0.85	0.88	0.78	0.47	0.83
Lysine	1.35	1.23	0.98	0.85	0.87	0.77	0.52	0.75
Methionine	0.39	0.36	0.28	0.24	0.25	0.22	0.15	0.20
Methionine+cysteine	0.74	0.68	0.55	0.48	0.49	0.44	0.34	0.39
Phenylalanine	0.79	0.72	0.59	0.51	0.52	0.46	0.29	0.41
Phenylalanine+tyrosine	1.25	1.14	0.92	0.80	0.82	0.73	0.50	0.83
Threonine	0.79	0.73	0.59	0.52	0.53	0.48	0.37	0.47
Tryptophan	0.22	0.20	0.17	0.15	0.15	0.13	0.09	0.14
Valine	0.86	0.78	0.64	0.55	0.57	0.51	0.37	0.64
SID CP (%)	17.5	16.0	13.2	11.5	11.7	10.6	8.2	10.1

[a] Basal diet based on maize and soybean, [b]SID=standardised ileal digestible. [#]mean daily weight gain of nursing pigs. Source: NRC (2012).

2.3.2 Dietary requirement of energy and energy sources

Energy is the largest single component in the diet of pigs, given the economic importance of energy utilisation in pig nutrition. In growing pigs, energy is needed for maintenance, synthesis of body tissues and body heat regulation. Energy supplied in excess of the maintenance requirement can be used for production and the additional energy is deposited as body tissues. In pregnant and lactating animals, energy is required for maintenance, the developing foetus, supporting tissues for pregnancy and milk production. Providing insufficient energy to the sow during lactation results in weight loss and delays the time from post-weaning to oestrus. However, an excess of energy can also have negative effects on subsequent lactation performance (McDonald *et al.*, 2011).

In Lao PDR, potential feeds providing energy are abundantly available during the harvesting season, while there may be limited availability during the dry season. Many farmers could produce the feeds needed in the wet season and have the means to store for feed for their pigs for many months.

2.3.3 Dietary requirement of calcium and phosphorus

Calcium (Ca) and phosphorus (P) are essential minerals for the development of the skeletal system (NRC, 2012). The Ca and P requirements of pigs decrease as they grow (Suttle, 2010). Adequate Ca and P supply depends not only on sufficient amounts of total dietary supplies, but also on the chemical forms in which they occur in the diet and the vitamin D content in the diet. Calcium and P deficiency results in rickets and ceased cartilage growth. The clinical signs of Ca and P deficiency are inhibited growth, poor appetite, reduced production of milk, bone lameness and fractures, and animals becoming listless and dull (Suttle, 2010; McDowell, 2003). Excess Ca and P may cause bone disorders and reduce feed consumption and gain (NRC, 2012; Suttle, 2010). Calcium is found in rock meal, limestone, fish meal, meat and bone meal, milk and green leafy crops, especially legumes (McDonald *et al.*, 2011; McDowell, 2003). The main sources of P are milk, cereal grains, fish meal and meat and bone meal (McDonald *et al.*, 2011).

2.3.4 Dietary requirement of sodium, potassium and chlorine and functions

Common feedstuffs provide insufficient NaCl for pigs to meet their requirement of sodium (Na) and chlorine (Cl). Therefore, common salt is usually added at a level of 0.2-0.5% of the diet in commercial pig production (Pond & Mersmann, 2001). The dietary requirement of pigs for Na ranges from 0.1-0.35%, for potassium (K) from 0.19-0.28% and for Cl from 0.08-0.45% (NRC, 2012) (Table 1). However, it has been suggested that supplementation of Na and Cl in the diet of growing-finishing pigs should not be higher than 0.08-1.00% for Na and 0.08% for Cl (Mahan *et al.*, 1996; Honeyfield & Froseth, 1985; Alcantara *et al.*, 1980). Furthermore, it has been found that supplementing a maize-soybean diet with 0.20-0.25% NaCl would meet the requirements of pigs (Hagsten *et al.*, 1976; Hagsten & Perry, 1976b). Potassium can be derived from green plant materials, and if these are provided in the diet, it should not be necessary to supplement with K.

The electrolytes Na, K and Cl are required to maintain osmotic balance, membrane potential, acid-base balance and substrate transport (NRC, 2012; Pond & Mersmann, 2001).

Insufficient Na or Cl in the diet reduces the rate and efficiency of growth in growing pigs, increases the interval between weaning and oestrus in sows and reduces appetite (Suttle, 2010). On the other hand, excess Na in the diet and water deprivation results in health problems and can result in death. However, pigs can tolerate high Na intakes if non-saline water is available (Mason & Scott, 1974; Bohstedt & Grummer, 1954).

2.3.5 Vitamins

Vitamins are required by pigs in very small amounts compared with other nutrients. The vitamins are required for normal growth and for numerous cellular, physiological and metabolic functions in the body that support health and well-being (McDonald *et al.*, 2011; Pond & Mersmann, 2001).

Vitamin D is important in Ca metabolism and plays an active role in the regulation of both Ca and P status (Sjaastad *et al.*, 2003). It is essential for the maintenance of a healthy skeleton throughout human and animal lives (Holick, 1994). Vitamin D is found in two forms, ergocalciferol (D_2), which is produced in animals, and cholecalcifarol (D_3), which is a constituent of plants (McDonald *et al.*, 2011; Sjaastad *et al.*, 2003).

The small intestine is the major site for absorption of vitamin D_2 and D_3 from the diet (Miller *et al.*, 1991). They are transported in the blood to the liver, where they are converted into 25-hydroxycholecalciferol. This is transported to the kidney, where it is converted into 1,25-dehydroxycholecalciferol, the most biologically active form of the vitamin. This compound is then transported in the blood to the target tissues, the intestine and bones (McDonald *et al.*, 2011; Lawson, 1980). The compound 1,25-dehydroxycholecalciferol acts as a steroid hormone (Lawson, 1980), regulates DNA transcription in the intestinal microvilli and induces the synthesis of specific messenger RNA, which is responsible for the production of calcium binding protein (McDonald *et al.*, 2011).

2.4 Mineral status

2.4.1 Regulation of calcium status

Calcium is the most abundant mineral in the body, with 99% found in the skeleton (Suttle, 2010), and 1% in blood, extracellular fluids, soft tissues and various membrane structures (Sjaastad *et al.*, 2003; O'Dell & Sunde, 1997; Pike & Brown, 1984). Calcium ions (Ca^{2+}) bind readily to protein. The concentration of Ca in plasma is around 2.5 mmol/L. About 40% of the Ca is bound to proteins, mainly albumin, and about 10% exists in soluble complexes with negatively charged ions, such as bicarbonate and citrate. The remaining 50% (1.0-1.25 mmol/L) is free (ionised) (Sjaastad *et al.*, 2003).

Calcium acts as a cofactor in many enzyme reactions and also acts as an activator of adenosine triphosphatase (ATPase) and stabiliser of enzymes (Peo, 1976). Moreover, Ca is important for secretion of a number of hormones and hormone releasing factors (Arnaud & Sanchez, 1996). Non-skeletal Ca has functions in body metabolism (McDowell, 2003) and occurs as free ions, bound to serum proteins and in complexes with organic and inorganic acids (Suttle, 2010). Calcium ions are essential for normal blood clotting, as they must be present for prothrombin to form thrombin, which reacts with fibrinogen to form the blood clotting agent fibrin (Suttle, 2010; McDowell, 2003).

Active vitamin D_3 stimulates Ca absorption and Ca mobilisation from bone. Low dietary Ca has been shown to markedly stimulate 1-hydroxylase activity, but the effect of dietary P levels on the enzyme remains controversial (Henry, 1980)

In the pig's body, vitamin D, Ca and P are necessary nutrients for growth and maintenance of hard and soft tissue. Therefore, they cannot be considered separately because of the interacting forces that exist between them (Miller *et al.*, 1991). Signs of vitamin D deficiency are similar to those manifested with Ca and P deficiency. In young pigs the symptoms are usually enlarged joints, broken bones, stiffness of the joints and occasionally paralysis (McDonald *et al.*, 2011). In adult pigs, deficiency of vitamin D results in demineralisation of the skeleton, osteomalacia. A reduced concentration of Ca^{2+} in the plasma leads to chronically elevated levels of parathyroid hormone, which in return enhances degradation of bone and release of Ca and P. Production of uncalcified osteoid matrix occurs at a normal rate even when the body is deficient in vitamin D. (Sjaastad *et al.*, 2003). Excess vitamin D results high levels of Ca and P in the blood and low growth rate (NRC, 2012; McDonald *et al.*, 2011).

2.4.2 Regulation of sodium, chloride and potassium status

The body contains around 0.2% Na. The ion (Na^+) is found in the skeleton in insoluble form and in the extracellular fluids where active metabolism occurs (McDowell, 2003). The chloride ion (Cl^-) is also found in the extracellular fluid. In addition, Cl is found in gastric secretions where its role in hydrochloric acid is important for protein digestion. It is also found in the bile, pancreatic juice and secretions from the intestine. Chloride is essential for activation of intestinal amylase (Cheekee & Dierenfeld, 2010).The K ion (K^+) can be found in the soft tissues, especially in muscle (Suttle, 2010).

Sodium is the major extracellular cation in the body, at a concentration of 140 mmol/L, Cl^- is the major anion of extracellular fluid at a concentration of 105 mmol/L and K^+ is the major cation in the intracellular fluid (Suttle, 2010). Sodium and Cl^- have a function of maintaining osmotic pressure, regulating acid-base equilibrium and controlling water metabolism in the body (Suttle, 2010; McDowell, 2003). Sodium has been said to provide an osmotic skeleton that is clothed with an appropriate volume of water (Michell, 1995) and plays a major role in the transmission of nerve impulses and in maintaining proper muscle and heart contraction. Chlorine has the function of transferring between plasma and electrolyte in respiration and regulation of blood pH through a process known as the chloride shift (Block, 1994). The two main compartments of extracellular fluid are interstitial fluid and plasma (McDowell, 2003). Acid-base status can be indicated by the difference between total intake of cations and anions (NRC, 2001).

Aldosterone is a steroid hormone originating from the adrenal cortex (Sjaastad *et al.*, 2003) and has an essential function in Na^+ and water homeostasis and in urinary excretion of K^+ (Roldán *et al.*, 2010). The kidney is the main target organ for this hormone, and is the organ where Na^+ retention occurs. In mammals, aldosterone has been shown to stimulate Na^+ absorption in other parts of body such as the gastrointestinal tract (Shields *et al.*, 1966; Lavitan & Ingelfinger, 1965), sweat glands (Conn, 1963; Shuster, 1962) and saliva glands (Denton *et al.*, 1959).

Increasing Na^+ intake elevates the Na^+ concentration in the extracellular fluid, which triggers the thirst centre of the brain (Sjaastad *et al.*, 2003). In Na^+ deficiency, saliva Na^+ is replaced on a molar basis by K^+ to conserve Na^+ (Blair-West *et al.*, 1963), in an adaptation modulated by aldosterone. Sodium, Cl^- and K^+ are lost via skin secretions, but there are major differences between *e.g.* horses, ovines and people. Regulation of Na^+ status is principally achieved in the kidneys by control of re-absorption of Na^+. Re-absorption from the distal tubule can be enhanced by aldosterone so that urinary losses become negligible when Na^+ intake is low. The ovine aldosterone response to Na^+ depletion is enhanced by K^+. Aldosterone reduces urinary excretion of Na^+. Availability of K^+ can be measured in urine (Suttle, 2010). It has been reported that low Na^+ intake in the horse results in an increase in plasma aldosterone concentration and an increase in the faecal K/Na ratio (Jansson *et al.*, 2010; Jansson & Dahlborn, 1999).

3 Materials and Methods

3.1 Study site

A survey on smallholder pig keeping practices was conducted in Borikhamxay province in central Lao PDR, approximately 180 km from the capital Vientiane, in April-August 2009 (Papers I and II). Three districts (Borrikun, Khamkeuth and Pakkading) (Figure 1) were chosen for collecting data, based on information from the Provincial Agriculture and Forestry Office. The selected districts represent those with the highest pig populations among all districts in the province. The village selection was based on information on pig population, pig breed and also road access to the village, which was obtained from the District Agriculture and Forestry Office.

The experiment described in Paper III was conducted on an experimental farm at the Faculty of Agriculture, National University of Laos, Vientiane, Lao PDR in June 2011.

The experiment reported in Paper IV was carried out at the Livestock Research Center of the National Agriculture and Forestry Research Institute, Vientiane, Lao PDR, in February 2012.

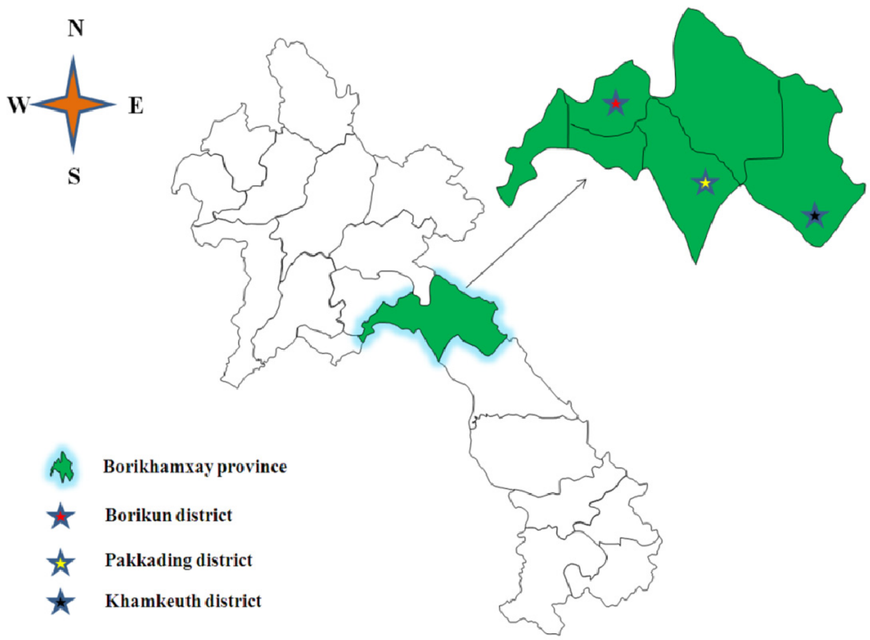

Figure 1. Location of Borikhamxay province in Lao PDR where the studies described in Papers I and II were performed. Source: Lao National Tourism Administration, Vientiane, Lao PDR

3.2 Experimental animals, feed, design and management

In Paper I, 216 households in nine villages (72 households per district) that kept local pigs were interviewed using questionnaires. Information collected in the survey included main activity of the farmer and pig management. The questions about pig management focused on feed resources, health status and pig production system.

In Paper II, questionnaires were used to interview 54 pig keeping households in Borrikun, Khamkeuth and Pakkading districts. The interviews focused on pig feeding regime. Samples of blood and faeces were collected from 27 lactating sows, 54 piglets (27 smallest and 27 largest piglets in each litter, selected based on visual observations) and 27 growing pigs.

In Paper III, 30 local breed castrate weaning pigs with an initial BW of 9-10 kg (6-8 weeks) were used in an experiment lasting 15 weeks (105 days), divided into five 3-week periods. During the last three days of each period, faeces and urine was collected quantitatively twice daily (05:00 and 17:00 h) from individual pigs kept in metabolism cages. Three levels of sodium chloride

(2.4, 2.8 and 3.2 g/kg diet) were fed according to a completely randomised design with 10 replicates per dietary treatment. The basal diet was composed of rice bran, cassava root meal, taro leaf and stem silage, supplemented with di-calcium phosphate and soybean meal as the protein source. The diets were formulated to have the same CP content and to meet nutritional requirements for growing pigs as recommended by NRC (1998).

The growth trials in Paper IV were carried out with local castrated weaned male pigs. They were allocated to diets in a completely randomised design and were fed twice a day, in the morning (07:00 h) and afternoon (16:00 h). The diets were formulated to contain six different levels of NaCl (0.9, 1.2, 1.5, 2.25 and 3.0 g/kg diet). Crude protein in the diet was the same for all diets (13% in DM). The diet was composed of cassava root meal, rice bran and soybean meal. The feedstuffs were bought from the local market near the Livestock Research Centre. The pigs were bought from the Vientiane province. Before being moved to the experimental unit, the pigs were kept in quarantine for a week to ensure that they were free from swine fever and were de-wormed (Ivermectin) prior to the experiment.

3.3 Measurements and recordings

In the pig management survey (Papers I and II), sows, growing pigs and piglets were weighed before feeding in the morning. Total feed and water offered were recorded at the time of feeding and 300 g of fresh feed samples were collected from each farmer during the interviews. In Paper I, pen soil samples were collected from each district, with samples (300 g each) taken from three different areas in each district. After sampling, feed, faeces (Papers I and II) and soil samples (Paper I) were immediately analysed for DM by microwave radiation (Undersander *et al.*, 1993). The samples of feed, faeces and soil were dried at 60ºC for 24 hours and milled through a 1 mm diameter mesh for later chemical analysis.

In Paper III, urine and faeces were collected every 12 hours and 10% was pooled into one urine and one faeces sample per day. The samples from all three days were mixed thoroughly by hand and 10% was kept frozen at -4ºC until analysis. The pigs were weighed every three weeks. Feed and water offered and refused were recorded daily.

In Paper IV, the pigs were weighed every second week. Water intake, feed offered and feed refusals were recorded daily. Total faeces and urine were collected for three days after 6 and 12 weeks.

3.4 Blood samples

In Paper II, blood samples from sows, piglets and growing pigs were collected before feeding early in the morning of the visit. Whole blood samples (2 mL) were taken from the jugular vein in tubes and analysed immediately after sampling for pH, Na, K, ionised Ca, glucose and haematocrit using an i-STAT1 analyser and $CG8^{+}$ cartridges (Abbott Point of Care Inc., NJ, USA).

In Paper III, blood samples were taken every 12 hours, before feeding at 05:00 and 17:00 h, during the first collection day in each collection period. In Paper IV, blood samples were taken in the morning (07:00 h) before feeding.

In Papers III and IV, blood samples were collected by venepunture from the jugular vein (5-7 mL in lithium-heparinised tubes) and were kept cool until centrifuged at 3400 x g for 12 minutes. The plasma was stored at -20ºC until analysis.

Plasma protein concentration (Paper IV) was determined using an automatic compensation clinical refractometer (ATAGO CO., LTD Japan 2007) and osmolarity was determined using freezing point depression (a single sample osmometer, model 3250, Advanced Instruments, INC. USA).

Prior to analysis of aldosterone (Papers III and IV) using the ELISA method (Enzo Life Science AG, Switzerland), blood plasma samples were extracted with acetone and petroleum ether according to Jansson & Dahlborn (1999).

3.5 Chemical analysis

Feed samples were analysed for CP and ash according to methods of AOAC (1990). Feed, faeces and soil samples were wet-digested (HNO3:H2SO4:HCLO4) and analysed for Na and K by flame photometry. Feed samples were analysed for Ca using atomic absorption spectrometry and P using a molybdenum-blue method after wet digestion (in HNO3:H2SO4:HClO4 and HNO3:HClO4, respectively) (AOAC, 1990).

3.6 Statistical analysis

In Paper I, reproductive performance, feed allowances and nutrient intake were analysed using the General Linear Models procedure of ANOVA in the MINITAB 15 programme (Minitab, 2007). The data on human activity, pig management, type of feed, age at weaning and cause of death were analysed using PASW Statistics18 (PASW, 2009) for frequency of distribution and variation, descriptive analysis of means, medians and range. A chi-squared analysis was performed for proportional data. The significance level was set to $P<0.05$.

In Paper II, data on body weight, blood parameters in piglets, sows and growing pigs and feed intake were analysed using the General Linear Models procedure of ANOVA in the MINITAB 16.0 programme (Minitab, 2010). The model used was:

$$Y_{ij} = \mu + \alpha_i + e_{ij}$$

where Y_{ij} is the dependent variable, μ is the overall mean, α_i is the difference between the mean value of piglets of size i, or between salt supplementation and non-supplementation *i*, and ε_{ij} is a random error. Least square means which showed significant differences at the probability level $P<0.05$ were compared using Tukey's pairwise comparison procedure. Values are presented as least squares means (LSMeans) ± standard error of the mean (SEM). Regression and correlations were analysed using PASW statistic 18 (PASW, 2009) and MINITAB 16.0 (Minitab, 2010), respectively.

Statistical analyses in Papers III and IV were performed with Minitab programme version 16.0 (Minitab, 2010) and SAS 9.3 (SAS, 2010), respectively. The statistical model used in Papers III and IV for evaluating the treatment effect on Na/K and K/Na ration in faeces and urine, Na and K balance (except Paper IV), plasma aldosterone, plasma protein (except Paper III) and plasma osmolality (except Paper III), daily intake, daily gain, feed conversion ratio (except paper IV) was:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha_i \times \beta_j) + \varepsilon_{ij}$$

where Y_{ij} is the dependent variable, μ is the overall mean, α_i is effect of dietary sodium Na level i, β_j is effect of time period j, $(\alpha_i \times \beta_j)$ is interaction between Na level i and time period j and ε_{ij} is a random error.

Feed (except Paper III) and water intake, body weight, feed conversion ratio and balance (except Paper III) were analysed using the model:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

where Y_{ij} is the dependent variable, μ is the overall mean, α_i is effect of treatment i, and ε_{ij} is a random error. The level of significance within and between treatments was set at $P<0.05$. Data are presented as LSMeans ± SEM.

4 Summary of results

4.1 Feedstuffs used, chemical composition and nutrient intake of Local pigs (Paper I)

The main feed resources used for pigs in Borrikun, Khamkeuth and Pakkading districts were planted feed, agriculture by-products and green plant material such as cassava root, maize, rice bran, broken rice, brewer gains, taro, elephant yam and thick head.

Between 58 and 99 % of households reported that rice bran was the main feedstuff used in pig diets, while only between 21 and 36 % of households reported that cassava root was the main feedstuff used in pig diets. Rice bran and cassava root made up more than 50% of total feed ingredients in diets for growing pigs and sows in Borrikun, Khamkeuth and Pakkading districts.

The highest CP content was found in thick head in Borrikun and Khamkeuth. The lowest CP was found in cassava root in all districts. Fresh thick head had the highest Ca and K content and taro had the highest Na content of all ingredients tested. Crude protein and mineral composition of some feed ingredients used in Borrikun, Khamkeuth and Pakkading districts are shown in Table 2.

Table 2. *Crude protein, calcium, sodium and potassium (% of DM) content of selected feeds used in Borrikun, Khamkeuth and Pakkading districts (mean±SD)*

	Rice bran	Cassava root	Taro#	Thick head¤
Borrikun	n=64	n=25	n=2*	n=1
Crude protein	9.5±1.2	2.0±0.5	9.8-10.9	27.2
Calcium	0.04±.01	0.05±<(0.01)	0.1-1.0	0.9
Sodium	0.1±0.2	0.1±<(0.01)	0.7-0.8	0.3
Potassium	2.1±0.6	1.6±0.6	1.9-2.7	9.8
Khamkeuth	n=72	n=2	n=11	n=3
Crude protein	8.8±0.7	1.4-2.7	9.3±1.1	24.8±1.7
Calcium	0.03±0.01	0.01-0.1	0.2±0.3	0.9±0.01
Sodium	0.1±0.01	0.07-0.09	0.8±0.8	0.3±0.01
Potassium	2.5±0.5	0.8-2.2	4.6±1.2	9.8±0.01
Pakkading	n=52	n=35	n=2*	-
Crude protein	8.7±0.5	2.1±0.5	9.4-10	-
Calcium	0.1±0.1	0.05±<(0.01)	0.2-0.4	-
Sodium	0.1±<(0.01)	0.1±0.1	0.1-1.8	-
Potassium	2.3±0.7	1.6±0.8	2.7-3.5	-

n number of observations, * minimum and maximum value, #cooked, ¤fresh

The DM allowance for growing pigs was 1491, 1842 and 1842 g in Borrikun, Khamkeuth and Pakkading districts, respectively, and 1400, 2634 and 1846 g for sows in Borrikun, Khamkeuth and Pakkading districts, respectively. The DM allowance to both sows and growing pigs was higher than the level recommended by NRC (1998) (except for sows in Borrikun district). Crude protein allowance to both sows and growing pigs in all districts was lower than that recommended by NRC (1998).

Growing pigs and gestating and lactating sows in Borrikun, Khamkeuth and Pakkading districts were provided with less Ca than the requirements suggested by NRC (1998). Furthermore, the daily allowance of Na was marginal for growing pigs in Borrikun and Khamkeuth and lower than the requirement for lactating sows in all districts. The daily allowance of P was low for growing pigs in Pakkading and for lactating sows in Borrikun and Pakkading. For K, the daily allowance was higher than the requirement suggested by NRC (1998).

4.2 Breed, pig rearing systems and management (Paper I)

Three different pig breeds, Moo Lath, Moo Chid and Moo Hmong, were found in the province. The most common breed was Moo Lath. The pig production systems practised in Borrikun, Khamkeuth and Pakkading districts were raising growing/finishing pigs, piglet production and raising growing pigs, and piglet production only. In general, piglet production was the most common production system with the exception of Pakkading district, where piglet production and raising growing pigs was more common.

Three pig management systems, enclosure, penning and free-range scavenging, were identified, but the most common pig management system in the three districts was enclosure (79.2, 29.9 and 62.5 % of household in Borrikun, Khamkeuth and Pakkading, respectively). The pigs were fed twice a day, in the morning and in the afternoon in all districts. Most of the survey farmers supplied water to the pigs only during feeding as a mixture with feed.

The average number of sows kept per household was 1.1, 1.1 and 1.2. Sow age was 2.4, 2.8 and 3.0 years and sow live weight was 53, 52 and 50 kg in Borrikun, Khamkeuth and Pakkading, respectively.

The average number of piglets at birth was 6.7, 6.8 and 7.5, the number born live was 6.2, 6.6 and 6.9 and the number at weaning was 5.1, 5.6 and 5.9 in Borrikhun, Khamkeuth and Pakkading districts, respectively. The weaning age was more than four months in all districts. However, a weaning age at 1-2 months was also found in Borrikun district.

4.3 Effect of low nutrient intake on growth performance and blood parameters of Local pigs (Paper II)

Most sows and growing pigs were fed rice bran or cassava root only, a mixture of cassava root and rice bran, a mixture of rice bran and cooked taro or a mixture of rice bran and distiller’s waste. Daily feed allowance to sows was 1394-1764 g/day and to growing pigs 918-1032g/day. Crude protein allowance to the sows and growing pigs was 107-139 g/day and 79-97 g/day, respectively.

The feed used for piglets was a mixture of rice bran and cassava root, a mixture of rice bran and soaked broken rice, or cassava root or rice bran alone. Daily feed allowance to piglets ranged from 69 to 123 g/day and CP allowance ranged from 4 to 8 g/day.

There was no extra mineral supplementation to the piglets and growing pigs. However, some of the sows (44.4%) were fed supplementary salt. The mineral allowance to sows, piglets and growing pigs is presented in Table 3.

Table 3. *Mineral allowance to sows (supplemented or not supplemented), piglets and growing pigs, g/day, in Borrikhun, Khamkeuth and Pakkading districts*

	Sows*		Piglets (age, days)		Growing pigs (age, months)		
	Suppl.	No suppl.	1-30	31-90	2-3	4-6	>6
Calcium	0.53	0.55	0.13	0.10	0.31	0.88	0.60
Sodium	1.15	1.43	0.03	0.11	0.75	1.27	0.82
Potassium	24.5	37.8	0.6	2.3	26.9	22.1	13.8
Phosphorus	4.2	6.7	0.1	0.3	3.9	4.1	2.7

*Salt supplementation (2-5 g/day)

The sows, piglets and growing pigs had a BW of 30, 3 and 11 kg at an age of 39.3, 1.5 and 5.2 months, respectively.

Sows supplemented with Na showed a tendency for higher Na^+ concentration in blood than non-Na supplemented sows and the ratio of K/Na in faeces in Na-supplemented sows tended to be lower than that in non Na-supplemented sows, while there were no significant differences in the Na/K ratio.

Feed supplementation had no effect on blood pH and concentration of Na^+, K^+, glucose, haematocrit and haemoglobin in young and old piglets, but affected the iCa concentration. Both feed-supplemented and non feed-supplemented young piglets had higher iCa concentration than older piglets. The largest piglets in each litter had a higher haemoglobin content in blood than the smallest piglets. Haematocrit and iCa tended to be higher in the largest piglet than in the smallest piglets. The blood profile of growing pigs was not significantly different at different ages.

4.4 Effect of low and high sodium intake on growth performance, sodium and potassium balance, aldosterone, plasma protein and plasma osmolality (Papers III and IV)

The daily water and feed intake was lowest on the lowest Na intake. Increasing Na level in the diet did not affect the FCR (except on diet Na0.6 in Paper IV). There were no significant differences in BW gain between diets (except between pigs on diets Na0.6 and Na3.0 in Paper IV). The Na balance gradually increased with increasing dietary content of Na. The faecal K/Na ratio decreased as Na intake increased. In contrast, the faecal Na/K ratio increased as Na in the diet increased. Plasma aldosterone concentration dropped as dietary Na increased. Increasing Na level in the diet affected total plasma protein content.

5 General discussion

5.1 How to improve pig rearing systems and management (Papers I and II)

Local pigs in the current study were kept in mixed production systems characterised by confinementor free-range scavenging during the day, and confinement in an enclosure at night with supplementation of small amounts of feed. This was similar to what has been observed in Northern Lao PDR (Phengsavanh *et al.*, 2010) and in Kenya (Kagira *et al.*, 2010), where free-range scavenging is the most common pig production system.

Rice bran and cassava root were the dominant feedstuffs used for pigs in the study areas. A mixture of rice bran or cassava root with green plants, such as taro, elephant yam and thickhead, was also used in some households. There is a wide range of local feed resources available, although the amount given per pig might be not adequate and the diet can be of poor nutritional value. The feed provided to the pigs is usually bulky and is characterised by medium to high energy content and low protein content. No households supplied commercial feed to their pigs. Most of the feed used were homemade and derived from on-farm production and/or local markets near the village. The availability of local feed resources is not stable all year round, but is dependent on the season. In the rainy season green plants are abundantly available, but in the dry season there is often a shortage (Phengsavanh, 2006).

No extra minerals were supplemented to the growing pigs and piglets in the study area. However, some households provide salt to their sows during lactation. In all households, pigs were fed twice a day, with little or no extra clean water supplied to the pigs during the day besides that used to mix in the feed. Some feed and water were lost due to the design of feed troughs, which prevented pigs from consuming all the feed and water provided. This may have contributed to the poor nutrient supply and eventually to underfeeding (Phengsavanh *et al.*, 2011; Phengsavanh *et al.*, 2010; Ajala *et al.*, 2007).

In Lao PDR, most green forages such as taro leaves, sweet potato leaves, water spinach (*Ipomoea aquatic)*, cassava foliage and stylosanthes (*Stylosanthes quianensis, CIAT 184*) are high in protein and contain EAA that fairly closely match the pig's requirement, and could therefore be used as potential protein sources in pig nutrition (Kaensombath & Frankow-Lindberg, 2012; Chiv, 2007; Ogle, 2006; Khoutsavang, 2005). The fresh leaves of New Cocoyam (*Xanthosoma sagittifolium*) and ensiled taro leaves can be used to replace up to 50% of the soybean meal protein in the diet of local and crossbreed pigs without negative effects on growth performance and carcass traits (Kaensombath & Lindberg, 2012; Rodríguez *et al.*, 2006). Furthermore, Chittavong *et al.* (2008) reported that a mixture of taro leaf silage and water spinach could replace 100% of soybean meal in the diet of pregnant and lactating Mong Cai gilt diets without negatively affecting reproduction. Other available protein sources, such as fish meal and soybean meal, will provide adequate amounts of EAA for pigs, especially lysine, cysteine, methionine (except in soybean meal) and tryptophan (except in soybean meal) (McDonald *et al.*, 2011; Sauvant *et al.*, 2004). However, these feedstuffs are imported and are too expensive to be an alternative for supplementing the diet of pigs in smallholder farms in Lao PDR.

5.2 Performance of local pigs (Papers I and II)

The pigs used in the study area were of three different local breeds, Moo Lath, Moo Chid and Moo Hmong. Pig breed was identified in the survey on the basis of phenotypic characters, but there is no available genetic information on local pig breeds in Lao PDR (Oosterwijk *et al.*, 2003). The three breeds in the study area are mostly black in colour and are characterised as fat genotype pigs. In rural areas of Lao PDR, pig fat is important and is used for cooking. Furthermore, the local pigs are important for use in cultural ceremonies such as weddings, births and deaths, especially among the Hmong ethnic group. Local pigs are valued by farmers as they are well adapted to free-range scavenging and are tolerant to poor production conditions (Kennard *et al.*, 1996).

The growth performance of pigs in Papers I and II was similar to that in earlier reports from Lao PDR (Phengsavanh *et al.*, 2010; Phengsavanh, 2006; Oosterwijk *et al.*, 2003). The farmers surveyed here reported that it took nearly 2 years for local pigs to reach a BW of 60-70 kg and the average daily gain ranged from 100 to 140g. The farrowing rate was reported to be around 1.5 per year, with a litter size of 7-8 piglets per litter. The performance of pigs in smallholder pig production systems was poor, as it was affected by the use of imbalanced diets and by underfeeding.

In general, the reproductive performance of the sows described in this study was poor in comparison to that in other tropical smallholder pig production systems. The mean live born litter size in this study ranged between 6.7 and 7.5. In particular, the live born litter size in Borrikhamxay province (6.0 piglets) compared unfavourably with data reported from smallholder pig production in Kenya, with a litter size of 9 piglets (Wabacha *et al.*, 2004) and in the Philippines, with a litter size of 8-14 piglets (Taveros & More, 2001). The average live born litter size in Thailand ranges between 8 and 10 piglets (Kunavongkrit & Heard, 2000), in the Philippines between 11 and 12 (Taveros & More, 2001) and in Vietnam between 7.5 and 11.5 (Lemke *et al.*, 2006), while that in European countries such as Denmark is >12 piglets (Cutler, 2008). In Sweden the mean litter size is 11.8 piglets (Grandinson *et al.*, 2005).

In Papers I and II, pre-weaning piglet mortality ranged from 18 to 24%, which on average was lower than reported from the North of Lao PDR by Phengsavanh *et al.* (2010) (28-45%), from the North of Thailand by Nakai (2008) (0-44%), from the Philippines by Taveros & More (2001) (0-37%) and from the North of Vietnam by Lemke *et al.* (2006) (12-33%). However, pre-weaning piglet mortality in Papers I and II was higher than on commercial farms in Denmark, where it ranges from 11.6-13.0% (Cutler, 2008) and in Sweden, where the range is 13-16.4% (Persdotter, 2010; Grandinson *et al.*, 2005). The most common cause of death of pre-weaning piglets in Sweden is starvation and crushing by the sow (Persdotter, 2010; Grandinson *et al.*, 2005). The major causes of piglet death in Papers I and II were diarrhoea, runts and crushing by the sow. Similar findings have been reported from the North of Lao PDR by Phengsavanh *et al.* (2011) and Phengsavanh (2006). It appears reasonable to assume that the major cause of piglet mortality in Papers I & II was the poor body condition of sows due to low feed allowance of diets of low nutritional quality. This would have negative impacts on colostrum amount and quality (Pond & Mersmann, 2001), and on milk production of the lactating sow (Phengsavanh *et al.*, 2010; Close & Cole, 2000).

5.3 Effect of low and high sodium supplementation on intake and sodium balance of local pigs (Papers III and IV)

Dietary Na levels affected feed and water intake and Na and water retention in growing pigs. The lowest Na intake (0.24 and 0.6g/kg DM in Papers III and IV, respectively) reduced feed and water intake, which is similar to findings in adult ponies on low Na intake (Lindner *et al.*, 1983). A reduction in daily weight gain in pigs fed the diet with the lowest Na content was observed in Paper IV. This result is similar to findings in growth and balance trials by Alcantara *et al.* (1980), who observed 8% lower feed intake by pigs fed the lowest Na level in the diet (0.032%), but nearly 50% less gain compared with the highest Na level in the diet (0.114%). Furthermore, Honeyfield *et al.* (1985) reported that the average daily weight gain of pigs fed a diet containing 0.02% sodium is lower than that of pigs fed higher levels of Na (0.11-0.18%). The reduced growth on the lowest Na intake in Paper IV was probably the result of poor development of the gastrointestinal tract, which may reduce the feed intake capacity. Moreover, the digestibility of DM and CP and the FCR of pigs on the diets with the lowest Na content were low compared with other diets, indicating limitations within the gastrointestinal tract. Possible limitations could be small area for absorption and low microbial digestive capacity.

Urinary and faecal Na excretion increased when Na levels in the diet increased, which was similar to results in horses (Jansson & Dahlborn, 1999). Sodium retention was also highest in pigs with the highest Na levels in the diet (0.32 and 3.0 g Na/ kg DM in Papers III and IV, respectively).

5.4 Detection of sodium deficiency in pigs (Papers II, III and IV)

In the current study, Na^+ balance was measured by measuring Na^+ intake and Na^+ excretion by performing total collection of faeces and urine following well-established procedures (Alcantara *et al.*, 1980; Mason & Scott, 1974; Meyer *et al.*, 1950). Total collection of faeces and urine was carried out daily for three consecutive days (Papers III and IV), which is considered appropriate to obtain reliable excretion data (Alcantara *et al.*, 1980).

According to Meyer *et al.* (1950), plasma Na^+ concentration cannot be used to detect Na deficiency in pigs. However, Na^+ excretion with faeces can be used in evaluating the Na^+ status (Jansson, 1999; Alcantara *et al.*, 1980). It has been shown that the concentration of Na^+ and K^+ in spot samples of faeces can be used as a tool to evaluate the Na^+ status in horses (Jansson, 1999). When Na intake is excessive, Na^+ excretion increases in faeces. In contrast, when Na intake is low, aldosterone induces reduced Na^+ excretion and increased K excretion.

Na deficiency has a negative impact on BW gain in pigs (Paper IV). The low weight gain on the lowest Na intake is also in accordance with other observations in growing pigs fed diets with 0.005-0.03% Na (Meyer et al., 1950; Honeyfield et al., 1985). The low weight gain could be due to both reduced tissue growth and small extracellular fluid volume (Scott *et al.*, 1969).

The latter is supported by findings of increased packed cell volume in pigs on unsupplemented diets (Hagsten and Perry, 1976a; Alcantara et al., 1980; Honeyfield and Froset, 1985). In Paper IV, there were no clear signs of reduced extracellular fluid volume, but the osmolality was numerically lowest on diet Na0.6, confirming findings by Alcantara et al. (1980) of a lowering of plasma Na concentration.

6 General conclusions and implications

6.1 Conclusions

- Smallholder pig farmers in central Lao PDR use locally available feed resources, leading to imbalanced diets and a low supply of nutrients, especially protein, calcium, sodium and phosphorus.
- Local pigs in central Lao PDR suffer from poor nutrition, particularly regarding crude protein, calcium, sodium and phosphorus.
- Taro and thickhead have a high calcium content, and can be alternative calcium sources for local pigs on smallholder farms.
- Thick head, elephant yam and taro are locally available in the study area, and can be used as a protein feed for pigs on smallholder farms.
- Salt supplementation of traditional smallholder pig diets can improve pig growth performance.
- With free access to water, excessive salt intake does not appear to have any adverse effects on feed intake and growth performance in native Lao pigs.
- A dietary sodium content of 1.2 g per kg dry matter supported a positive sodium balance and maximum growth, without any elevation of plasma aldosterone concentration.
- Faecal K/Na ratio can be used as a rough indicator of sodium intake in pigs.

6.2 Implications

Introducing more extensive use of green plant materials (such as taro, thick head and elephant yam), in combination with rice bran, cassava root and maize, in smallholder pig production should make it possible to rectify the poor nutritional status of local pigs at low cost. This should be combined with implementation of feeding systems that will ensure a well-balanced supply of essential nutrients, free access to fresh water and improved pig pens and buildings for pigs.

The main constraint for smallholder farmers in the field study was small litter size and low growth rate of the pigs. The weaning age was more than four months, which resulted in a low number of litters per year. Therefore short basic training courses on how to improve pig management and pig reproduction should be provided in the future.

Information and education on how to improve pig management in Lao PDR should be directed towards to women, because they are more engaged in smallholder pig production than men.

7 Future research

Future studies should consider the problem of feed quality and quantity in pig production systems based on local available feed resources. This should not only include energy and protein supply, but also mineral and vitamin supply.

Three different kinds of local pigs were found in the study area, but there is no available information on the genetics of local pigs. Better knowledge of the genetic potential and limitations of Lao pig breeds can be an important precondition for the long-term improvement of pig production in the country.

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