Impact of Smallholder Management Strategies on Sow and Piglet Condition and Performance

Ammaly Phengvilaysouk
Faculty of Veterinary Medicine and Animal Science
Department of Anatomy, Physiology and Biochemistry
Uppsala

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Cover: Moo Lath sow-piglet production in Lao PDR
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Abstract

This thesis examined the impact of management strategies on performance and condition of sows and piglets owned by smallholder farmers in Lao PDR. A survey was performed on smallholder pig farms (SHPF) and larger-scale pig farms (LSPF) to identify factors with potential to improve performance. Sows on SHPF produced fewer litters per year, with a small number of weaned piglets per litter compared with sows on LSPF. Piglet mortality was the main problem on SHPF, especially in remote villages. Sow feeding on SHPF was based on rice bran and piglets were fed rice bran only. On around 70% of SHPF, water intake was limited to that included in the feed and only 7-25% of sows were given nesting material.

Studies investigating the effect of providing extra water, nesting material, and simple cooling to Moo Lath sows showed that sows provided with nesting material and extra water (*NMW*) had higher water intake and lower body weight (BW) loss from two weeks prior to farrowing until weaning than the untreated *Control* and sows only given nesting material (*NM*). Total plasma protein concentration (TPP) declined from farrowing until 21 days of lactation in *NMW* sows, whereas it increased (indicating dehydration) or was unchanged in *NM* and *Control* sows. Re-mating period was shorter and number of litters per year greater in *NMW* than in *Control* and *NM* sow. Piglet mortality was lower in treatment *NMW* than in *Control* and *NM*.

Body weight increased from mating until weaning in sows provided with cooling, whereas BW decreased in sows without cooling (*Control*). Weight loss from two weeks prior to farrowing until weaning was smaller in sows with cooling than in *Control* and TPP was maintained from farrowing until 21 days of lactation in sows with cooling, but steadily increased in *Control*. Piglet mortality at weaning was lower in sows with cooling than in *Control*. Analysis of plasma cortisol concentration in blood samples from sows showed that provision of a cooling system had no effects, while restricted water intake increased cortisol concentrations.

Thus the performance, condition and welfare of sows and piglets on smallholder farmers in Lao PDR and other countries with similar conditions can be markedly improved by simple means such as providing cooling and water *ad libitum* and providing nesting material.

Keywords: cooling, pig, management, survival, growth, plasma protein, water.

Author's address: Ammaly Phengvilaysouk, Livestock Research Centre, National Agriculture and Forestry Research Institute, P.O. Box: 7170, Vientiane, Lao PDR. *E-mail:* aphengvilaysouk@gmail.com

Dedication

To my parents, my family, my sisters and brothers

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 Phengvilaysouk, A., Jansson, A., Phengsavanh, P., Tiemann, T., Phangvichith, V. & Lindberg, J.E. (2017). Sow and piglet management in smallholder and larger-scale pig farms in Northern part of Laos. *Livestock Research for Rural Development. Volume 29, Article #201*. Retrieved November 10, 2017, from *http://www.lrrd.org/lrrd29/10/jan29201.html*.

II Phengvilaysouk, A., Lindberg, J.E., Sisongkham, V., Phengsavanh, P. & Jansson, A. (2017). Effects of provision of water and nesting material on reproductive performance of native Moo Lath pigs in Lao PDR. *Tropical Animal Health and Production*, DOI:10.1007/s11250-018-1541-7.

III Phengvilaysouk, A., Lindberg, J.E., Phengsavanh, P. & Jansson, A. (2017). Effect of cooling methods on reproductive performance in native Moo Lath sows. (Submitted).

IV Phengvilaysouk, A., Lindberg, J.E., Phengsavanh, P. & Jansson, A. (2018). Effect of watering and cooling strategies on cortisol levels in sows kept in tropical conditions (Manuscript).

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Abbreviations

ACTH	Adrenocorticotrophic hormone
ADF	Acid detergent fibre
CIAT	International Centre for Tropical Agriculture
Cm	Centimetre
CP	Crude protein
CRH	Corticotrophin-releasing hormone
CSF	Classical swine fever
DM	Dry matter
DNA	Deoxyribonucleic acid
DW	Dripping water provided
F	Fan provided
FAO	Food and Agriculture Organization
G	Gram
HPA	Hypothalamus pituitary-adrenal
IU	International units
Kg	Kilogram
Km	Kilometre
L	Litre
Lao PDR	Lao People's Democratic Republic
LCA	Lao Census of Agriculture
LSPF	Larger-scale pig farms
LW	Live weight
L4PP	'Legumes for Pigs' project
MAF	Ministry of Agriculture and Forestry
MMA	Mastitis metritis agalactia
N	Nitrogen
NAFRI	National Agriculture and Forestry Research Institute
NB	Nest-building
NDF	Neutral detergent fibre

NM	Nesting material provided, but no extra water
NMW	Nesting material and extra water provided
PDS	Postpartum dysgalactia syndrome
PC	Plasma cortisol concentration
POMC	Proopiomelanocortin
SEM	Standard error of mean
SHPF	Smallholder pig farm
TPP	Total plasma protein concentration

1 Introduction

Asia is the largest producer of pork in the world, accounting for 56% of global pork production (FAO, 2011). In Southeast Asia, pork is the most important source of meat, estimated to comprise more than 50% of total meat output (Huynh *et al.*, 2007). In Lao PDR, meat consumption in 2009 was approximately 21 kg per capita per year (LCA, 2014), but the aim is to achieve a total meat supply of 40-50 kg per capita and year by 2020 (MAF, 2010). Pigs are the main source of meat in Lao PDR, accounting for more than 40% of total meat production (FAO, 2005).

In Lao PDR, about 90% of households live in rural upland areas. Their livelihood is based on existing traditional agriculture for survival and livestock is one of the major farm activities (LCA, 2014). The pig population is about 3.1 million head in Lao PDR (Lao Statistics Bureau, 2014; FAO, 2014) and more than 80% of pig herds are native breeds. Pig production is mainly based on smallholder pig farms (SHPF) with combined rearing systems (Keonouchanh *et al.*, 2011). Native pig production is a great option for poor farmers, as these pigs have an efficient feed conversion rate and shorter breeding cycle and produce a greater number of offspring than cattle and most other large domestic animals (Levy, 2014; Mutua *et al.*, 2012). In addition, pigs play an important role in farmers' livelihood as a source of cash income reserve and pork is used in traditional ceremonies in households in upland areas (Phengsavanh, 2013; MAF, 2010). In general, SHPF tend to sell their pigs to meet critical cash requirements such as farm inputs, buying medicines and paying school fees and in times of food shortage rather than waiting for a greater cash return when pigs reach slaughter weight (Ouma *et al.*, 2014; Mutua *et al.*, 2012; Phengsavanh *et al.*, 2010).

Traditionally, native pigs are mainly raised in extensive low-input systems that take advantage of naturally occurring feed. Indigenous pigs are mostly found in rural regions, where they extensively scavenge around the village, in forests and in fallow fields. Some farmers keep pigs in enclosures or pens

(Phengsavanh, 2013; Phengsavanh *et al.,* 2011). Farmers always use local feed sources, including rice bran, cassava roots, maize, local tuber crops, taro leaves and green feeds from the forest, for feeding their pigs. These feed sources are generally high in energy but low in protein content, while green feeds are high in fibre (Phengsavanh *et al.,* 2011; Phengsavanh & Stür, 2006).

Moreover, SHPF farmers have a poor understanding of pig management and pigs are often fed the same diet, irrespective of stage of growth and reproductive state. In addition, pigs often have to compete with each other for the limited amount of feed provided (Stür *et al.,* 2008). Time spent on taking care of animals is limited in SHPF production systems, in particular during the critical period from gestation until weaning (Tiemann *et al.,* 2017). In addition, SHPF farmers do not provide high-quality feed to sows during lactation and do not give weaning piglets the high-protein diet needed for good growth. The major problem on SHPF is poor reproductive performance, and piglets usually have a low growth rate (20-50 g/day) and high mortality rate from birth to weaning (30-50%). This is because the poor management and feeding regime leads to poor health and susceptibility to diseases (Chittavong *et al.,* 2012a; Phengsavanh *et al.,* 2011; Phengsavanh *et al.,* 2010; L4PP, 2010).

It is common practice to provide water to pigs mixed with the feed (~2.5 L per day) (Phengsavanh, 2013; Chittavong *et al.,* 2012b). Providing extra water is unusual (Tiemann *et al.,* 2017). This practice might result in insufficient water intake and dehydration. Low water intake can decrease feed intake and milk production, and thereby piglet growth rate (Kruse *et al.,* 2011).

An effective management strategy to increase the health and survival rate of piglets could be to assist sows before and during farrowing, in order to minimise the level of stress. Provision of bedding material to permit nest building may reduce stress during farrowing and can have positive effects on stillbirth rate (Cutler *et al.,* 2006; Thodberg *et al.,* 2002). In addition, nesting material improves floor heating and has been reported to cause faster recovery of piglet body temperature after birth, to reduce latency to suckle and to decrease piglet mortality (Malmqvist *et al.,* 2006). However, provision of nesting material to permit nest building seems to be rare in smallholder systems (Wischner *et al.,* 2009).

By nature, pigs do not pant and do not have functional sweat glands to assist them in removal of excessive body heat (Brown-Brandl *et al.,* 2004). They are thus dependent on environmental conditions to control heat balance during periods of heat load. If the ambient temperature exceeds the upper critical temperature of the individual's thermoneutral zone and no cooling opportunities are provided, heat stress will develop. The thermoneutral zone depends on the individual's physiological condition and in reproductive sows is approximately between 16 and 25 °C (Sivanilza *et al.,* 2016). Thus, heat stress is one of the major concerns in pork production in tropical countries (Einarsson *et al.,* 2008), where the ambient temperature is often high (above 30 °C) for long periods. Heat stress may result in poor growth rate, reduced milk production and increased piglet mortality rate (Suriyasomboon *et al.,* 2006). Furthermore, heat stress may have negative impacts on litter size, farrowing rate and weaning to first service interval (Bloemhof *et al.,* 2013; Tantasuparuk *et al.,* 2000). Therefore, this thesis work primarily focused on management strategies (water, nesting and cooling) that can be implemented to reduce the level of stress and improve sow performance and piglet survival rate and growth.

Objectives of the thesis:

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

- Obtain more detailed information on sow management and reproductive performance in SHPF production systems in northern Lao PDR and to identify factors with potential to improve performance and to reduce piglet mortality.
- Investigate the effect of providing extra water and nesting material to sows 14 days before expected farrowing until weaning on sow performance and condition, and on piglet survival rate and piglet growth.
- Investigate the effect of providing cooling to sows in tropical conditions, using either a fan or dripping water, from 14 days before expected farrowing until weaning on sow performance and condition, and on piglet survival rate and piglet growth.
- Compare plasma cortisol concentrations in sows kept under conventional smallholder conditions in Lao PDR and in sows provided with a cheap cooling system and water *ad libitum*.

Hypothesis of the studies:

- Free access to water and nesting material has positive effects on body weight and plasma volume of sows, and on stillbirth, piglet survival and growth performance.
- Cooling in heat-stressed sows has a positive effect on the maintenance of plasma volume and reduces stillbirth and improves piglet survival and growth performance.

Sows provided with cooling and water *ad libitum* show a different plasma cortisol response to sows with no cooling or extra water.

2 Background

2.1 Native Moo Lath pigs in Lao PDR

Native pigs in Southeast Asia, which were probably domesticated from the wild pig (*Sus vittatus*) about 2900 years ago, are known as *Sus indicus* in Lao PDR, Thailand and Vietnam (Falvey, 1982). Studies by Shenglin (2007) have shown that the cytochrome-b gene sequences of native domestic pig (*Sus scrofa*) in Lao PDR and Vietnam are identical to those of the Meishan pig, a Chinese breed, suggesting that both pigs had a late common ancestor.

There are several indigenous breeds of pigs in Southeast Asia. These include Mong Cai, Muong Khuong, Meo and Co pigs in Vietnam (Dang Nguyen *et al.,* 2010); short-eared Hailum, Murad and Mukuai pigs in Thailand (Nakai, 2008); Moo Lath, Chid, Hmong and Khong pigs in Lao PDR; and native pigs (small head, concave back, pendulous belly) in Myanmar (Deka *et al.,* 2014). There are also some Chinese domestic pig breeds, including Jinhua, Meishan, Xiang pig and Qianbei black (Shenglin, 2007). The advantages of indigenous pig breeds are high tolerance to harsh conditions and low quality feed, low-input management and high disease resistance (L4PP, 2010). In Lao PDR, more than 90% of native pigs are raised on SHPF in upland areas (LCA, 2014) and play an important role in farmers' livelihoods and contribute to traditional ceremonies for households (MAF, 2010).

In Lao PDR, studies on specific genotypes and DNA genome analysis for different breeds of native pigs are limited (Oosterwijk *et al.,* 2003). The native breeds have been preliminarily classified into four types by Keonouchanh *et al.* (2011), based on phenotypical differences recorded in a field survey focusing on general characteristics, production performance and carcass composition (Table 1). This classification is similar to previously reported classes of pig breeds in Lao PDR (FAO, 2007; Wilson, 2007).

Table 1. *Classification of phenotype characteristics and reproductive performance of native pigs produced under smallholder farm (SHPF) conditions in Lao PDR*

	Native pig breed			
	Moo Chid/ Markadon/ Boua	Moo Lath	Moo Nonghad/ Hmong	Moo Deng/ Berk
Age at 1st service, months	6-7	6-7	5-6	6-7
Weight at 1st service, kg	21-31	~39	30-40	30-40
Mature weight, kg				
Female	42-48	47-61	65-85	65-90
Male	18-30	30-50	60-80	65-90
No. of litters/sow/year	1.5	1.5-1.8	1.5-1.8	1.5-1.8
No. of piglets/litter	7-8	7-8	7-10	7-10
Age at weaning, months	3	2-3	2-3	2-3
Weight at weaning, kg	7.8	9.5	8	8.5
Phenotype characteristics				
Body length, cm	75-92	85-100	100-105	88-120
Girth circumference, cm	72-85	84-102	115-130	84-116
Body high, cm	46-54	51-70	56-76	60-70
Ear type	Small, short and directed forward	Small, short and directed forward	Larger ears and directed forward	Large hanging ears
Body and colour	Black coat, white legs	Straight face, black coat, leg and front of face are white	Short and bent face. Mostly black coat	Brown colour, bent face

Source: Keonouchanh *et al.* (2011).

The development plan of the Lao PDR government prioritises domestic animal production for commercialisation and exportation (MAF, 2010). The major concentrations of SHPF are found in rural upland areas, with more than 95% of pigs in these systems being of native breeds (LCA, 2014). The advantage of native pigs is that they are hardy, resistant to disease, achieve early sexual maturity and are adaptable to harsh rural environments with low inputs (Phengsavanh & Stür, 2006). In local markets, pork from indigenous pigs fetches a price premium compared with pork from imported breeds (Deka *et al.*, 2014). However, the productivity of native Moo Lath pigs is often far below the true potential level in SHPF systems. There have been a number of studies on growth performance of native pigs in Lao PDR. It has been reported that daily weight gain of native pigs in traditional smallholder systems is around 100 g/day, but that supplementing the diet with leaves of the stylo plant (*Stylosanthes* sp.) can double the weight gain (Phengsavanh & Stür, 2006).

Keoboualapheth *et al.* (2003) reported a growth rate in native pigs in Lao PDR fed stylo leaves of 154 to 230 g/day. Another study observed a growth rate of 155 to 193 g/day in native Lao pigs fed diets supplemented with cassava leaf silage (Xaypha *et al.*, 2007). Growth rate was 340 to 400 g/day in a study where native pigs received supplementary feeding with soy bean meal and taro silage (Chittavong, 2012). However, the potential growth rate of native pigs in Lao PDR is markedly higher than reported above. For example, Keonouchanh *et al.* (2011) concluded that Moo Lath pigs can grow by up to 560 g/day on a high-energy, nutrient-balanced diet.

2.2 Sow-piglet production systems on smallholder farms

In countries in Southeast Asian, the main source of income is agriculture, with pig farming being one of the major contributors (Kunavongkrit & Head, 2000). Pigs also play an important role in the livelihood of rural households in many other parts of the world. In traditional systems in rural upland areas of Lao PDR, income from pigs accounts for about 14% of total household income (Tiemann *et al.*, 2017). In North Vietnam, pigs contribute up to 41% of rural household income (Lemke *et al.*, 2007). Pigs contribute about 15% of income in Kenya (Njuki *et al.*, 2010) and 31-48% of income in SHPF in DR Congo (Kambashi *et al.*, 2014).

Small-scale backyard rearing of pigs is the dominant practice worldwide. In Lao PDR, Vietnam, the Philippines, Cambodia and Myanmar, about 80% of pigs are raised by smallholders (FAO, 2011). In Lao PDR, small-scale pig production systems can be categorised into three types: free-range scavenging, confined in enclosures, and confined to pens (Phengsavanh & Stür, 2006). The herd size on SHPF varies between countries, *e.g.* a small farm in the Philippines and Vietnam has less than 20 pigs, while a small farm in Lao PDR, Cambodia and Myanmar has less than 5 pigs (FAO, 2005). Herd size can be considered an indication of the extent of market orientation (Kambashi *et al.*, 2014).

Pigs are reared for both sow-piglet production and for fattening, but the percentage of SHPF with piglet production is relatively high in upland areas of Lao PDR, whereas fattening pig production is greater in lowland areas (L4PP, 2010; Phengsavanh, 2013). In the SHPF system, natural breeding still dominates, but only a few households rear and keep boars. Boars are commonly used for breeding with sows in the villages irrespective of their breed or size, and smallholder farmers often have inadequate knowledge about the breeding system and breeding management (Phengsavanh & Stür, 2006; Phengsavanh *et al.*, 2011).

Smallholder farmers use locally available feedstuffs, which are harvested and collected using family labour. Pigs are fed mainly on rice bran, cassava root, maize, natural tuber crops and green feed from the forest. In villages close to the city, limited amounts of purchased concentrates are occasionally used (Chittavong *et al.,* 2012a; Phengsavanh *et al.,* 2011; L4PP, 2010). The composition of pig feeds mainly depends on availability of feedstuffs rather than on the nutritional requirements of pigs at different stages of the production cycle (L4PP, 2010; Lemke *et al.,* 2007). This leads to imbalanced nutrient supply, as the nutrient requirements of pigs differ with age and physiological performance (NRC, 2012). Poor nutrition of sows during lactation and of piglets after weaning has been identified as a major contributing factors to low growth (20-50 g/day) and high piglet mortality (30-50%) on SHPF in Lao PDR (Phengsavanh & Stür, 2006; L4PP, 2010). In addition, the lack of protein in traditional diets restricts the growth of pigs, resulting in average daily weight gains of less than 100 g/day (Phengsavanh & Stür, 2006; Thorne, 2005).

The period with the highest risk of piglet mortality is during and after farrowing. It is common practice on SHPF to let sows farrow unsupervised in the forest, which has been shown to result in high piglet mortality (Tummaruk *et al.,* 2017; Andersen *et al.,* 2007).

Another factor that has an effect on pig performance is disease. The most common diseases affecting pig population on SHPF are classical swine fever (CSF), piglet diarrhoea, anaemia and parasite infestation (both internal and external) (Kunavongkrit & Head, 2000). Conlan *et al.* (2008) reported that less than 10% of pigs on SHPF are vaccinated to prevent CSF. The mortality rate of pigs infected with CSF in rural areas in northern Lao PDR is 70 to 80% (Phengsavanh & Stür, 2006). The disease causes more damage on SHPF mainly because of inadequate availability of vaccine and/or poor awareness among smallholders and limited control programmes (Deka *et al.,* 2014).

Moreover, a tropical climate (25 to 31 °C) can have negative effects on reproductive performance, *e.g.* boar semen quality, gilt and sow fertility and litter size (Kunavongkrit & Heard, 2000). In addition, the quality and quantity of feed in tropical countries are major issues. Feed contaminated with fungi and bacteria can cause abortion in sows and stillborn piglets. Moreover, the hot environment affects feed intake, which becomes critical during lactation when the energy and nutrient requirements are high (Kunavongkrit & Heard, 2000).

Poor pig performance on SHPF could also be partly due to several other reasons, including management practices and the genetic status of native pigs (Chittavong *et al.,* 2012a; Phengsvanh *et al.,* 2010). Overall, poor nutrition, poor breeding management and disease are suggested to be the factors of major concern in SHPF production systems in Lao PDR (Stür *et al.*, 2010; Phengsavanh *et al.*, 2010).

2.3 Causes of piglet mortality

Piglet survival is an important indicator of profitability in pig production. In Europe and North America, average live-born pre-weaning mortality rates are typically within the range 11 to 13%. The extent of piglet mortality is influenced by many factors, such as birth weight, litter size, gestation period, frequency and quality of human supervision, management practices, housing, husbandry system and nutrition of the sow (Biswajit *et al.*, 2014; Kirkden *et al.*, 2013; Ruediger & Schulze, 2012; Andersen *et al.*, 2009, 2007).

It has been suggested that a combination of breeding, management and housing strategies that keep sow behaviour less restricted can be a way to improve piglet vitality and pre-weaning survival rate (Muns, 2015; Baxter *et al.*, 2011). According to Muns (2015), piglet birth weight is the most important factor determining early piglet survival and pre-weaning performance. Small-sized newborn piglets have limited glycogen stores to cope with decreased temperature and to compete with their siblings for sucking colostrum (Tummaruk *et al.*, 2017). Most piglet deaths occur around farrowing and during the first few days of life (72 hours), and therefore this critical time is very important for management interventions intended to reduce piglet mortality (Kirkden *et al.*, 2013, Su *et al.*, 2007).

2.3.1 Intrapartum stillbirth and low vitality

Piglet survival depends on individual vitality at the time of birth. Low vitality during the first few days of life and mortality after birth are closely linked (Milligan *et al.*, 2002). Vitality in newborn piglets is in turn affected by piglet birth weight (Hoy *et al.*, 1997). Dystocia, defined as difficult parturition to the point of needing human intervention, is generally caused by fatness or poor uterine muscle tone. Dystocia is associated with asphyxia, a risk factor for stillbirth (Kirkden *et al.*, 2013). Perinatal asphyxia is the proximate cause in most cases of stillbirth and also results in reduced viability and vitality, both of which increase the risk of mortality after birth (Alonso-Spilsbury *et al.*, 2007; Herpin *et al.*, 2002; Edwards, 2002).

Management strategies to reduce stillbirth and improve viability and vitality generally aim at: i) reducing the duration of farrowing or the time taken to deliver individual piglets, and ii) providing weak piglets with assistance immediately after birth (Kirkden *et al.*, 2013). Therefore, common recommendations include culling old sows, controlling body condition during pregnancy to avoid fat sows at farrowing, providing assistance to sows experiencing dystocia, helping weak piglets to start breathing, keeping weak piglets warm, assisting weak piglets to reach the udder and minimising sow stress during farrowing (Oliviero *et al.,* 2010; Fangman & Amass, 2007; Lucia *et al.,* 2002; Herpin *et al.,* 1996). Stress during farrowing causes the production of natural opioids, which inhibit oxytocin and can prolong farrowing (Lawrence *et al.,* 1992). Provision of bedding material to permit nest-building behaviour before farrowing may act to reduce stress and can reduce farrowing duration and stillbirth rate (Thodberg *et al.,* 2002). Heat stress in late gestation may be a risk factor for stillbirth. Therefore, maintaining the farrowing house temperature below 29 °C or cooling sows in hot weather is recommended (Cutler *et al.,* 2006).

2.3.2 Hypothermia

Hypothermia occurs when the ambient temperature of the farrowing house is below the lower critical temperature of the newborn piglets. In hypothermia, piglets must initially use their energy reserves to maintain body temperature. However, low birth weight piglets have low energy reserves and poor ability to compete at the udder (Herpin *et al.*, 2002). Therefore, it is essential to assist weak piglets to reach the udder and obtain colostrum promptly in order to avoid hypothermia (Kirkden *et al.,* 2013).

Management strategies to reduce hypothermia include providing piglets with a warm environment using for supplementary heat source such as a heat lamp, floor heating, an enclosed box or an insulated corner of the creep area (Andersen *et al.,* 2009; Cutler *et al.,* 2006). The latter two options may also reduce the risk of crushing and decrease pre-weaning mortality. Newborn piglets prefer temperatures in excess of 30 °C and their preference to lie close to another piglet is stronger than their thermal preference (Vasdal *et al.,* 2010; Hrupka *et al.,* 2000). Provision of heat close to the sow should help to prevent weak piglets from becoming chilled at the site of birth, and can also ensure that all piglets meet their two most urgent needs, *i.e.* warmth and colostrum, in the same place (Malmqvist *et al.,* 2006). Reducing heat loss is also an important factor. Provision of deep straw is an effective way to reduce both hypothermia and crushing in loose-house sow systems, with bedding to a depth of 10-15 cm recommended (Baxter *et al.,* 2011).

2.3.3 Starvation

Starvation in sows has negative impacts on colostrum and milk production. Starvation in individual piglets may be due to them failing to consume enough milk because they have to compete for sucking teats and small or weak piglets may be unsuccessful in this (Fraser & Rushen, 1992). Newborn piglets have low energy reserves and need to obtain colostrum (~200 g) for immunoglobulins levels to provide immunity and to refill energy stores (Ruediger & Schulze, 2012). Timing of colostrum ingestion is very important, as piglets need to obtain colostrum immunoglobulins within 24 hours post farrowing (Bland *et al.,* 2003). The content of immunoglobulins in colostrum can be up to 80% lower at 24 hours post farrowing (Foisnet *et al.,* 2010). Colostrum production does not increase with litter size, which means that the amount of colostrum available to each piglet is significantly less in larger litters (Devillers *et al.,* 2007; Le Dividuch *et al.,* 2005; Auldist *et al.,* 1998). Piglets born early and heavier piglets may have more opportunity to explore the udder and select teats that produce a lot of milk (Rooke & Bland, 2002; Fraser & Rushen, 1992). Therefore, smaller and weaker piglets should be prioritised for first colostrum intake after birth (Andersen *et al.,* 2007; Tuchscherer *et al.,* 2000).

One management strategy to reduce piglet mortality and improve growth performance can be fostering piglets soon after birth. Individual piglets may be fostered onto a sow that farrows at around the same time and has a smaller litter (Kirkden *et al.,* 2013). In practice, fostering or cross-fostering routines should be performed as early as possible. Piglets fostered very early (at 2 to 9 hours of age) do not differ from natural offspring in the frequency of successful suckling (Price *et al.,* 1994). The extent of fostering required on farms is generally increasing, as sows are being bred for greater litter size (Fraser, 1975). Successful fostering requires skill and attention to detail on the part of the stockperson, because decisions need to be made on a litter-by-litter basis, depending on the number of available teats and the vitality of the piglets (Andersen *et al.,* 2007).

2.3.4 Crushing

Crushing deaths generally occur when the sow changes posture, particularly when lying down from standing or rolling over (Damm *et al.,* 2005). Piglet safety and avoidance of crushing may depend on sow carefulness, such as rolling behaviour and the speed of lying down (Damm *et al.,* 2005). The behavioural instinct of piglets to stay close to the sow during the first day of life is a risk factor for crushing (Andersen *et al.,* 2007). Higher parity number and larger litter size are linked to more crushed piglets (Lensink *et al.,* 2009; Weber *et al.,* 2009). Low birth weight, weakness and low vitality increase the risk of crushing (Grandinson *et al.,* 2002; Roehe & Kalm, 2000). Risk of crushing also increase with increasing slipperiness of floors (Boyle *et al.,* 2000) and body weight of the sow (Lensink *et al.,* 2009).

Recommended strategies to reduce crushing mortality include improvement of sow behaviour by genetic selection and modifications to pen or crate design and management practices (Lawlor & Lynch, 2005; Vangen *et al.,* 2005). Provision of straw and other bedding materials may reduce the risk of crushing by allowing the sow to build a nest, thereby improving her behaviour during and after farrowing (Wechsler & Weber, 2007). Indoor-housed sows can show restlessness and may be unable to build a nest during and after parturition (Damm *et al.,* 2010). Under natural conditions, the sow builds a nest and neither the sow nor the piglets normally leave the nest during the first day after farrowing (Jensen, 1986). Farrowing supervision in the immediate post-farrowing period, when the risk of crushing is greatest, may have positive results (Spicer *et al.,* 1986).

2.3.5 Savaging

Savaging is aggressive behaviour directed at piglets by the sows, which may result in injury or death. Deaths occur predominantly around the time of farrowing (Vieuille *et al.,* 2003; Harris & Gonyou, 2003; Harris *et al.,* 2003). Savaging is most common in gilts and is thought to be associated with novel and stressful events for instance the change of environment, fear of contact with humans, pain occurring during parturition, fear of the newborn piglets and discomfort when sucking if the sow suffers from postpartum dysgalactia syndrome (PDS) (Jarvis *et al.,* 2004; Marchant Forde, 2002; Harris *et al.,* 2001). There is some evidence that the skill of the stockperson affects the frequency of savaging deaths (Harris & Gonyou, 2003; Harris *et al.,* 2003). Savaging also has a clear genetic component (Chen *et al.,* 2009; Quilter *et al.,* 2008).

Savaging could be reduced by training stockpersons to use positive handling techniques that decrease sow fearfulness, as sows that are fearful of humans during gestation are more likely to savage their piglets (Marchant Forde, 2002). Kirkden *et al.* (2013) suggest that, when observing an aggressive sow, all piglets should be removed and confined in the creep area until the end of farrowing or until the sow becomes quiet. Thus, supervision of farrowing is important, as it is difficult to prevent savaging when a stockperson is not present in the farrowing house.

2.3.6 Piglet diseases

There are two mains groups of disease in piglets, non-infectious and infectious. Common non-infectious diseases that occur during the sucking period includes splay-leg, anaemia and leg and foot injuries (Kirkden *et al.,* 2013). General management strategies that are important for the prevention of infectious diseases include vaccination of the sow against specific bacteria and viruses, basic hygiene measures, including all-in all-out management, cleaning and disinfection of pens between batches, frequent removal of faeces, preventing cross-contamination between pens and ensuring maximal colostrum intake for immune protection (Le Dividich *et al.,* 2005). Vaccination of the gestating sow can be an effective way to protect young piglets against bacteria such as *Escherichia coli* and *Clostridium* spp (Cutler *et al.,* 2006). Sows may also be washed and treated for parasites before entering the farrowing house. During the sucking period, it is important to keep the pen floor clean and dry (Kirkden *et al.,* 2013).

2.4 Farrowing supervision

Successful farrowing supervision can be achieved by assigning a stockperson to assist the sow and piglets at the time when the risk of mortality is highest (*i.e.* during and immediately after farrowing) (Kirkden *et al.,* 2013). The most important factors for successful swine production are to optimise farrowing management perform farrowing interventions in sows with dystocia, provide care for newborn piglets and optimise cross-fostering (Tummaruk *et al.,* 2017).

Providing assistance to the sow

Dystocia is commonly caused by conditions that obstruct the passage of the foetus through the birth canal. For instance, gilts have a narrower pelvis than mature sows and may have difficulty delivering large piglets (Kirkden *et al.,* 2013). The obstructions can include abnormal presentation of the piglet in the birth canal, the colon being full of faecal material and fat deposits in obese sows (Cowart, 2007). Stress also causes dystocia by inhibiting uterine contractions (Lawrence *et al.,* 1992). Parturition intervention should be considered if the interval between piglets exceeds 30 to 60 minutes (Fangman & Amass, 2007; Lawlor & Lynch, 2005) or if the sow has not yet expelled any piglet but appears distressed, weak or showing an abnormal vaginal discharge (Cowart, 2007). In cases of dystocia, intervention should initially involve manual examination of the birth canal, but such manual intervention may cause injury or infection in the sow and it is important to ensure high hygiene standards (Cowart, 2007). Oxytocin is widely used during farrowing to treat dystocia when the birth canal is open and unobstructed and the foetus is well positioned, but the sow is unable to expel (Gilbert, 1999). Oxytocin can be administered to all sows at the start of farrowing to stimulate uterine contraction. This results in decreased farrowing duration and thereby reduces stillbirths (Vanderhaeghe *et al.,* 2010; Le Cozler *et al.,* 2002; Straw *et al.,* 2000).

Management practices for piglet care

The most critical period of piglet deaths (50-80%) is during the first week after birth (first 72 hours of life) (Andersen *et al.,* 2007). Birth weight is strongly correlated with pre-weaning piglet mortality. In a study in Thailand, piglets with birth weight >1.8 kg had a survival rate of over 90%, whereas piglets with a birth weight of 700 g had a survival rate of only 33% (Tummaruk *et al.,* 2017). Piglets with low birth weight have a higher risk of death and required a longer period of supervision (Nguyen *et al.,* 2011).

Drying piglets with a towel, tying the umbilical cord, clearing out the nasal and oral cavities, cleaning mucus to help newborns start breathing and helping piglets sucking all result in reduced stillbirth rates and increase pre-weaning survival (Isberg, 2013; White *et al.,* 1996). Helping piglets to explore the udder immediately after farrowing for colostrum ingestion and placing them in an enclosed box with supplementary heating lamps in the creep area are also important way to increase survival (Vasdal *et al.,* 2011; Andersen *et al.,* 2009; Andersen *et al.,* 2007).

Increased frequency of farrowing supervision decreases stillbirths and mortality up to 3 days of age due to crushing, and gives lower live-born pre-weaning mortality (Kirkden *et al.,* 2013; Bille *et al.,* 1974). However, according to Pedersen *et al.* (2006), deaths from starvation are more frequent in litters born in the morning, when staffs are present in the farrowing house. This could be due to sows being frequently disturbed during daytime by human activity, causing stress and interrupting nursing (Fangman & Amass, 2007). Friendship *et al.* (1986) found that pre-weaning mortality was not affected by the amount of time the stockperson spent in the barn. The mortality is lower in herds where family members care for the pigs than when hired labour is used (Simensen & Karlberg, 1980). Therefore, it has been suggested that the quality of supervision may be as important as the quantity (Holyoake *et al.,* 1995; Vaillancourt & Tubbs, 1992). Reducing piglet mortality by providing extra effort and care during the critical time in the first day of life is very important (Andersen *et al.,* 2007), as is paying more attention to small and weak piglets.

Technical skill, motivation and relationship between stockperson and animals are also important for the success of management intended to assist the sow and piglets around the time of farrowing (Kirkden *et al.,* 2013). Sows that are fearful of humans during gestation are more likely to savage their piglets (Marchant Forde, 2002). Several studies indicate that averse handing of sows during the third trimester of gestation (repeated restraint using a nose sling) has a negative effect on piglet health (Tuchscherer *et al.*, 2002) and increases piglet mortality rate (Otten *et al.*, 2001).

2.5 Stress

Stress is defined as a biological response to an event when an individual perceives a threat to its homeostasis (Moberg, 2000). Stress in behavioural sciences is regarded as the perception of threat with resulting anxiety, discomfort, emotional tension and difficulty in adjustment (Fink, 2009). Perception of stressful stimuli leads to activation of the hypothalamus-pituitary-adrenal (HPA) system in release of a variety of peptides, principally corticotrophin-releasing hormone (CRH) and vasopressin from the hypothalamus. CRH stimulates the release of adrenocorticotrophic hormone (ACTH) and other proopiomelanocortins (POMC). ACTH acts on the adrenal glands and causes secretion of glucocorticoid hormones, *e.g.* cortisol and progesterone (Madej *et al.*, 2005).

There are many difficulties involved in evaluation of how different types of stress affect animal welfare (Einarsson *et al.*, 2008). Different external factors can produce a similar stress response, while the same stressful situation can produce a different response in the animal depending on its age, genetics, production system and previous exposure to the stimulus (Martínez-Miró *et al.*, 2016). The main causes of stress in general are social stress, environmental stress, metabolic stress, immunological stress and stress by animal handing.

Social stress can vary depending on the group size, space available and genetics of the pigs (Andersen *et al.*, 2004). Intensive housing involving a reduction in the space per animal may cause stress because of restricted movements and freedom to feed (Verdon *et al.*, 2015). Aggressive behaviour increases and growth rate decreases as the space allowance per pig decreases (Remience *et al.*, 2008; Weng *et al.*, 1998; Randolph *et al.*, 1981). Aggressive behaviour varies between individuals and genotypes (Muráni *et al.*, 2010).

Intensive pig farming requires control of temperature, humidity, light, ammonia levels and so on (Pearce *et al.*, 2013; White *et al.*, 2008). The ambient temperature should be as close as possible to thermal neutrality, for instance between 30 and 32 °C for pre-nursery pigs and between 16 and 26 °C for pregnant and lactating sows (Black *et al.*, 1993). The optimal environmental conditions sometime cannot be maintained in areas where there are extreme hot or cold seasons (Martínez-Miró *et al.*, 2016). Under tropical conditions, thermal discomfort is almost permanent in pig farms and heat stress is one of the main problems affecting pig production (Silva *et al.*, 2006; Ross *et al.,* 2015). By nature, pigs are sensitive to high ambient temperatures because they lack functional sweat glands and the heat losses must occur at respiratory and skin level (Lucas *et al.,* 2000). According to Baumgard & Rhoads (2013), a reduction in nutrient intake during thermal load is a highly conserved response across species in order to decrease metabolic heat production. Response to heat stress begins with increased respiration rate, continues with decreased feed intake and leads to increased rectal temperature (Huynh *et al.,* 2005). Sows begin to show negative effects of heat stress at a temperature of 20 °C and a temperature of 26 °C or higher is considered critical (Quiniou *et al.,* 2001). High ambient temperature (exceeding 30 °C) reduces feed intake and milk production, and increases piglet mortality and weaning to next service interval in sows (Cabezón *et al.,* 2017a; Bloemhof *et al.,* 2013; Renaudeau *et al.,* 2003; Tantasuparuk *et al.,* 2000). When the ambient temperature increases from 23 to 34 °C, fertility and/or total sperm counts decline and ejaculate volume decreases in boars (Stone, 1981). Heat stress will decrease fertility in sows and gilts (Bertoldo *et al.,* 2009). Heat stress has been reported to reduce implantation and impair embryo development in gilts, especially before day 15 of pregnancy and during day 15-30 post mating, which may cause a reduction in the conception rate and increase embryo mortality (Einarsson *et al.,* 2008; Renaudeau *et al.,* 2003; Edwards *et al.,* 1968). Omtvedt *et al.* (1971) reported that days 0-8 post breeding are the most sensitive stage of implantation. Heat stress may cause reduced and inconsistent growth, poor sow reproductive performance and increased mortality and morbidity (Ross *et al.,* 2015). Moreover, heat stress increases skin blood flow circulation to promote heat loss and reduced blood flow to the other tissues (Collin *et al.,* 2001). The ability of lactating sows to mobilise body reserves and to redistribute blood flow to the skin to increase heat loss might reduce nutrient supply to the mammary gland, thus reducing milk production (Eissen *et al.,* 2000). The decrease in milk production might also be explained by the low concentration of thyroxine, triiodothyronine and cortisol in the mammary glands (Black *et al.,* 1993).

Moreover, in intensive pig production systems with lack of space and bedding material, sows have limited possibility to perform nest-building behaviour pre-parturition, which might lead to stress (Oczak *et al.,* 2015). In addition, metabolic stress results from food and/or water restriction, and it can also appear in intensive farming conditions when pregnant sows are subjected to restricted feeding (Ott *et al.,* 2014; Arellnaro *et al.,* 1992). Immunological stress occurs when an animal is challenged by infectious agents, which can occur after vaccination or on exposure to infectious diseases (Song *et al.,* 2014).

2.6 Benefits of watering, nesting and cooling on sow-piglet production

2.6.1 Watering

Water is a nutrient essential for life, making up approximately 80% of the empty body weight of the newborn pig and about 53% of body weight in a mature pig (Almond, 1995). Pigs require water for a number of reasons, including most metabolic functions, transport of nutrients into the body tissues, removal of metabolic waste and maintaining body temperature, acid-base balance and fluid balance of the body. Thus, a supply of adequate drinking water is essential for maintaining the body's water content. A 10% loss of body water content results in death in pigs, as in other mammals (Meunier-Salaun *et al.,* 2017).

Pigs consume the majority of their water requirement by drinking, but some water is ingested with the feed and some is generated through metabolism. Pigs need to drink water regularly as their bodies lose water constantly via urine, respiration, faeces and skin (Almond, 1995). Additional losses that must be compensated for by water intake occur in sows during gestation, at farrowing and during lactation. During water loss, the osmolality of the extracellular fluid increases and neuro-endocrine signals trigger the release of anti-diuretic hormone, which concentrates the urine, and a sensation of thirst, which motivates the animal to ingest water and restore body water content to normal level (Harvey, 1994). The intake of water varies over time and between individuals (Renaudeau *et al.,* 2013). Water requirement and intake are related to the health status and physiological status of the pig. Thus, the water requirement and intake are high during lactation and at high ambient temperature. Schiavon & Emmans (2000) estimated that water intake by pigs increases by 0.1 L/day for every 1 °C increase in ambient temperature within a range of 6 to 32 °C.

Sow water consumption during lactation is influenced by several factors, including ambient temperature, genotype, parity, health status, lactation stage and litter size (Pheng *et al.,* 2007; Jeon *et al.,* 2006; Farmer *et al.,* 2001). The average daily water consumption during lactation varies from 17 to 27 L (Oliviero *et al.,* 2009; Pheng *et al.,* 2007; Quiniou *et al.,* 2000). Water intake can be influenced by feed composition and amount of feed intake (Oliviero *et al.,* 2009; Quiniou *et al.,* 2000). It has been suggested that providing lactating sows with *ad libitum* access to drinking water can improve sow feed intake and decrease sow body weight loss compared with sow with restricted access to water (Leibbrandt *et al.,* 2001). In lactating sows, water restriction may lead to reduced milk production, less nursing and reduced piglet growth (Jensen *et al.,* 2016). According to Schiavon & Emmans (2000), providing additional feed can be a reason for increasing water intake for digestion. Fraser & Phillips (1989) found a positive correlation between water intake in sows and piglet weight gain and sow performance. Kruse *et al.* (2011) showed that an increase in water and feed intake decreases the relative body weight loss and increases the weaning weight of piglets and reduces sow body weight loss, with positive effects on subsequent reproduction.

It is necessary to recognise that there is no single water requirement for a species or an individual, as the amount of water consumed depends on several factors. The values shown in Table 2 for the amount of water that pigs require are based on the requirement of pigs in a thermoneutral environment and under ideal conditions.

Table 2. *Water requirements of pigs in different stages of production*

Class of pig	Litres/pig/day	Litres/kg of feed
Nursery pigs (up to 25 kg BW)	2.8	2.5-3.0
Grower pigs (25-45 kg BW)	8.0-12	2.5-3.0
Finishing pigs (45-110 kg BW)	12-20	2.5-3.0
Non-pregnant gilts	12	-
Pregnant sows	12-25	-
Lactating sows	10-30	-
Boars	8-15	-

Source: Almond (1995).

2.6.2 Nesting

Pre-partum sows commonly exhibit a natural pattern of nest-building behaviour, including rooting, pawing and searching for suitable material to build a farrowing and lactating nest to protect their offspring against predators and cold (Yun & Valros, 2015; Wischner *et al.*, 2009). This nest-building behaviour is initiated by endogenous hormonal reactions and activated by exogenous environmental factors until completion of the nest (Chaloupkova *et al.*, 2011; Algers & Uvnas-Moberg, 2007).

In modern pig husbandry, risk factors such as predators, nutrient deficiency and heat loss are no longer a concern. Farrowing crates often give sows limited possibility to perform natural pre-partum activities, resulting in an increase in stress levels (Yun *et al.*, 2014a; Jarvis *et al.*, 2001). Inhibiting the expression of pre-partum nest-building behaviour may have consequences for parturition, lactation and animal welfare (Yun & Valros, 2015). Sows housed in an open crate and provided with abundant nesting material show more vigorous and intensive nest-building behaviour than sows housed in a closed crate or in an open crate with only minimal nesting materials (Yun *et al.,* 2014a).

Sows housed in crates without nesting material show nest-building behaviour such as rooting, but are also observed biting at steel bars, frequently changing their body position and frequently in contact with the ground, which can cause skin damage (Boyle *et al.,* 2002). Inhibiting the expression of pre-partum nest-building behaviour in crated sows has been shown to lead to increased plasma cortisol concentrations and heart rates (Jarvis *et al.*, 2001). In addition, continued confinement results in an increased endogenous opioid concentration that is negatively correlated with oxytocin and may influence parturition or early lactation performance (Yun *et al.,* 2013; Oliviero *et al.,* 2008).

Pre-partum sows with initial nest-building behaviour show an increase in plasma concentrations of prolactin (Algers & Uvnas-Moberg, 2007). Elevated prolactin concentration has been shown to affect motivation for nest-building behaviour in sows (Wischner *et al.,* 2009). In contrast, several studies have pointed out that prolactin concentration in pre-partum sows might not be correlated with the degree of nest-building behaviour and plays only a limited role in pre-parturient activity of sows (Rushen *et al.,* 2001). Prolactin concentrations may be correlated with oxytocin concentration rather than with performance of nest-building behaviour *per se* (Yun *et al.,* 2014a). Vigorous nest-building behaviour induced by the provision of abundant nesting materials and space is accompanied by an increase in plasma oxytocin concentrations in pre-partum sows (Yun *et al.,* 2014b).

Many studies have shown that restricted conditions or lack of material for nest-building behaviour in pre-partum sows results in prolonged farrowing duration (Hales *et al.,* 2015). Inhibiting the expression of pre-partum nest-building behaviour in crated sows, due to lack of space or substrates, increases endogenous opioids, which inhibit oxytocin secretion during farrowing. This can affect uterine contractions during parturition and thereby influence piglet birth interval (Yun *et al.*, 2014a; Oliviero *et al.*, 2008; Jarvis *et al.*, 2004).

Sow mammary gland growth is important to achieve high milk yield during lactation and hence optimal piglet survival and growth (Herly, 2001). Mammary gland development prior to parturition can be affected by prolactin, while oxytocin plays a key role in post-partum mammary growth. Therefore, pre-partum nest-building behaviour in sows may contribute to mammary gland development (Yun & Valros, 2015). Oxytocin and prolactin in sows induced by active nest-building behaviour during the pre-partum period could lead to improved nursing performance and improved post-natal piglet weight gain in early lactation (Yun *et al.,* 2014a). Prolactin is also essential for lactose synthesis and for colostrum production by mammary epithelial cells and thereby may lead to an overall increase in colostrum and milk yield in early lactation sows (Foisnet *et al.,* 2010). Crushing incidence can be reduced by pre-partum nest-building behaviour, as the condition induces behaviours of sow carefulness towards their offspring during early lactation. This can be affected by the link between oxytocin secretion and maternal characteristics (Yun *et al.,* 2014a). Oxytocin is known to encourage the maternal reaction in sows and also plays a role in decreasing stress hormone levels, and could improve maternal carefulness behaviour in early lactation (Yun *et al.,* 2013).

2.6.3 Cooling

The use of cooling techniques may help pigs with thermoregulation during hot weather (Huynh *et al.,* 2004). The recommended optimum air temperature for pregnant sows is 12 to 20 °C at a relative humidity of 50-75% (Botto *et al.,* 2014). Quiniou & Noblet (1999) suggest that a comfortable ambient temperature for lactating sows is in the range 16 to 22 °C, while piglets require a range of 30 to 32 °C, at least just after birth (Black *et al.,* 1993). The importance of facilitating thermoregulation should not be underestimated. It has been shown that supplying chilled water (10-15 °C compared with 22 °C) can improve the performance of sows and their piglets (Jeon *et al.,* 2006).

Using drip cooling in the farrowing room is a possibility to cool the microenvironment of the sow without cooling the microenvironment of the piglets. However, a disadvantage of drip cooling is that it causes restless sows (Dong *et al.,* 2001). There is a view that farrowing sows prefer a warm floor at farrowing, while after seven days they have a preference for a colder floor (Phillips *et al.,* 2000). Consequently, thermally comfortable pens are required and a suitable cooling system needs to be adopted.

There are two main types of cooling system based on water that are generally applied, evaporative cooling acting on the environment and showering acting directly on the animal (Barbari & Conti, 2009). Water evaporation causes air cooling in the building, but also causes an increase in humidity. Therefore, this method is usually acceptable in regions with a hot-dry climate (Panagakis & Axaopoulos, 2006; Lucas *et al.,* 2000). Evaporative cooling such as water dripping, a showering system and evaporative pads are common and are effective in practice (Botto *et al.,* 2014; Bull *et al.,* 1997). Water drip systems are currently used to reduce the heat stress of lactating sows (Barbari *et al.,* 2007). In addition, floor cooling can improve sow productivity and reproductive performance by removal of excess heat (Silva *et al.,* 2009; Wagenberg *et al.,* 2006). A cooling pad has been designed recently to increase the potential removal of excess heat in modern lactating sows in high environmental temperatures (Cabezón *et al.,* 2017b). Several studies suggest that heat removal through cooling pads is an effective method to alleviate heat stress in sows, since sows spend more than 70% of their time lying down (Silva *et al.,* 2006; Wagenberg *et al.,* 2006; Johnson *et al.,* 2001). Floor cooling provides greater comfort to sows during the lactation period and the nursing time has been shown to increase with a thermoneutral environment compared with sows kept under heat stress (Renaudeau *et al.,* 2001). Cooling the cage floor under the sow in the farrowing house improves the thermal environment leading to increased milk production and greater piglet and litter weight gain during lactation (Silva *et al.,* 2006). It has been suggested that a high velocity air steam combined with a wet floor is preferred by sows during the hottest period (Barbari & Conti, 2009).

3 Summary of materials and methods

3.1 Location of studies

In Paper I of this thesis, a survey on sow and piglet management on smallholder pig farms (SHPF) and larger-scale pig farms (LSPF) was conducted in the dry season (October to December 2014) in the two northern provinces Sayabouly (Sayabouly district) and Phongsaly (Mai district), Lao PDR.

In Papers II and III, two experiments were conducted at the Livestock Research Centre (Nam Xuang), 44 km north of Vientiane City, Lao PDR. There are two seasons in this region, a dry season (November-April) and a rainy season (May-October), with mean daily temperature of approximately 27 °C in both seasons (Lao Statistics Bureau 2014). The experiment was conducted from July 2014 to December 2015 (Paper II) and from March to September 2016 (Paper III).

In Paper IV, laboratory analyses of plasma samples from sows in the different treatments in Papers II and III were performed at Department of Anatomy, Physiology and Biochemistry at the Swedish University of Agricultural Sciences, Sweden.

3.2 Experimental design and treatments

In Paper I, a total of 175 SHPF were surveyed in interviews with 92 farmers from eight villages in Phongsaly province and 83 farmers from nine villages in Sayabouly province. In addition, six LSPF (three from each province) were selected for the survey. The criteria for LSPF selection were number of sows kept in the herd (30 to 100 sows) and location of LSPF (at a distance of about 30 to 60 min from the district main village by car). For SHPF, districts and villages with high numbers of sow-piglet production units were selected, based on data provided by the livestock sector and the district's agriculture and forestry office. Moreover, the villages selected were allocated into three groups according to road access, as indicated by the travel time by car to the district's main village: i) less than 30 min, ii) 30 to 60 min and iii) more than 60 min. Transects were randomly selected from those radiating out from each district main village. With this approach, two to four villages within each group were randomly selected for the survey. In each survey village, 10 to 15% of all households raising pigs in sow-piglet production systems were randomly selected for focus group meetings and the farmers were individually interviewed.

In Paper II, eighteen Moo Lath gilts were used in the experiment. The gilts were arranged in a randomised complete block design, with three treatments and six replicates per treatment. Gilts were blocked by expected time of farrowing, to minimise the effect of environmental conditions. Thus, gilts impregnated within the same month and by the same boar were allocated randomly to the three treatments within each of the three blocks. The treatments were: 1) *Control*, where no nesting material and no extra water were provided (traditional management); 2) *NM*, where nesting material was provided 1-2 days before expected farrowing, but no extra water was offered; and 3) *NMW*, where nesting material was provided 1-2 days before expected farrowing and water was provided *ad libitum* throughout the study. In treatment *NMW*, the extra drinking water was offered by a nipple connected to a graded bucket and water consumption was recorded daily. In both the *NM* and *NMW* treatments, 5 kg of rice straw per sow was provided as nesting material and sows were allowed to perform nest building by themselves. The nesting material was removed 3 days post farrowing.

In Paper III, fifteen Moo Lath sows were used in the experiment. The sows were arranged in a randomised complete block design, with three treatments and five replicates per treatment. Sows were blocked by expected time of farrowing, to minimise the effect of environmental conditions. Thus, sows impregnated within the same month were allocated randomly to the three treatments within each of the five blocks. The treatments were: 1) *Control*, where no cooling was provided; 2) *F*, where a fan was provided from 14 days before expected farrowing until weaning; and 3) *DW*, where dripping water was provided from 14 days before expected farrowing until weaning. In treatment *F*, one fan (Hatari HG-W16M4) per sow was run for 8 hours per day (08:00 to 16:00 h). The distance between the fan and the sow was approximately 1.3 m if the sow was standing as close as possible to the fan. Dripping water was provided using a bucket and a plastic tube with drip rates of 1.0 to 1.5 L/hour. The water was allowed to drip for 8 hours per day (08:00

to 16:00 h). The mean ambient temperature during the study was 38 °C, which is extreme even for Lao PDR.

In Paper IV, plasma samples from Papers II and III were analysed for cortisol concentration.

3.3 Experimental animal, management and feeding

In Paper I, the survey team comprised researchers, provincial/district staff and livestock advisors. The survey used two methods to collect the information: i) farmers' focus group meetings and ii) individual interviews with farmers using a semi-structured questionnaire. The farmers' focus group meetings were designed to generate general information on livestock and farming systems used by farmers in the villages. The individual interviews with farmers from SHPF and LSPF were used to collect more detailed information on pig reproductive performance, production systems, management, problems and a deeper understanding of existing SHPF and LSPF practices.

In Paper II, twenty Moo Lath gilts aged 6-8 months and with a live weight (LW) of 30-40 kg were purchased. All gilts were selected from six litters, to reduce genetic variability. Two Moo Lath boars from the same litter were purchased from a breeding station in Vientiane city. The two boars were kept in pens near the gilts to stimulate oestrus and all gilts were mated in their third oestrus (live weight 73±23 kg). A maximum of three gilts were mated per boar per week, and a maximum of ten gilts per boar. Eighteen pregnant gilts were selected for the experiment. Gilts entered the study at two weeks prior to farrowing and the study was completed at weaning, at 45 days after farrowing.

In Paper III, nine second parturition sows aged 1.5 to 2 years and with live weight 141 (±22) kg and six gilts aged of 8 to 10 months and with a live weight 77 (±4) kg were used. All gilts and sows were selected from five litters, to reduce genetic variability. One Moo Lath boar was purchased from a breeding station in Vientiane city. A maximum of three sows were mated per boar per week.

In Papers II and III, farrowing supervision was provided in all treatments, including cleaning the newborn piglets with a dry towel and disinfection of the navel, while cutting of teeth and iron injection were performed 7 days post farrowing. Moreover, each litter was provided with rice straw as bedding material (0.5 kg/piglet) in a secluded corner of the pen. All pigs were vaccinated for classical swine fever, de-wormed and given a vitamin A, D_3, and E injection before the start of the experiment. A non-pelleted feed mixed with water was fed to sows in all treatments. The feed was composed of rice bran, maize and soybean meal and offered at 3-5% of sow live weight, plus another 0.25 kg/piglet. Feed allowances were adjusted to maintain sows in a body condition score of 3 (considered optimal for breeding sows; Young & Aherne, 2005). The feed was mixed with 4-5 L water/sow/day. From two weeks of age until weaning at 45 days, the piglets were provided *ad libitum* with a non-pelleted creep-feed composed of maize and soybean meal. A mineral and vitamin premix was added to the diets (0.5% of the diet). Feed was provided twice daily (08:00 and 16:00 h). All animals were kept in individual pens (130 cm x 180 cm) in an outdoor open shelter with a roof.

3.4 Sample collection and analyses

In Papers II and III, number of piglets per litter was recorded in different categories (born, stillborn, dead within 3 days, and dead at weaning), as well as weight of piglets at birth and at weaning after 45 days. Weight of sows was recorded at mating, two weeks before farrowing and at weaning. Water consumption, feed offered and refusals were recorded daily. Feed samples were collected at the beginning, middle and end of the experiment (from farrowing until weaning). These feed samples were analysed for dry matter (DM), ash, nitrogen (N), neutral-detergent fibre (NDF) and acid detergent fibre (ADF), according to AOAC (1990). Crude protein (CP) was calculated as N x 6.25.

Blood samples (about 5-7 mL) were collected by venipuncture from the jugular vein into lithium-heparin tubes in the morning at 7 days pre-farrowing, on the first day of observed nest-building and at day 21 of lactation. The samples were refrigerated for 1 hour and then centrifuged at 3500 x g for 15 minutes. The plasma was collected and stored at -20 °C until analysis of total plasma protein concentration (TPP) using a handheld refractometer (Atago, Japan), and cortisol concentration using a commercial ELISA kit (Tecan Cortisol ELISA RE52061, IBL International, Hamburg, Germany).

3.5 Statistical analyses

In Paper I, the survey data were entered into a spreadsheet and analysed using PASW Statistics 18 (2009) for descriptive statistical analysis of means, standard deviation, ranges and frequency of distribution and variation. For sow reproductive performance data, continuous variables such as number of litters/sow/year, number of piglets/litter, number of piglets at weaning time and piglet mortality were analysed statistically using the ANOVA general linear model procedure in the statistical software Minitab 17 (2015). The data were divided according to four groups (SHPF less than 30 min, n=5; SHPF 30 to 60 min, n=5; SHPF more than 60 min, n=7 and LSPF, n=6). The difference between means was considered significant at the probability level P<0.05, and when significance was indicate the means were compared using Tukey's pairwise comparison test.

In Paper II, data were collected from two reproduction cycles per sow. Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., 2013). The General Linear Model (GLM) procedure was used to analyse the effect of treatments on post-farrowing reproductive performance, sow and piglet weight, number of piglets born and piglet mortality. The model included:

$$Y_{ijk} = \mu + \alpha_i + t_j + e_{ijk}$$

where Y_{ijk} is post-farrowing reproductive performance, sow and piglet weight, number of piglets born and piglet mortality, μ is overall mean, α_i is effect of reproductive cycle, t_j is effect of treatment and e_{ijk} is random error. Total plasma protein concentration (TPP) was analysed as repeated-measures data (Mixed procedure in SAS, 2014). The relationships between time points within sow were modelled using unstructured covariance. Due to the large variations sometimes observed in basal individual TPP levels, comparisons were only made within treatment. For these comparisons, the Tukey-Kramer test was used and the level of statistical significance was set to P<0.05. Data are presented as least squares (LS) mean ± standard error of the mean (SEM).

In Paper III, data were collected from one reproduction cycle per sow. Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., 2013). The General Linear Model (GLM) procedure was used to analyse the effect of treatments on post-farrowing reproductive performance, sow and piglet weight, number of piglets born and piglet mortality. The model included:

$$Y_{ij} = \mu + t_j + e_{ijk}$$

where Y_{ij} is post-farrowing reproductive performance, sow and piglet weight, number of piglets born, and piglet mortality, μ is overall mean, t_j is effect of treatment and e_{ijk} is random error. Data on total plasma protein concentration (TPP) were analysed as described for Paper II. For comparisons, the Tukey-Kramer test was used and the level of statistical significance was set to P<0.05. Data presented are least squares (LS) mean ± standard error of the mean (SEM).

In Paper IV, plasma samples were analysed in duplicate and the mean value was used for statistical analysis. The coefficient of variation (CV) for duplicates was $\leq$12 %. Analysis of variance was performed with the Mixed procedure and repeated measurements (SAS version 9.4, SAS Institute Inc., 2013) with the residuals following an autoregressive structure (experiment B) or compound symmetry structure (experiment A). The model in experiment A included effects of sample, treatment, cycle and the interaction between treatment and cycle. The model in experiment B included sample, treatment and the interaction between sample and treatment. Due to variations in cortisol levels between individuals, comparisons were only made within treatment. The level of significance was set to $P<0.05$. Data presented are least squares (LS) means ± standard error (SE).

4 Summary of results

4.1 Sow and piglet management on smallholder and larger-scale pig farms in northern Lao PDR (Paper I)

Herd structure and breed

Almost all SHPF surveyed (99%) kept indigenous breeds (Moo Lath and Moo Hmong) and the remainder kept crossbreed or exotic pigs or both, while all LSPF only kept exotic breeds (Large White x Landrace sows mated with Duroc boar). Pig herd size in SHPF was on average 6.1 (±5) head, while the average LSPF herd size was 208 (±93) head.

Pig reproductive performance and farrowing supervision

On SHPF, sows produced between 1.4 and 1.8 litters per year with a litter size of 7.0 to 7.6 live-born piglets and 4.3 to 6.2 weaned piglets. In contrast, sows on LSPF produced on average 2.0 to 2.3 litters per year, with 10 to 11 live-born piglets per litter and 9 to 10 weaned piglets. Piglet age at weaning ranged from 2.7 to 3.6 months in SHPF, compared with 1.3 months in LSPF. Piglet mortality was high, 36.9%, on remote SHPF compared with 17.1% on SHPF closer to the main village and 9.5% on LSPF.

On SHPF, a minority (20 to 40%) practised farrowing supervision while all LSPF practised farrowing supervision including cleaning the piglets, cutting teeth, disinfecting navel and injecting iron. The lowest frequency of farrowing supervision was found in the most remote villages (>60 min from main villages).

Feed and feeding system in sow-piglet production

In most villages, farmers commonly (61 to 74%) used rice bran only as creep feed for piglets. Complete commercial feed was mainly used by SHPF (35%) in villages close to the district main village. In contrast, all LSPF used complete commercial feed as creep feed for piglets.

All SHPF fed rice bran to sows as a basal feed and some added maize or cassava root and green feed. Protein-rich commercial feed was less used on SHPF, with the highest frequency in villages close to the district main village. Leaves of stylo (*Stylosanthes guianensis* CIAT-184) and other protein-rich sources such as distillers' waste were more commonly used in villages close to the district main village. All LSPF used commercial concentrate mixed with rice bran and maize feed for their sows.

Water provision and boar management

All SHPF provided water to pigs at feeding, in a mixture with the feed. A varying number of the SHPF surveyed (28 to 67%) provided extra water to sows, amounting to less than 7 L/pig/day. Around 70% of SHPF supplied extra water only once per day, while only 5% of farmers provided *ad libitum* access to water from water nipples. All LSPF provided water from nipples and pigs had *ad libitum* access to water.

On SHPF, there were only a few boars available for servicing sows and only around 18.9% of SHPF kept a boar. The existing practice was to select a boar from among male piglets in their own herd. The SHPF practised natural mating in free-range scavenging systems and boars were allowed to service at a young age. The feeding of boars on SHPF was the same as for sows, with rice bran as a basal feed and some added maize or cassava root and green feed. On LSPF, boars were preferably bought from disease-free herds and were selected based on factors such as soundness, conformation, age of puberty and parameters related to reproductive performance like mating behaviour and conception rate.

Pig reproductive constraints and farmers' experience in solving problems

The most important factor limiting sow-piglet production on the SHPF surveyed was high mortality of piglets followed by outbreak of disease, slow growth of piglets, lack of knowledge and difficult in finding feed. Around 75% of SHPF never vaccinated pigs and lacked management routines for control and prevention of disease. In cases of outbreaks of disease in the village, farmers tried to overcome the problem by several means, such as slaughtering and burying the sick pigs (more than 70%), trying to get assistance from village veterinarians or treating the pigs with medicines (20 to 23%), while less than 10% solved the problem in other ways.

4.2 Effect of provision of water and nesting material on reproductive performance in native Moo Lath pigs (Paper II)

Feed and water intake, body weight and plasma protein concentration in sows

In treatment *NMW*, with *ad libitum* water provision, sows had higher (*P<0.001*) water intake than sows in the *Control* and *NM* treatments. There were no differences between treatments in body weight from mating until weaning, but the weight loss from two weeks prior to farrowing until weaning was smaller (*P<0.001*) in sows in treatment *NMW*. In *NMW* sows, TTP decreased from farrowing until 21 days of lactation, whereas it increased or was unchanged in *NM* and *Control*.

Reproductive interval of sows and piglet performance

The re-mating period was shorter (*P<0.001*) and the number of litters/year was higher (*P<0.001*) in sows in treatment *NMW* than in sows in treatments *Control* and *NM*. There was no difference in the number and proportion of born and stillborn piglets between the treatments. The mortality rate of piglets after 3 days was lower (*P<0.001*) in *NMW* and *NM* than in *Control*. Moreover, at 45 days (weaning), mortality was lower (*P<0.001*) in *NMW* than in both *NM* and *Control*. The control treatment had the highest mortality. There was no difference in the weight of piglets at birth, but at weaning piglets in treatment *NMW* were heavier and had higher (*P<0.001*) average daily weight gain than piglets in *NM* and *Control*.

4.3 Effect of cooling methods on reproductive performance in native Moo Lath sows (Paper III)

Water and feed intake, body weight and plasma protein concentration in sows

Sows provided with cooling (*F* and *DW* treatments) had significantly lower (*P<0.05*) weight loss from two weeks prior to farrowing until weaning than sows in the *Control* treatment. The body weight from mating until weaning increased (*P<0.001*) in sows provided with cooling (*F* and *DW* treatments), whereas it decreased in *Control*. In sows given cooling (*F* and *DW* treatments), TPP was maintained from farrowing until 21 days of lactation, whereas it steadily increased in sows in the *Control* treatment.

Piglet performance

The mortality rate of piglets at weaning was lower (*P<0.001*) with cooling (*F* and *DW* treatments) than in the *Control* and the number of piglets at weaning at 45 days was higher (*P<0.01*) with cooling (*F* and *DW* treatments) than in the *Control*. There was no difference in the number of piglets born, stillborn and born alive and dead after 3 days between treatments and there were no differences in the weight of piglets at birth, at weaning and daily weight gain between treatments.

4.4 Effect on cortisol concentrations of providing water *ad libitum* and cooling (Paper IV)

Effect of proving extra water and cooling

There were no changes in plasma cortisol concentrations in sows provided with water *ad libitum*. In sows offered no extra water, the plasma cortisol concentration was elevated after 21 days of lactation compared with when nest building was observed and there was also a tendency for this level to be higher than the pre-farrowing level. There were no differences in the cortisol concentration from 7 days pre-farrowing until 21 days of lactation in any of the cooling treatments or in the control.

5 General discussion

5.1 Sow and piglet management on smallholder and larger-scale pig farms in northern Lao PDR (Paper I)

The survey in Paper I showed that sow-piglet performance on SHPF in northern areas of the Lao PDR is poor, although in agreement with available performance data for indigenous Lao pigs (Wilson, 2007). There could be several reasons for the poor performance, including management practices and genetic status of pigs (Chittavong *et al.,* 2012a; Phengsavanh *et al.,* 2010). Poor nutrition of sows during lactation and piglets after weaning are major limiting factors in smallholder pig production (Phengsavanh & Stür, 2006; L4PP, 2010). Farmers' production aim may be one additional factor that could explain the level of production intensity in saving-orientated production systems with limited resource supply (Kumaresan *et al.,* 2009; Lemke *et al.,* 2007).

The survey results showed that SHPF with sow-piglet rearing systems mainly kept indigenous pig breeds. Similar results have been reported for SHPF in other Asian countries (Kumaresan *et al.*, 2009; Lemke *et al.,* 2006) as well as in South America (Ocampo *et al.,* 2005). The major reason for this is that native pigs are well adapted to hot weather in tropical climate conditions and traditional management practices (Kumaresan *et al.*, 2009; Phengsavanh *et al.*, 2011). In addition, pork from indigenous pigs fetches a premium price in local markets compared with pork from exotic breeds (Deka *et al.,* 2014).

The results also showed that most farmers surveyed kept their pigs in confinement all year round, with animals housed in pens around the villages. However, in the past free scavenging was very common in village pig production systems in northern Lao PDR (Phengsavanh *et al.,* 2010; Phengsavanh & Stür, 2006). The change to using confined pig production systems was influenced by many factors, such as village regulations, more intensive crop production and prevention of disease outbreaks. Moreover, the possibility to implement improved management practices in confined production systems has been a strong reason promoting this change (Stür *et al.,* 2010).

Sow performance on the SHPF surveyed in Paper I was well below the potential performance level for sows in Southeast Asia of genetically improved breed from Europe and North America (Kunavongkrit & Head, 2000). Thus, the better sow-piglet performance on LSPF in the survey could be partly explained by breed differences (Keonouchanh *et al.,* 2011; Kumaresan *et al.,* 2007; Lemke *et al.,* 2007). The poorest sow reproductive performance and piglet survival on SHPF were reported in villages that were more remote from the district's main village, and could be due to differences in feeding and management practices (Phengsavanh *et al.,* 2011; Hong *et al.,* 2006; Lemke *et al.,* 2006). Moreover, farmers from SHPF reported high piglet mortality (up to 37%) compared with farmers from LSPF (9.5%) (Paper I). This is in agreement with Phengsavanh *et al.* (2010), who found that piglet mortality ranged from 28 to 45% on SHPF in the north of Lao PDR. It is also within the range (12-40%) reported for northern Thailand, the Philippines and Vietnam (Lemke *et al.,* 2006; Taveros & More, 2001; Kunavongkrit & Head, 2000).

High piglet mortality is an issue of major concern in SHPF production systems in Lao PDR and can be related to poor nutrition, poor breeding management and diseases (Stür *et al.,* 2010; Phengsavanh *et al.,* 2010). The LSPF in this survey provided creep feed to piglets pre-weaning, while this was not common practice on SHPF. Moreover, the creep feed used on LSPF was nutritionally well balanced and composed of appropriate feed ingredients. In addition, the LSPF had adopted structured management practices for sows and piglets. Poor pen hygiene is very common on SHPF in Lao PDR and is a factor which increases the risk of disease outbreaks (Kunavongkrit & head, 2000).

The LSPF surveyed provided nest-building material to the pen during the farrowing period and they supervised farrowing. These are factors that could prevent high piglet mortality (Cutler *et al.,* 2006; Thodberg *et al.,* 2002). In contrast, it was common practice on SHPF to let sows farrow in the forest without supervision (Paper I). Under these conditions sows can express their nest-building behaviour using available material such as tree leaves and banana leaves, but lack other forms of support. Approximately two weeks post farrowing, farmers collect sows and piglets and confine them in pens in the village. Thus the true piglet mortality in these conditions is not known.

Common staple feed resources used for pig feeding by SHPF were cultivated crops, such as maize and cassava and crop by-products, particularly rice bran. The main protein feed sources were naturally occurring wild green plants. Availability of protein-rich feed ingredients is the most limiting factor for appropriate pig feeding on SHPF (Phengsavanh *et al.*, 2011). Moreover, the availability of local feed resources depends on season and variations in yield due to weather conditions and agronomic practices. All SHPF surveyed fed rice bran to the sows as a basal diet all year round. In addition, they commonly used rice bran only as a creep feed for piglets. The common practice on SHPF in Lao PDR is to feed all pigs the same diet, irrespective of age (Phengsavanh, 2013). This can lead to malnutrition due to imbalanced nutrient supply, as the energy and nutrient requirements of pigs differ with age and physiological performance (NRC, 2012).

Sow reproductive performance on SHPF was also poor. Sows produced between 1.4 to 1.8 litters per year, with a litter size of 7.0 to 7.6 live-born piglets and 4.3 to 6.2 weaned piglets (Paper I). This is similar to finding in previous studies of smallholder pig production system in Lao PDR (Phengsavanh, 2013; Chittavong *et al.*, 2012a). It represents poorer sow performance than in Thailand, Vietnam and the Philippines (8-10, 7-11 and 11-12 live-born piglets/litter, respectively) (Lemke *et al.*, 2006; Taveros & More, 2001; Kunavongkrit & Head, 2000).

On SHPF, only few boars are available for servicing sows and very young boars are used, which results in low fertility and low sperm production (Phengsavanh *et al.*, 2010). Natural mating is still the normal practice on most farms (Kunavongkrit & Heard, 2000). According to the survey results (Paper I), around 19% of SHPF kept boars and these farmers tended to use a male pig from their own herd as a boar, which leads to inbreeding with implications for performance and health. In addition, around 75% of SHPF never vaccinated pigs (Paper I).

Another important factor in poor sow reproductive performance and pig health was water availability and quality. Inadequate water provision decreases feed intake and milk production, which has consequences for the performance and health of both sows and piglets (Robert & Swick, 2001). Low feed intake during lactation results in increased weight loss and poor body condition, which has negative impacts on sow post-weaning reproductive performance (Kirden *et al.*, 2013). The SHPF surveyed in Paper I mainly provided water to pigs at feeding and as a mixture with the feed. Most farmers in the upland areas of Lao PDR are faced with insufficient water supply for family consumption (Phengsavanh *et al.*, 2010). This becomes a major issue in the dry season and is due to poor infrastructure in the water supply systems. In the survey, only farmers living close to rivers and households in villages close to a main village/city reported having a good water supply system, and provided extra water to their pigs during the day.

5.2 Effect of provision of water and nesting material on reproductive performance of native Moo Lath pigs (Paper II)

Reproductive performance was markedly improved with *ad libitum* access to water, as re-mating period was shortened by 21 days, the number of piglets per litter at weaning was increased by more than 2.5 and mortality at weaning was lowered to 9.5%, compared with 44% in the *Control* treatment. This improved level of mortality is similar to that reported for European and North American production systems (Kirkden *et al.*, 2013), and shows that it is possible with fairly simple means to improve performance in local smallholder systems. Provision of nesting material also improved the reproductive response, but the effect seemed to be restricted to increased survival of piglets during the first 3 days. According to Yun & Valros (2015), pre-partum nest-building behaviour in sows may contribute to mammary gland development, which can be affected by prolactin and oxytocin. Sow mammary gland growth is necessary to achieve high milk production during lactation (Herly, 2001), and produce colostrum for the piglets (Devillers *et al.*, 2007). However, provision of nesting material without access to water *ad libitum* induced a loss of plasma volume (dehydration) in sows (Paper II), which will make them more susceptible to *e.g.* heat stress.

In the treatment with ad *libitum* water provision, the sows drank almost 15 L/day, three times the allowance in the *Control* treatment. The level of intake corresponded to a water to feed ratio of 4.5 kg/day, and is of similar magnitude to intake observed in sows of breeds that are twice as large (5.8 kg/day; Kruse *et al.*, 2011). Voluntary water intake is strongly affected by environmental factors, with ambient temperature and the resulting evaporative losses being one such factor. Renaudeau *et al.* (2001) report a doubling in water consumption when ambient temperature increases from 20 to 29 °C, *i.e.* near the temperature in the present study (27 °C). In Paper II, the sow, especially those without extra water, were often observed lying down and with elevated breathing frequency, indicating that they were out of their thermoneutral zone.

The loss of body weight from two weeks prior to farrowing to weaning was significantly lower (6 kg) in sows with *ad libitum* access to water than in sows with restricted water intake. Greater body weight loss in sows with restricted water intake has been reported previously (Leibbrandt *et al.*, 2001). However, Paper II also shows that sows supplied with water *ad libitum* were able to increase their plasma volume (indicated by lower TPP) during this period, in contrast to the sows in the other treatments. An increase in blood and plasma volumes can be expected during gestation in normal, healthy sows (Matte & Girard, 1996). In contrast, in sows provided with only nesting material (treatment *NM*), the plasma volume seemed to decrease during this period. This might be due to extra evaporative losses caused by the heat production from nesting activity and feeding, if some straw was consumed, and the lack of possibility to restore these losses.

Provision of water *ad libitum* had marked positive effects on piglet survival and growth. Survival at weaning and weight gain was greatest with the water *ad libitum* treatment (*NMW*). These results are in agreement with finding by Kruse *et al.* (2011) of a positive relationship between water intake and weaning weight of piglets. Jeon *et al.* (2006) pointed out that to produce a higher amount of milk, the sow has to increase its water intake, since water is the major component of milk. The improved growth in *NMW* piglets was most likely a result of increased milk production by the sow, but some of it could also be due other positive effects of available water. During the last two weeks before weaning, some piglets were observed drinking from the nipples. It has been shown that even very young piglets can drink up 200 mL/day (Fraser *et al.,* 1988). Creep feed was available from two weeks of age and the possibility to drink water may also have increased feed intake, but piglet feed intake was not measured in the present study. It is known that restricted water intake can affect voluntary feed intake (Leibbrandt *et al.,* 2001).

Provision of nesting material increased the number of piglets that survived (*i.e.* did not die) after 3 days by 70% ((2.3x0.7)/2.3), but otherwise there were no effects that could be linked to this treatment. In a study by Westin *et al.* (2014), weight at weaning was found to increase in systems providing 15-20 kg straw compared with 0.5-1 kg, but this effect could not be confirmed in Paper II. There are conflicting results on the effect of nesting material and the risk of death in piglets (Kirkden *et al.,* 2013). In one recent study comparing systems providing either 15-20 kg or 0.5-1 kg of straw, the number of piglets crushed was higher in the former system, but overall pre-weaning mortality of piglets born live was not affected by treatment (Westin *et al.,* 2015). However, piglet survival was improved in Paper II, which could be due to increased oxytocin and prolactin secretion due to stimulated nest-building behaviour, altered nursing behaviour and increasing carefulness of sows when lying down (Yun *et al.,* 2014a).

5.3 Effect of cooling methods on reproductive performance in native Moo Lath sows (Paper III)

Paper III showed that, under extreme tropical conditions (38±1.7 °C), provision of very simple cooling systems around farrowing until weaning of piglets can markedly improve piglet survival and help sows to maintain body weight and plasma volume. The number of piglets surviving at weaning was higher with cooling (8.4 and 7.8 per litter in treatments *F* and *DW*, respectively) compared with no cooling (6.2 live piglets per litter in the *Control*). Piglet mortality rate at weaning was lower with cooling (10.1 and 15.2% in treatments *F* and *DW* treatments, respectively) compared with no cooling (31.3% in the *Control*). This is comparable to pre-weaning mortality in Europe, the Philippines and Thailand (13, 9 and 12%, respectively) (Tummaruk *et al.,* 2017). Providing sows with cooling at high ambient temperatures can minimise their level of stress around the time of farrowing and during lactation (Fangman & Amass, 2007; Cutler *et al.*, 2006). Heat stress is a risk factor for stillbirth in late gestation (Vanderhaeghe *et al.*, 2010; Cutler *et al.,* 2006). During farrowing, heat stress induces opioid production, which inhibits oxytocin. This can reduce uterine contractions, which can prolong farrowing (Lawrence *et al.*, 1992) and also decrease milk yield during lactation (Andersen *et al.,* 2007). Cooling of sows can reduce the incidence of mastitis-metritis-agalactia (MMA), a condition which inhibits colostrum and milk let-down (Jackson & Cockroft, 2007; Messias de Braganca *et al.*, 1998).

The concentration of total plasma protein was maintained from farrowing until 21 days of lactation with cooling (*F* and *DW* treatments), whereas it steadily increased in the *Control*. The loss of plasma volume observed in the *Control* probably also elevated body temperature. Loss of plasma volume reduces mammary blood flow, and thereby also milk production (Farmer *et al.*, 2008). In agreement with finding by Collin *et al.* (2001), heat stress increased skin blood flow circulation, to promote heat loss and reduced blood flow to other tissues. In addition, lactating sows that redistribute blood flow to the skin to increase heat loss may reduce the nutrient supply to the mammary glands, thus reducing milk production (Eissen *et al.*, 2000). Moreover, in sows kept at 30 °C compared with 20 °C, there is a drop in milk yield of 25% (Barb *et al.,* 1991). When the ambient temperature is above 22-25 °C, feed intake and milk production are decreased (Quiniou & Noblet, 1999). In the study by Fraser (1970), there were even cases of agalactia in sows in hot environments. In Paper III, the loss of milk production was not reflected in the weight of the piglets, but in their survival.

Surprisingly, although the work in Paper III was conducted during the hot season, with very high average ambient temperature (38±1.7 °C), there was no significant difference in feed and water intake between treatments when cooling was provided. The reason for this might be that sows were sometimes observed playing with the water nipples and the recorded water intake might therefore not be accurate or overestimated. Fraser & Phillips (1989) reported that the greatest waste of water from nipple drinkers was 23 to 80% in sows, and it is possible that native Moo Lath pigs are very tolerant to hot weather in tropical climate conditions (Phengsavanh *et al.,* 2011).

Interestingly, the body weight of sows provided with cooling (*F* and *DW* treatments) increased from mating until weaning, whereas *Control* sows lost weight. The difference was approximately 15 kg and most likely reflected a water deficit in *Control* sows. However, a minor part could be due to increased tissue growth in cooled sows, since some of sows probably had some growth potential. Fraser & Phillips (1989) found a positive correlation between water intake by sows and sow performance. In addition, studies by Kruse *et al.* (2011) have shown that an increase in water and feed intake decreases the relative body weight loss of sows.

There were no significant differences between the two cooling systems used in Paper III, which means that farmers can choose a system that fits the local conditions. However, future behavioural studies might reveal whether sows prefer one system over another. Sows might prefer certain cooling opportunities (Barbari & Conti, 2009), but the set-up used in Paper III has not yet been evaluated in this regard.

5.4 Effect on cortisol concentrations of providing water *ad libitum* and cooling (Paper IV)

It was interesting to observe that sows provided with cooling did not respond differently in term of cortisol concentrations than *Control* sows when the reduction in performance and condition of both sows and piglets was marked. However, it is known that animals can habituate to stressful conditions and, after a period of adaptation, normal cortisol concentrations and patterns are shown. In a study by Jansson *et al.* (1999) in which horses were subjected to one month of 12-hour or 4-hour feeding intervals in a cross-over design, plasma cortisol concentrations showed the same uninterrupted diurnal pattern, although many individuals showed aggression and frustration around feeding on the 12-hour regime. These findings suggest that cortisol is not a good indicator of possible discomfort and decreased in physiological condition and performance in sows provided with no cooling compared with sows provided with cooling.

However, in sows where water allowance was restricted, plasma cortisol increased after 21 days of lactation. An increase at that time is in contrast to earlier reports on sows with *ad libitum* access to water (Mosnier *et al.*, 2009). There are probably multiple reasons for this. One reason could be dehydration, and thereby concentration, since total plasma protein concentration was elevated by 7% compared with pre-farrowing (Paper II). Another possible explanation is that the release of cortisol was secondary to thirst. The sows were most likely thirsty and could observe water buckets and/or the staff handing water for sows on the water *ad libitum* treatment. This might have been a stimulus for cortisol release. Sows with restricted water intake in Paper II had a longer re-mating periods, despite the fact that they had free access to water from weaning (cycle 1) until 14 days prior to the next farrowing (cycle 2), when the experimental practice was not applied. The reason for this is unclear, but Kluivers-Poodt *et al.* (2010) showed that with increasing cortisol levels, onset of oestrus is delayed. If the effects of the elevated plasma cortisol levels persisted after weaning in Paper II, this might have contributed to the longer re-mating period, despite free access to water around mating.

6 General conclusions

- Sow and piglet performance on smallholder pig farms in Lao PDR can be improved by providing better nutrition, water *ad libitum*, nesting material and a simple cooling system. The three latter measures are also low-investment strategies which will not only benefit production but also animal comfort and health.
- Provision of nesting material without *ad libitum* water access might increase the susceptibility to heat stress in sows. A management strategy including both nesting material and *ad libitum* water should therefore be recommended to farmers, from both a farm income and an animal welfare perspective.
- A simple cooling system can have marked positive effects on the fitness of sows and on survival of piglets on smallholder pig farms in tropical countries. The recommendation is therefore to provide sows with either a drip water system or a fan.
- Plasma cortisol does not seem to be a good indicator of the lowered condition and performance in sows subjected to long-term heat stress. Restricted water intake increases plasma cortisol concentrations during lactation, but further studies are needed to identify the mechanisms.

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