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**COMPARATIVE STUDY ON REPRODUCTIVE PERFORMANCE
AND MANAGEMENT METHODS OF HUNGARIAN AND LAO
INDIGENOUS PIG BREEDS**

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**Comparative Study on Reproductive Performance and Management Methods of
Hungarian and Lao Indigenous Pig Breeds**

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ABBREVIATIONS AND ACRONYMS

ADG	Average daily gain
AI	Artificial insemination
AFI	Age at first insemination
AFF	Age at first farrowing
AR	Altrenogest Regumate
ASF	African Swine Fever
BF	Backfat thickness
BFI	Backfat thickness at insemination
BFF	Backfat thickness before farrowing
BM	Blonde Mangalica
BWF	Body weight of sow before farrowing
BFLF	Backfat thickness lost 1 week after farrowing
BFLW	Backfat thickness lost at weaning
BFLW	Backfat thickness lost 1 week after farrowing
BWF	Body weight before farrowing
BWLW	Body weight lost at weaning
BWI	Body weight at insemination
BW	Birth weight
BWW	Body weight of sow at weaning
CM	Crossbred-Mangalica
CMD	Crossbred <i>Moo Lath</i> x <i>Duroc</i> pigs
CSF	Classical Swine Fever
CRS	Confinement rearing system
DATC	Dongkhamxang Agriculture Technical College
DLF	Department of Livestock and Fisheries
DLP	Day one live born piglets
DAFO	District Office of Agriculture and Forestry
ES	Estrous synchronization
FE	Firs estrous
FI	Farrowing interval
FM	First mating

FRS	Free scavenging rearing system
FSH	Follicle stimulating hormone
h	hour
HHs	Households
HM	Hungarian Magalica pigs
IU PMSG	International Unite, Pregnant Mare Serum Gonadotropin
LDC	Least Developed Countries
LH	Luteinizing hornmone
LS	Litter size
LY	Litter per year
MAF	Ministry of Agriculture and Forestry
ME	Metabolizable Energy
MM	Mummified piglets
MBW	Mortality before weaning
min	minute
NAMB	National Association of Mangalica Breed
NA-Laos	National Assembly of Laos
N/A	Not available
NAFRI	National Agricultural and Forestry Research Institute
PML	Pure Moo Lath
PWM	Pre-weaning mortality
RM	Red Mangalica
SM	Swallow-bellied Mangalica
SRS	Semi-scavenging system
SP	Suckling period
VFI	Village Focus International
WEI	Weaning-oestrous-interval
WLF	Weight lost 1 week after farrowing
WM	Weight at maturity
WW	Weaning weight

1. INTRODUCTION

In Hungary and Laos, pig production is an essential source of meat supply. According to the Hungarian Central Statistics Office, Hungary had a pig population of roughly 2.7 million in 2021. Nearly 5% dropped from 2020 when the pig population in Hungary reached 2.8 million, almost 1.56 times lower than the pig population in Laos, which covered 4.3 million in the same year. Nearly 4.33% of the pig population in Laos increased in 2020 after recovering from the epidemic of ASF in the second half of 2019 (MAF, 2020). In 2013, business groups owned over 73% of pig farms in Hungary, with individual farmers owning the remaining 27% (RAJCSANYI, 2017). In contrast, almost 92% of the pig population in Laos in 2019 were indigenous pig breeds owned by small-scale farmers, and only 8% were owned by commercial patterns (MAF, 2020). Although the pig population in Hungary gradually declined, pork production increased from 517 thousand tons in 2012 to 557 in 2014 and 599 in 2016 (BENE et al., 2016). Laos produced only 65 thousand tons of pork in 2015, despite the country's requirement for more than 80 thousand tons per year. As a result, Laos needed to import fattening pigs from neighbouring countries to slaughter around 124,000 heads each year (KEONOUCHANH and DENGKHOUNXAY, 2017).

Hungary and Laos also have unique indigenous pig breeds i.e, *Mangalica* and *Moo Lath*, which produce unique fat and marbled meat. *Mangalica* pig breeds are not only famous and well-known indigenous pig breeds in Hungary and other European countries. Still, it is prominent in other parts of the world, such as the USA and Japan (GAÁL, 2019). *Mangalica* breeds have been developed and raised in semi-extensive farming systems for almost 200 years. Over these periods, farming systems have been developed regarding housing, with extensive and intensive systems have been set up to exploit *Mangalica* pigs' productive and reproductive performance.

The limitation of morphometric data from gilts and sows, and some semen characteristics for *Moo Lath* boars. Improving reproductive management and a new farm operation, including a semi-extensive management system, might increase indigenous pigs' economic and social impact in Laos. In addition, some successful practices of experienced Hungarian researchers in developing their *Mangalica* pigs may be applied in the Laos setting with *Moo Lath*. Some successful methods include modifying body weight for first insemination, estrus synchronization, and improving farrowing and lactation

management. This approach could be adopted and developed for *Moo Lath* breeds in Laos. Therefore, a study on Lao indigenous pig breeds' reproductive performance and management methods has been carried out at Dongkhamxang Agriculture and Technical College (DATC) in Vientiane, Laos.

1.1. Research aims

The overall objective of this research is to improve the reproductive performance of Lao indigenous pig breeds using the similar successful experience of Hungarian experts used to improve the quality and management of *Mangalica* pig breeds. Laos is one of the least developed countries (LDC). However, Lao government has spent a lot of effort to improve pig breeding in Laos since the early 1980s. Still, until now, there has been no complex approach regarding the reproductive biology of gilt and sow, including the meat and fat quality of native pigs in Laos. Therefore, the specific objectives are:

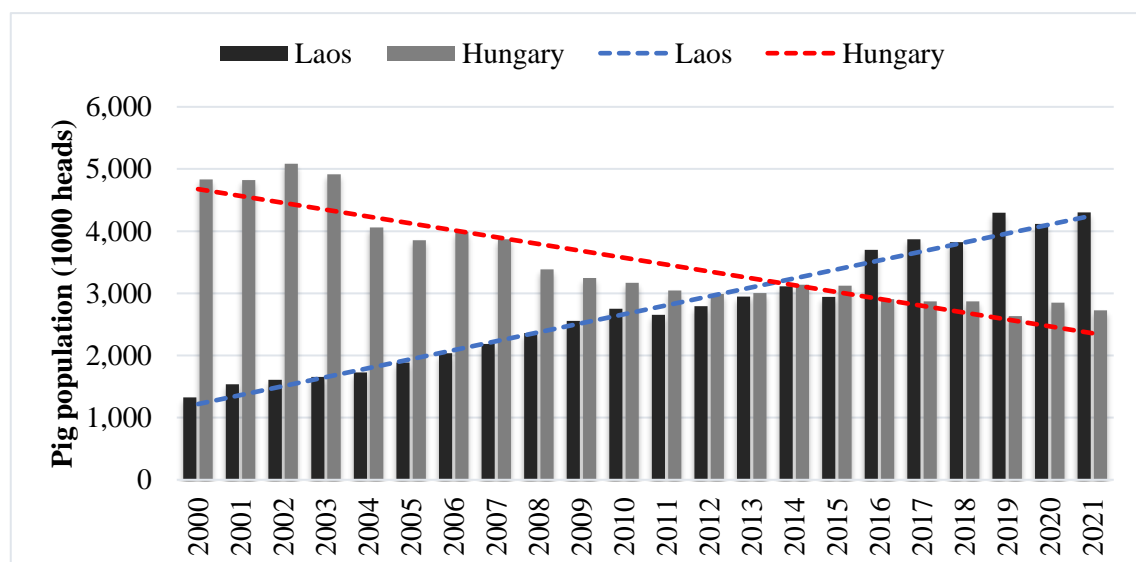
- (1) to evaluate and identify the reproductive management methods in *Mangalica* pig farms to be adopted to improve indigenous pig breeds in Laos.
- (2) to evaluate the efficiency of utilizing estrous synchronization (ES) and artificial insemination (AI) with *Duroc* semen in improving the quality of the reproductive performance of *Moo Lath* gilts.
- (3) to evaluate the effects of weaning age on the growth performance of piglets and body conditions of *Moo Lath* primiparous sows.
- (4) to evaluate the effects of supplementing dried green banana to reduce diarrhoea in post-weaning piglets.
- (5) to examine the bacteria-infected post-weaning diarrhoea in *Moo Lath* piglets. (so-called by-products)
- (6) to study the effects of birth weight on age at puberty and first mating and reproductive performance of crossbred *Moo Lath* x *Duroc* gilts.

2. LITERATURE REVIEW

2.1. Pig population trends in Hungary and Laos (2000-2021)

Hungary's pig population declined from 4.8 million in 2000 to 3.2 million in 2010, gradually decreasing to 2.6 million in 2019. That is, the population of pigs declined by almost 45.5% compared to 2000. However, the peak pig population was recorded in 2002 (5.08 million), which increased by 5% compared to 2000. After that, the pig population in Hungary gradually dropped in 2021 to 2.7 million (Hungarian Central Statistical Office, 2022). In contrast, the pig population in Laos steadily increased from 1.3 million in 2000 to 2.8 million in 2010 and 4.11 million in 2020, increasing almost by 216.46% since 2000 (Lao National Statistics Bureau 2020-2022; *Figure 1*). The pig population in Laos seemingly has not gotten to peak yet. However, it had a slight decrease in 2015 by about 5.8% compared to 2014 and 4.33% in 2020 compared to 2019 due to a new economic strategy that promotes intensive crop production. Furthermore, the epidemic diseases, including African Swine Fever (ASF) and other infectious diseases like classic swine fever (CSF), also contributed to the population decline. The number of breeding sows in Hungary also gradually decreased from 219,000 in 2010 to 197,000 in 2015 and 155,000 in 2019 (Hungarian Central Statistical Office, 2020).

Figure 1: Pig population trend in Hungary and Laos (2000–2021)



Source: Hungarian Central Statistical Office (2020); Lao National Statics Bureau (Yearbook 2000–2022).

Unfortunately, the existing recording system regarding the number of breeding sows has neither been shown in the Lao Statistic Bureau nor the Department of Livestock

and Fisheries (DLF) records. Although it was estimated that Laos had around 25,000 breeding sows in 2016 (KEONOUCHANH and DENGKHOXAY, 2017), this number is expected to be increased to 45,000 sows by 2025 (MAF, 2015).

Both Hungarian and Lao indigenous pig breeds play an essential role in the livestock sector. The number of *Mangalica* sows steadily increased from 6,832 in 2010 to 9,360 in 2016, increased by 37% in 2016 compared to 2010 (PAPP, 2016). More than 40 years ago, 120 breeding sows and 12 boars of European pig types were first introduced from Thailand into Laos in 1980, and many commercial pig farms have been established since 2000 (KEONOUCHANH and DENGKHOXAY, 2017). Still, the ratio of indigenous pigs was above 84% in 2015 and went to nearly 88% of the total pig population in 2019 (DLF, 2020). Especially in some Northern provinces such as Phongsaly and Huaphanh, it was high to 98% in 2020, as shown in one of our findings.

2.2. Indigenous pig breeds and pig production in Laos

2.2.1. Overviews of Lao indigenous pig breeds

Indigenous pigs are essential for pig production in Laos, especially in remote areas where different ethnic tribes live (MESSERLI et al., 2008). Indigenous pigs are vital for their households' consumption and traditional activities. They are also a saving treasure that could be used whenever needed, such as supporting their children's education and family health care. Based on their phenotypes, Lao indigenous pig breeds can be classified into four types and named locally as *Moo Chid*, *Moo Lath*, *Moo Daeng*, and *Moo Hmong* (Table 1).

Table 1

Reproductive performance of Lao indigenous pig breeds

Types of Moo	Sow				Average performance result of one farrowing		
	FE (d)	WM (kg)	LY	AFF (d)	DLP (n)	SP (d)	WW (kg)
<i>Moo Chid</i>	182-197	42-48	1.5	360	7-8	90	7.8
<i>Moo Lath</i>	189-586	47-61	1.5-1.8	360	7-8	60-90	9.5
<i>Moo Mhong</i>	150-180	65-85	1.5-1.8	300-330	7-10	60-90	8
<i>Moo Daeng</i>	-	65-90	1.5-1.8	330-360	7-10	60-90	8.5

KEONOUCHANH et al., (2011). FE: first estrus; WM: weight at maturity; LY: litter per year; AFF: age at first farrowing; DLP: day one live born piglets; SP: suckling period; WW = weaning weight.

Lao indigenous pigs typically have a small body size with a black colour (KEONOUCHANH et al., 2011). Most Lao indigenous gilts attain puberty with a body weight of about 21-30 kg, and the boars reach puberty at about 30 kg at roughly 150–180 days of age. Sows farrowed approximately 1–1.5 litter per year, with about 6–7 piglets per each. The piglets were commonly weaned at about 8.57–12.86 weeks with a body weight of about 7–8 kg (WILSON, 2007).

2.2.2. Indigenous pig production systems in Laos

In Laos, pig production systems are still based on smallholders' production and are reared under a traditional extensive system. Recently, in Laos, there has been no evidence that indigenous pig farms were owned by any business organization or any pig farm operation as a business. A free scavenging system, a semi-enclosure system, and a penned system were the most common indigenous pig production systems in Laos (WILSON, 2007). Most farmers always left their pigs scavenging during the daytime, some confined at night. All pig-raising systems will confine their pigs in a simple wooden pen during the main cropping season.

The main challenges of indigenous pig production in Laos are low growth rate (80-100 g/day), high-fat content (more than 70% of carcass weight), lack of feed supply in both quantity and quality and annual disease outbreaks (KEONOUCHANH, 2018; HOLT et al., 2019). Farmers feed their pigs with rice bran, kitchen waste, green vegetables, and other plants collected from the surrounding forests, and these practices result in a low growth rate (PHENGSAVANH et al., 2010; KAENSOMBATH, 2012). The task of managing the pigs is always on women and children, and they usually spend no more than 1 h per day taking care of their pigs, with 1–2 sows per household (CHITTAVONG et al., 2012; WILSON, 2007). Due to the increasing popularity of urban consumers, many urban farmers in Laos turn to own indigenous pig breeds. The benefits of native pigs may be considered their ability to survive by kitchen garbage, local feed sources, and organic product.

2.2.3. Indigenous pig reproductive management in Laos

The indigenous pigs' existing reproduction in rural Laos cannot be controlled based on the traditional extensive raising methods. Notably, farmers never select the effective boar for their gilts or sows in the free scavenging system. Instead, farmers leave them

scavenging together in the yard and nearby forest, where boars and sows can freely mate or breed. As a result, it was difficult to control and enhance reproductive performance for Lao indigenous pig breeds (KEONOUCHANH et al., 2011). However, the average litter size of Lao indigenous pigs was between 5–8 piglets, while the mortality was up to 20–50% per litter (PHENGSAVANH et al., 2010; CHITTAVONG et al., 2012). This critical situation could be minimized by providing better management and improving the feed and feeding regimen (KAENSOMBATH, 2012; PHENGVILAYSOUK et al., 2018). One of our findings (XAYALATH et al., 2021) showed approximately 15% of the pre-weaning mortality of indigenous pigs reared under a traditional extensive system in the Northern provinces of Laos. In 2016, Nongtaeng Pig Production Research Station conducted research on the reproductive performance of Lao indigenous sows by cross-breeding with *Duroc* boar to achieve a better growth rate and lower fat content (KEONOUCHANH, 2018). Unfortunately, this initial project was only performed for two years and was terminated in the second half of 2019 due to an uncontrolled ASF outbreak.

2.2.4. Main problems in indigenous pig reproduction in Laos

Small litter sizes and a low average number of alive piglets per year per sow are two of the most persistent challenges in smallholder pig reproduction in Laos. Sows typically produce 5–8 piglets every litter, with just a few surviving piglets at weaning due to high pre-weaning mortality (20–50%). (CHITTAVONG et al., 2012, PHENGSAVANH et al., 2010, respectively). The average daily gain (ADG) of piglets during lactation is less than 135g/day (PHENGVILAYSOUK et al., 2018). However, providing sufficient feed and proper management for sows and piglets will enhance the number of pre-weaning surviving (PHENGSAVANH et al., 2010). Furthermore, the sows were too tinny after birth due to insufficient feeding, both in amount and quality (XAYALATH and SACKLORKHAM, 2010). The appropriate reproductive management methods, including gilts and sows' management before and after pregnancy, housing, feed, and feeding regimens, still need more improvement. Improving pre-weaning piglets' survival and the severe body condition of sows could be minimized by supplying water *ad libitum* during lactation and providing enough nesting materials 1–2 days before the expected farrowing day (PHENGVILAYSOUK et al., 2018). Additionally, the small number of pigs produced per sow per year and the product

quality not matching consumers' demand was also significant challenge for Lao indigenous pig farmers (XAYALATH et al., 2016).

2.2.5. The role of native pig breeds on food supply and rural development in Laos

Indigenous pig production is always considered a crucial promotion activity for many rural development projects in Laos. For instance, CARE International Organization in Laos launched a project named “Village Pig Bank” in Khoua and Samphanh districts, Phongsaly province, in 2008. Each household member would own 2 native sows at the same time, and the sows would be moved to the next household after each weaning round. Under this condition, farmers could get more income from pig production by approximately 15% (XAYALATH and SACKLORKHAM, 2010). Village Focus International (VFI), a similar concept, established one component to promote household income by improving native production for its target villages in the southern province. That could increase household income for farmers by more than 9% from native pig production (XAYALATH et al., 2016). One of our reviews found that more than 85% of households in rural Laos in 2019 owned at least one native pig, and at least once per month, that family consumed pork produced by native pig breeds.

2.3. Hungarian indigenous pig breeds and their production systems

2.3.1. Overviews of Hungarian indigenous pig breeds

Mangalica pigs are famous lard-type breeds in the history of Hungarian animal husbandry. The breeds were introduced into Hungary (Győr, Sopron, and Kisjenő) in the first half of the 19th century. It started from the curly-bristled *Sumadia* breed, which formed the blonde *Mangalica* breed in the 1830s. Then the Swallow-bellied *Mangalica* came from the crossbreeding of Blonde *Mangalica* and *Szeremsegi* pig. Finally, the red *Mangalica* resulted from the cross-breeding of blonde *Mangalica* with the *Szalontai* type and the crossbreeding with *Ujszalontai*-type pigs (SZABÓ et al., 2013). The first National Association of *Mangalica* Breeders was established in 1927 and reformed in 1994 (EGERSZEGI et al., 2003). Since the consumption habits changed from fatty pigs to more lean meat after World War II, *Mangalica* pigs nearly disappeared between the 1950s and 1970s. Presently, there are three *Mangalica* pig breeds, i.e., Blonde *Mangalica*, Swallow-bellied, and Red *Mangalica*.

At the same time, the Black *Mangalica* was not found in NAMB registered book in 2003 or 2013. With dedicated scientific breeding efforts, Black *Mangalica* might be re-survival or appear in the next registered book. The maturation of *Mangalica* is slow, and intensive supplement nutrients could not improve it in a short period as the modern breeds. The litter size ranged from 5 to 7 piglets per litter. After one year of rearing, body weight was around 100 to 120 kg, while the appropriate body weight at slaughter should be between 140–160 kg. Typically, the lard proportion of *Mangalica* was between 65 and 75% (SZABÓ et al., 2013). *Mangalica* sow would be the most prolific at the age of 5.5 to 6 years old when they can produce the maximum piglets per litter and farrow per year (EGERSZEGI et al., 2003). *Table 2* indicates the different number of days between two litters, frequency of farrowing, and piglets per sow of three different types of *Mangalica*.

Table 2

Prolificacy and rearing Performance of *Mangalica* pigs (2003-2012)

Types of <i>Mangalica</i> pigs	The sow			Average performance result of one farrow within 21 days of piglets age		
	FI	LY	AFF	DLP	21DAF	WP21
Blonde <i>Mangalica</i>	221-387	0.94-1.65	516-930	5.30-6.00	5.00-5.60	3.80-4.60
Red <i>Mangalica</i>	212-385	0.84-1.72	510-969	5.40-6.60	5.1-5.9	4.20-4.60
Swallow-bellied	202-448	0.81-1.80	481-980	5.80-6.50	5.40-6.00	4.30-4.70

SZABÓ et al., 2013. FI = Farrowing interval (day); LY = Litter per year; AFF = Age at first farrowing (day); DLP = Day one live born piglets; 21DAF = 21 days after farrowing piglets; WP21 = Weight piglets at 21 days after farrowing (kg).

2.3.2. *Mangalica* pig production systems in Hungary

Approximately 3,096 sows and 246 boars of *Mangalica* were registered on 30 June 2003, and 7,327 sows and 258 boars were recorded on 30 April 2013, which increased by more than 136% within 10 years. This number continuously increased to 9,360 sows in 2016 (PAPP, 2016). Not only the number of sows and boars increased, but the number of farms, as well “117 farms in 2003 and 170 farms in 2013” (SZABÓ et al., 2003 & 2013). Most farms are operated semi-intensive; farmers play more roles in pregnant sow and piglet management, including housing and feeding technology. Finishing and breeding gilts are always raised in semi-enclosed group housing with adequate feed, free water access, and deep straw bedding to keep them warm and comfortable. The gilts can access

the wetland for rooting or exercising their natural behaviour. They are separated into the specific house when they are detected pregnant. The sows are kept in a certain pen after service for 3–4 weeks, and the pregnant sows are kept in the specific farrowing crate 5–7 days before the expected delivery date. They are kept there until the lactation period ends when piglets are weaned between 4 and 8 weeks. After this period, piglets are grouped (20–25 heads) until they are separated between boars and gilts at roughly 120 days of age. In the past, the breeding gilts were kept in the wetland and pastures until their first mating at 450–540 days of age with a body weight of about 80–100 kg (EGERSZEGI et al., 2003). However, *Mangalica* could be reared under intensive farm conditions, where the fattening was highly developed. Still, the carcass quality did not change significantly (DEBRECENI et al., 2016). Typically, the *Mangalica* could produce around 9 weaners per sow per year for the purebreds. In contrast, in the case of cross-bred sows produce about 12–13/sow/year (EGERSZEGI et al., 2003).

2.4. Reproductive physiology of sows

2.4.1. Puberty

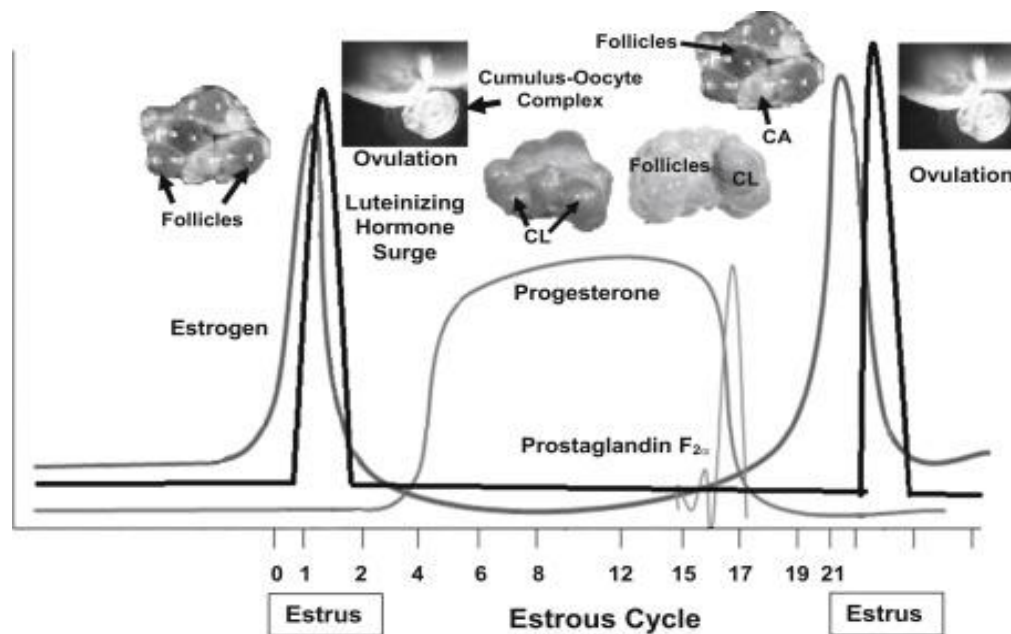
The gilts typically attain puberty between 150–200 days old or approximately 200 days on average. However, different breeds attributed to differences in age at puberty, such as Chinese *Meishan* gilts, attained puberty at 115 days (KYRIAZAKIS and WHITTEMORE, 2006). Iberian gilt is around 180 days (GONZALEZ-ANOVE et al., 2010), Hungarian *Mangalica* gilt is about 180–240 days (EGERSZEGI et al., 2018), *Moo Lath* Lao gilt ranges from 180–210 days depending on rearing conditions (KEONOUCHANH et al., 2011). Vietnamese *Mong Cai* gilts are between 180–240 months (DANG-NGUYEN et al., 2010), and Indian *Nicobari* gilts reach puberty at about 160–173 days of age (KUNDU et al., 2020). Many studies have shown that gilts raised in individual pen housing reach puberty later than gilts raised in group housing (CEDE and BILKEI, 2004). Most gilts had at least one or more oestrous cycles when they were between 210–270 days (LEVIS et al., 1989).

2.4.2. Oestrous cycle

The oestrous cycle of gilts and sows lasts 18 to 24 days, averaging 21 days. It is divided into two phases: follicular (5–7 days) and luteal (13–15 days) phase (SOEDE et al., 2011). More specifically, it was also divided into four sub-stages of the oestrous cycle

i.e., metestrus, diestrus, proestrus, and estrus (GEISERT et al., 2020). The oestrous cycle occurs due to changes in the major hormones associated with the oestrous cycle (*Figure 2*): progesterone, estradiol, follicle-stimulating hormone (FSH), and luteinizing hormone (LH). During the proestrus stage (days 16 to 18), the circulating progesterone rapidly drops, while estradiol and LH dramatically rise to stimulate ovarian follicles' ovulation. The average estrus duration in gilts last 52.6 h, ranging from 30–72 h. Ovulation occurred between 30 to 60 h (44 h on average) after the onset of estrus (ALMEIDA et al., 2000). While the estrus period in sow ranges from 24 to 96 h, and ovulation varies from 10 to 85 h after the onset of estrus (SOEDE and KEMP, 1997).

Figure 2: Ovarian hormones change during the oestrous cycle



Source: GEISERT et al. (2020).

2.4.3. Ovulations

Ova is released from the ovaries after the onset of estrus in 38 to 42 h. The ovulatory procedure takes almost 4 h to complete. Mated gilts or sows ovulate about 4 h earlier than unmated animals (ANDERSON, 2009). The number of ova is increased gradually from the fourth or fifth oestrous cycle. Many studies reported the gilts that bred at their first estrus would have less than one or two piglets than those bred at their second or third oestrous cycle (YOUNG and KING, 1981; SOEDE et al., 2011). Typically, the litter size at birth has about 60–70% of the total number of ova released during the oestrous cycle.

Approximately 15–24 ova were released by a mature sow (KNOX, 2022), and around 17 ova were released by a gilt (ALMEIDA et al., 2000). The ovulation rate usually increases during the first four parities of their production.

2.4.4. Breeding and fertilization

Mating or artificial insemination (AI) is usually performed 12–24 h before ovulation (MAES et al., 2011). By the way, gilts should be inseminated between 8–12 h after estrus detection and repeated again 12–16 h later. While sows should be inseminated within 24 h after standing heat was detected and between 18–24 h later for the second insemination to ensure that ovulated follicles are fertilized as much as possible (KNOX, 2022). Breeding targets are expected to have a high pregnancy rate and more than 12 piglets per litter (GEISERT et al., 2020), usually between 14–16 piglets born alive (KRAELING and WEBEL, 2015). A mature boar will ejaculate up to 300–500 ml of sperm during mating. Ejaculation takes over 10–15 min and encompasses three distinct stages, i.e., initial, sperm-rich, and post-sperm-rich. Transporting spermatozoa to the utero-tubal junction takes around 1–2 h. The spermatozoa are protected and preserved by an oviductal sperm reservoir (GEISERT et al., 2020). Fertilization occurs in the ampullary-isthmic junction within 2–3 or up to 6 h after mating (HUNTER, 1981).

2.4.5. Early embryo development and embryo mortality

Within 24 h of fertilization, the zygotes undergo their first cleavage division to form the 2-cell embryo (blastomeres). On days 4 to 6, the developing 4-cell to 8-cell embryos are transported through the oviduct into the uterine horns. At this stage, mitosis processes continue to enclose the embryos developed by zona pellucida into a solid ball of cells (called morula or 16-cell stage). Finally, the development of the blastocyst occurs by day 6–7 after fertilization. After fertilization, the blastocysts will be hatched as zona pellucida from days 7–8. Conceptuses (pre-embryos) occur between days 10 to 11 of gestation. Day 8–12 of gestation, the pre-implantation conceptuses will be migrated to each uterine horn. The conceptuses continue to grow and expand until day 18 of pregnancy and provide adequate space for placental development (GEISERT et al., 2020). Between 30–40% of oocytes released at ovulation are not survived or are not represented by piglets at birth (KYRIAZAKIS and WHITTEMORE, 2006). Most embryo death occurs in the

first 2–3 weeks of gestation, linked to fertilization and embryo growth within the litter. (GEISERT and SCHMITT, 2002).

2.4.6. Litter size

The number of ovulations, early embryo mortality, and uterine capacity are determined by genes and influenced by environmental factors to define litter size (EGERSZEGI et al., 2003). The ovulation rate in pigs continues increasing up to seven or more parity, the number of pigs born reaches the peak at the fourth or fifth parity (ANDERSON, 2009). However, the sows' lifespan may be up to many years. Pigs typically give 1–2.5 litters per year based on breeds and their prolificacy. The indigenous pigs that were reared by the traditional system usually gave birth to less than 2 litters per year, while hyper-prolific sows gave birth to 2.5 litters per year. For instance, *Mangalica* sows give 1–2 litter per year with 4–7 piglets per litter (EGERSZEGI et al., 2003; PETROVIC et al., 2013), 2.2 litter per year with an average of 7.5 piglets in Iberian sows (NIETO et al., 2019), and 1–1.8 litter per year with 6–8 piglets per litter in *Moo Lath* pig sows (KEONOUCHANH et al., 2011). Chinese *Meishan* and Vietnamese *Mong Cai* were more prolific breeds than other indigenous pig types. When Vietnamese *Mong Cai* sows gave 1.5–2 litters per year with about 10–14 piglets per litter (DANG-NGUYEN et al., 2010), and Chinese *Meishan* gave 2 litters per year with about 14–20 piglets per litter. Due to a lower embryo mortality rate of only 16% in *Meishan* compared to 26% in Large White and 41% in hyper-prolific sow Large White (BOLET et al., 1986).

2.4.7. Gestation

The gestation duration of domestic pigs varies from 105 to 125 days, with an average of about 115 days (NOWAK et al., 2020). The gestation length might influence stillborn and mummified piglets and the weaning-to-oestrous interval (PIETRUSZKA et al., 2020). The gestation length between gilts and sows was not different but correlated slightly with litter size and birth weight (EMERY et al., 2018). The small litter size may increase a bit longer gestation period compared to the large number per litter. Sows with a gestation length between 112 to 116 days had more pigs born alive than those delivered before day 112 and over day 117 (SASAKI and KOKETSU (2007). Incidentally, the season did not influence the gestation length of swine (EGBUNIKE and STEINBACH, 1977; LEIGH, 1981).

2.4.8. Farrowing and lactation

Sows usually farrow between 111 and 117 days after service. The farrowing procedures were defined into three stages: myometrial contractions or preparing for farrowing covers 2–12 h; delivery of piglets or fetal expulsion takes 2–3 h; and 1–4 h for the delivery of the placenta (GEISER et al., 2020). Typically, the piglet is delivered every 10–20 min (van DIJK et al., 2005). Over 30 min of the birth interval is considered abnormal delivery and a high risk for stillbirth (UDOMCHANYA et al., 2019).

The environmental conditions might influence the duration of farrowing (THODBERG et al., 2002). Sows farrowed in pens had a shorter mean duration of farrowing than those sows farrowed in crates (3.5 h vs. 4.5 h, respectively). The average piglets' birth interval was also longer when the sow farrowed in crates compared to sows farrowed in pens (29 ± 29 min vs. 19 ± 10 min) (OLIVIERO et al., 2010). The parity also influences the duration of farrowing of the sows. The most prolonged period was found in the 9th parity and the shortest in the 3rd (4.5 h vs. 3.4 h) (FAHMY and FRIEND, 1981). Another interesting thing to note is that sows with an average farrowing of 5.9 h had a higher rate of failure in the first insemination after weaning than sows with an average farrowing period of 4.3 h (OLIVIERO et al., 2013). The duration of lactation or the suckling period influenced the wean-to-oestrous interval (KNOX and RODRIGUEZ ZAS, 2001). Sows with a lactation period of 8–10 days came to oestrous with an average of 10 days, compared to 6–7 days for sows with a lactation of 23–25 days (Levis, 1997).

2.4.9. Reproductive physiology of *Mangalica* and *Moo Lath*

The average ovary weight of *Mangalica* gilts (7.3 ± 0.4 g) was weightier as compared to both *Moo Lath* gilt (4.3 ± 0.6 g) and mature sows (5.3 ± 0.8 g). In contrast, the mean oviduct length of *Mangalica* gilt was 24.13 ± 0.9 cm, shorter than *Moo Lath* gilt and sow, which measured 26.3 ± 1.3 and 33 ± 3.1 cm, respectively. The uterine horn length of *Mangalica* gilt was longer (142.75 ± 9 cm) than that of *Moo Lath* gilt (77 ± 6 cm), but it was shorter, almost 30 cm compared to *Moo Lath* sow (229 ± 9 cm). The weight of the uterine horn of *Mangalica* gilt and sow were quite different when BRÜSSOW et al. (2004) found that the uterine weight of *Mangalica* gilt was 301.5 ± 22 g, while RATKY et al. (2013) discovered the uterine horn weight of *Mangalica* sows were 250 ± 12 g (Table 3). However, both uterine horn weights of *Mangalica* gilts and sows were heavier than

Moo Lath gilts and sows, measuring 131±75 g and 219±21 g, respectively. The same research teams also found differences in the number of ovulations among *Mangalica* gilts and sows (10.6±2.2 vs. 9.9). This is not much different from *Moo Lath* gilts and sows (8.8±2.9 and 10.5±4.5, respectively).

Table 3

Comparative of reproductive tracts and reproductive physiology of *Mangalica* and *Moo Lath* sows

Reproductive organs	<i>Mangalica</i>		<i>Moo Lath</i>	
	Gilt	Sow	Gilt	Sow
Ovary weight, g	7.3±0.40**	-	4.3±0.60*	5.3±0.80*
Oviduct length, cm	24.13±0.90**	-	26.3±1.30*	33±3.10*
Oviduct weight, g	3.73±0.30**	-	-	-
Uterine horn length, cm	142.75±9**	-	76±5*	229±9*
Weight of uterine horn, g	301.5±22**	250±12*	131±57*	219±210*
Number of corpora lutea	17±1.20**	20±6.80*	-	-
Number of ovulations	10.60±3.10**	9.9*	8.80±2.90*	10.5±4.50*

* RATKY et al. (2013); ** BRÛSSOW et al. (2004)

2.5. Factors influencing the reproductive performance of pigs

2.5.1. Nutrition

Nutritional status is a critical issue that has a more significant impact on pig reproduction. Feed intake is always considered the fundamental component for maintaining physiological conditions and the reproductive performance of pigs, particularly gestating gilts (KIM et al., 2013). Energy diets influence the body weight of sows during both gestation and lactation (EINARSSON and ROJKITTIKHUN, 1993). The gestating gilts fed with a diet containing 3,400 kcal of ME/kg of feed had a higher number of weaner piglets per sow than those provided 3,100, 3,200, and 3,300 kcal/kg of feed, respectively. The proper daily energy intake should not be less than 6,400 kcal/day to maintain optimal body weight and backfat thickness loss during lactation (JIN et al., 2016). Additional daily feed levels of more than 50% for gilts from days 45 to 85 of gestation led to better body condition and backfat at weaning and litter weight at birth than non-supplement groups (CERISUELO et al., 2008).

In contrast, the ovulation rate did not depend on the feeding level during lactation. Although, an increase in feeding levels during early gestation (days 0 to 30) is associated with a risk of embryo mortality (SHANNON, 2005). The post-weaning feeding level did not affect the weaning-to-estrus interval. However, many researchers reported that sows fed with an appropriate feed level between weaning and mating had higher ovulation rates and greater litter size at the subsequent farrowing (KING, 1984). The quantity and quality of nutrition influenced the prolificacy of pigs (AHERNE and KIRKWOOD, 1985). The main reason that sows produce smaller litter size may be associated with the number of oocytes and nutrition intake, i.e., protein and vitamins (EGERSZEGI et al., 2003). Another critical factor to note is that sows will be late in the growth of antral follicles, decreased ovulation rate, delayed puberty, and late return to estrus after weaning if sows are undernourished (PRUNIER and QUESNEL, 2000).

2.5.2. Environment

The environment creates many critical factors in the reproductive performance of breeding pigs. Those factors might concern one or more of the following: large group of sows, increased outdoor temperature, decreased lactating feed intake and increased lactation length (KOKETSU et al., 2017). The environment that created excellent or poor animal welfare conditions could be associated with a different productive efficiency level. Light and temperature are two environmental factors that may play a role in determining sows' litter size capacity (VARLEY, 1989). The knowledge of the ecological variations attributable to non-genetic factors is used to assess the essential environmental factors. These factors identify specific non-heritable factors, including parity, sow age, seasons, nutrients, and management practices (KABARE, 1991). The season might not influence much on the performance of the pigs. However, spring and summer were associated with a slightly decreased pregnancy rate compared to fall and winter (90% vs. 93%). Similarly, the farrowing rate also decreased in spring and summer compared to fall and winter (88.50% vs. 90.90%) (MELLADO et al., 2018).

2.5.3. Management

Management is a key determining factor of the success and efficiency of pig reproductive performance. It covers all areas of pig reproduction, such as sow management pre-and post-parturition and caring for piglets during lactation and post-

weaning. One of the essential phases of the pig reproduction unit is mating management; poor management in this phase will result in inadequate conception or effect on the litter size (WEBSTER, 2011). The selection criteria for gilts as a new replacement should be considered to attain the maximum birth weight of piglets (FLOWERS, 2020). Gilt management strategies that begin from birth have more influence on the future reproductive performance of the herd (PATTERSON and FOXCROFT, 2019). Sow fertility and prolificacy, pre-weaning mortality, management, nutrition, housing and environment, health, and retention in the breeding herd are all factors that affect sow lifetime productivity (KRAELING et al., 2015). Another interesting thing to note is that increasing space for gilts before parturition is manifested in lower levels of physiological stress indicators (JARVIS et al., 2002).

In the case of Lao native pig breeds, improving or increasing the number of litters per year with a higher number of surviving piglets at the weaning should be a priority action. One of those actions includes providing better nutrition for sows and piglets and providing an adequate water supply for sows, especially during lactation (PHENGVILAYSOUK et al., 2017). However, the proper reproductive management methods need more improvement, especially sow management before and after pregnancy, weaning, and housing. PHENGVILAYSOUK et al. (2018) found that providing nesting materials for *Moo Lath* sows 1–2 days before the farrowing day and providing water *ad libitum* during lactation could decrease pre-weaning mortality and increase weaning weight, compared to the non-providing group (9.50 vs. 26.70% and 7 vs. 6 kg, respectively).

2.5.4. Disease and health

Diseases are always considered a major problem that can influence reproductive performance in pigs. Significantly, the native pigs are raised by farmers as traditional practice in rural areas where there is less care consideration for disease control (KUNAVONGKRIT and HEARD, 2000). Lameness is an example of a factor directly affecting the general health condition of sows in the pig industry (SUPAKORN et al., 2018). Lameness indirectly impacts the sow's reproductive performance due to the cause of stress and pain, which are associated with alterations in the immune system and changes in animals' susceptibility to many diseases (HEINONEN et al., 2013). POZZI and ALBORALI (2012) reported that various infectious diseases might affect the sows'

fertility parameters. It happened at different stages of gestation: embryo death mainly occurred between days 0–14, early embryonic absorption (days 14–30), fetal mummification (days 30–70), late abortion (days 105–115), and stillbirth at farrowing.

2.5.5. Genetics

The prolificacy of a sow may be influenced by its genetics or breed, which might not be able to be improved by providing quality nutrition or a better environment. Throughout a 15-year study on genetic and environmental aspects of three pig breeds on a large-scale in Kenya, KABARE (1991) found that the average litter size was 9.78 ± 2 in Large White, 8.79 ± 2 in Landrace, and 7.08 ± 2 in Hampshire. BOLET et al. (1986) found that the litter size of hyper-prolific sows (Large White) was 13.10 ± 1.30 compared to 12.10 ± 1.10 in typical Large White and 15.70 ± 1.50 in *Meishan* due to their ovulation rate and embryo mortality was the difference. Regarding new breeding technology programs, especially the selection for prolific traits. Most of the sows in the pig production industry are expected to have more than 2 litters per year and at least 12 pigs born alive per litter (LAWLOR and LYNCH, 2007). For instance, in France, the number of piglets born per litter increased from 11.90 in 1996 to 13.80 in 2006 (BOULET et al., 2008).

2.6. Reproductive management in pigs

2.6.1. Gilt and sow management

The failure of selection breeding gilts led to culling the gilts, or only first litter sows, out of the breeding herd. For example, due to improper gilt selection, around 38–51% of the culling frequency of gilts and first parity sows from two large pig farms in Southern China (LI et al., 2018). The effective gilts selection might be considered based on birth weight, growth rate, disease status, reproductive history of the dam, body conditions, and the number of teats (ATHORN and PLUSH, 2019). Gilt should be introduced to the gilt development for replacement, with a body weight of about 113–125 kg and 150–180 days of age. The gilts need to be fed a certain feed formulation and exposed by mature boars to stimulate the function of the oestrous cycle (KNOX, 2021). The optimum age of gilts at first mating is between 233–253 days of age to maintain and increase lifespan, litter size, and reduce culling sows due to failure or poor reproductive performance (MALANDA et al., 2019).

Based on the different breeds, the ages and live weights of gilts needs to be considered for first mating/insemination. For instance, *Mangalica* gilts reached their optimum age at first mating or insemination at about 270–300 days (EGERSZEGI et al., 2018) and should not be less than 90 kg at the time of first breeding (SZABÓ et al., 2013). In case, *Moo Lath Lao* gilts were between 180 to 240 days of age and weight less than 40 kg (KEONOUCHANH et al., 2011). Similarly, Vietnamese *Moung Chai* had the optimum age for their first mating at 180–240 days and a body weight of less than 25 kg (DANG-NGUYEN et al., 2010). However, Chinese *Meishan* reached puberty at about 93–95 days of age (BAZER et al., 1988; WHITE et al., 1993). But they should not be mated at less than 115 days of age to increase the reproductive efficiency of gilts (KYRIAZAKIS and WHITTEMORE, 2006).

2.6.2. Estrus detection

Usually, estrus will not appear during pregnancy and lactation periods. Due to uterine physiology, it typically returns to its normal condition within 17–32 days postpartum (ELZE et al., 1975). Estrus in a gilt lasts shorter (36–48 h) than in a sow (48–72 h) (ALTHOUSE, 2015). Commonly, the oestrous cycle of gilts and post-weaning sows will be divided into two phases: the luteal phase occurs from day 5–16 after estrus. The follicular phase occurs from day 17 of the previous cycle to day 4 of the coming cycle (KYRIAZAKIS and WHITTEMORE, 2006). The sows' ability to exhibit estrus post-weaning depends on lactation length, nutrition, body condition, and the animal's environment. However, many researchers proved that it occurred between 4–7 days after weaning, with an average of about 5 days (SOEDE et al., 2011). The oestrous cycle is directly regulated by hormones, especially progesterone, LH, and FSH, which sows need at least 2–3 days after weaning to stimulate the function of these hormones. Sometimes sows took more than 10 days of estrus interval if sows had lactation length less than 10 days, compared to 5 days of weaning estrus interval for sows with lactation length between 23–25 days (LEVIS, 1997).

2.6.3. Breeding management

Typically, there are three pig breeding methods: pen mating, supervised mating, and AI (HINES, 2020). In the pen mating, a boar would be allowed to stay with sows in pen during their estrus. It may be performed during the estrus exhibition or let boar and

sows live together in a pen as group mating, which can occur at various oestrous cycle stages. Supervised mating, the sows will be bred once on the day of standing estrous, and another service will be on the day after 12–24 h intervals. Using two boars as the pen or supervised mating, the number of piglets per litter will increase, but it may cause infertility in another boar (ALTHOUSE, 2015). Another mating method is ground mating for outdoor production. Still, the capacity of one boar should not be over 15 sows. However, 20 sows/boar are acceptable for natural mating, while more than 150–300 sows are for AI. The optimum use of boars for natural mating should not be over 2 sows per week; boars need enough time to rest before mating (KYRIAZAKIS and WHITTEMORE, 2006).

The optimum time for insemination always relies on ovulation time, which typically occurs within 24–48 h when the estrogen reaches the peak (WEITZE et al., 1994). The sow should be inseminated the preceding 24 h, while the gilt should be inseminated 12 h before ovulation. The sow or gilt should be inseminated twice during the estrus period with 12 h difference, for example, 12 and 24 h in gilts and 24 and 36 h in sows (ESTIENNE, 2009). Actual ovulation prediction during the oestrous cycle is the most important for determining the time of performing insemination to increase higher fertilization rate and improve the reproductive performance of the breeding herd (ALMEIDA et al., 2000). Due to the fact that sperm lives for approximately 24 h after insemination, litter size would be smaller if insemination was performed more than 24 h before ovulation. Similarly, the egg will also be fertilized only 12 h after ovulation (KRAELING and WEBEL, 2015).

2.6.4. Pregnancy and pregnancy diagnosis

Fertilization occurred in the oviduct within 2–6 h after the sperm reached the oviducts, approximately 30 min to 1 h after insemination. The fertilization rate is based on embryo mortality, usually up to 30–34%, with a litter size of 10–16 (ALTHOUSE, 2015). There is a high risk of embryo mortality during the first 30 days of gestation. Therefore, keeping sows in individual breeding stalls for the first 4 weeks after service to prevent the free movement of sows should be considered to reduce the number of embryo mortality or loss. Feed intake is one consideration for reducing the number of losing early embryos (LANGENDIJK, 2021). The amount of feed intake should be reduced to 2–2.5 kg/day after mating until pregnancy diagnosis. To maintain a good body conditions, sows

typically are fed 2–3 kg of gestation feed with 13 MJ/kg of digestible energy and 14% crude protein. However, the feed intake should be increased to 3–3.5 kg/day for the last three weeks of gestation to conserve more to produce milk for their piglets. Again, this amount of feed intake should be reduced to 2–2.5 kg/day at least three days before the farrowing day (WEBSTER, 2011). There were no differences in birth weight, weaning weight, stillbirth, and subsequent reproductive performance of sows between two different feeding levels for gilts and sows (1.8 kg/day and 2.2 kg/day) from day 90 until farrowing (MALLMANN et al., 2018). However, increasing the feed intake level from 1.8–3.2 kg/day for the first month of gestation for first and second-parity sows impacted the total number of piglets born (MALLMANN et al., 2020).

Pregnancy diagnosis could be performed after breeding at 18–25 days. Gilt or sow are considered pregnant (75–85%) if they do not return to estrus by this time. In modern pig farming, ultrasonography is used to determine the pregnancy of gilts and sows, with an accuracy of over 85% from day 22 after breeding (ALTHOUSE, 2015).

2.6.5. Farrowing management

Parturition management aims to provide a suitable farrowing procedure to the sows, minimize the number of piglets lost during farrowing or within 72 h after farrowing, and prepare the sow for their lactation (HOLYOAKE et al., 1995; VILA and TUMMARUK, 2016). Sows are usually moved into the farrowing house 5–7 days prior to the expected farrowing day. The farrowing might take 2–4 h (gilts will be shorter than sows) to complete delivery of all piglets, and the delivery interval is 20 min on average or ranges between 10–30 min (WEBSTER, 2011). When the delivery duration of piglets takes longer than 5 h, a problem in farrowing concerns a difficult birth and increased stillborn, which may require the assistance of a stockman (DOVE, 2009).

Pre-weaning mortality ranged from 11–24%, mainly during the first 2 days after farrowing, and 30–40% of all deaths were stillbirths. Stillbirth is mainly associated with multifactor such as disease infection, incorrect position during delivery, larger litter size, the prolonged interval between piglets, parity, body condition of sows, stress or farrowing environment, farrowing supervision or birth assistance, stockmanship (KRAELING and WEBEL, 2015; VANDERHAEGHE et al., 2013). Birth or farrowing assistance may include (1) preventing every violence of the sow to its newborn piglets, (2) helping to deliver piglets in case they had intervals longer than 30 min, (3) removing placental

around piglets and cleaning noses for piglets, (4) proper cutting the umbilical cord, (5) drying and positioning piglets to the provided heat lamp, (6) helping the lower weight and weaker piglets away from the sow to prevent crushing, (7) helping the lower weight piglets to be able to consume colostrum or supplement milk based on necessary, (8) splitting suckling or cross-fostering litters to ensure piglets from large litters consume enough colostrum, and (9) providing proper fluids to dehydrated piglets (KRAELING and WEBEL, 2015).

2.6.6. Pre-weaning management

The objectives of pre-weaning management are to manage a large number of litters as much as at the time of weaning with better quality and prepare the optimum body condition of the sow for her next breeding cycle (WEBSTER, 2011). Piglets' mortality is one of the crucial issues to consider in managing the pre-weaning, especially in a large litter that is bigger than 12 (NUNTAPAITOON and TUMMARUK, 2018). Pre-weaning mortality relates to piglets and sows management and environmental factors (MUNS et al., 2016). Management is key to minimising preweaning piglet mortality (TUCKER et al., 2021). The pre-weaning mortality rate differs in different farms and regions, such as 11% in commercial pig farms in Thailand (NUNTAPAITOON and TUMMARUK, 2018), 12% in England (KILBRIDE et al., 2012), 8% in China regarding management matter, e.g., crushing by the sow, starvation, diarrhoea, low viability, chilled and splay legs (LIU et al., 2018). Supplementing milk during the suckling and using the cross-fostering strategy in pre-weaning management may be an alternative to increase the weaning weight for the lower birth weight piglets. (DOUGLAS et al., 2014). The functional number of teats and the ability of milk production of sow also play an important role in reducing the pre-weaning mortality of piglets (OBERMIER et al., 2021). For instance, AZARPAJOUH (N/A) reported in Pig Progress, indicated increasing one functional teat of the second parity sows can increase 3.25% of pre-weaning survivor piglets and increase more than 3.6 kg of total litter weight.

3. MATERIALS AND METHODS

3.1. Comparing the reproductive performance of *Mangalica* and *Moo Lath* pigs

All existing data regarding reproductive performance were collected from NAMB, particularly from the registration book of 2003 & 2013. The physiological traits of *Mangalica* and *Moo Lath* gilts and sows were analyzed based on the previous research of BRUSSOW et al. (2004), and RATKY et al. (2013). The current reproductive management at *Mangalica* and *Moo Lath* farms was investigated both in Hungary and Laos:

In Hungary (survey)

A survey on reproductive management at Hungarian *Mangalica* farms was carried out with the support of NAMB. The semi-structured questionnaires were used as a main tool for collecting data, and 32 *Mangalica* pig farms participated in this study. The farm's size ranged from 10 to 835 breeding sows, with over 3,357 breeding sows involved in this study. The farms were grouped into three groups: A “farms with < 30 sows”, B “farms \geq 30 to $100 \leq$ sows”, and C “farms with > 100 sows”.

In Laos (survey)

164 native pig-raising households (HHs) in Northern Laos, where around 60–90% of the families owned at least one native pig (EPPRECHT et al., 2018), were involved in this study. We worked closely with 5 representative provinces in Northern Laos, especially the District Agriculture and Forestry Office (DAFO) team, to identify the proper pig-raising households to answer the questionnaires. The two main objectives of this study are to investigate the constraints problems and the existing reproductive management of indigenous pigs reared by small farmers in Laos. The number of sows owned by families varied from 1–10, with an average of about 1.98 sows per family. The villages were grouped into three clusters based on kilometres (km) distance from towns. It was slightly different from the PHENGSAVANH et al. (2011) study, which classified based on distance in hours. It was very similar to the methods used by VALLE ZÁRATE et al. (2010), carried out in Northwest Vietnam, which was close to Laos' border. The 1st cluster was < 15 km (n = 54 HHs), the 2nd was ≥ 15 –30 km \leq (n = 41 HHs), and the 3rd cluster was > 30 km (n = 69 HHs) away from the towns.

3.2. Experiment on improving the reproductive performance of *Moo Lath* in Laos

3.2.1. Animals and accommodation

All animals used were raised and cared for under the Livestock and Veterinary Law of Laos (No.: 08/NA-Laos, 11 April 2016), which addressed the protection and welfare of all animals used in this study. Additionally, the experiment aimed to collect only primary farm data. All practice procedures in this study were judged to have a low risk of injury or harm to animal welfare. So, the research ethics committee did not need to approve it. 36 *Moo Lath* gilts aged between 150–240 days, with a mean body weight of about 25–40 kg, were involved in the study. Gilts were kept in individual pens (1.5 x 2 x 1 m, made with a concrete floor and under the tile roof) during the experimental period. They were divided into three groups, insemination with *Duroc* semen, G1 (18 gilts) was synchronized using Altrenogest Regumate[®] (AR), while G2 (12 gilts) was not. G3 (6 gilts) was the control group mated naturally with a local boar.

3.2.2. Feed and feeding strategies

Gilts, sows, and piglets were fed with the categories of complete mixed feed from the Lao-Hungarian feed factory (Hungarian background VITAFORT Co.). All gilts and sows got the same feed and the same portion. Each gilt was fed 1.5 kg/day before and after oestrous. After insemination, this amount was reduced to 1.2 kg/day between days 1 and 28. From days 28 to 100 of gestation, each pregnant gilt was fed 1.8 kg/day, and this amount was increased to 2 kg/day between days 101 of pregnancy until farrowing. During lactation, all sows got 2.3 kg/day. This feeding strategy is similar to MALLMANN et al. (2019); MIDDELKOOP et al. (2019 a); ŠKORJANC et al. (2008); NEWTON and MAHAN (1993), but that was a completely different pig breed and body weight of gilts and sows (*Picture 1*). In our case, the average body weight of gilts at insemination was 49.59 ± 7.20 kg (ranging from 36.60–72.50 kg), and before farrowing was 75.99 ± 7.33 kg (ranging from 62.45–92.40 kg).



Picture 1: Overall bodyweight of *Moo Lath* sow (A) hardly reaches 100 kg at 1st parity, and gilt (B) hardly reaches 50 kg at 270 d

The nutrient content in the feed for gilts, gestation, lactating sows, creep feed, and post-weaning feed was demonstrated in *Table 4*. All animals were fed twice a day at 7:00 am and 5:00 pm. All animals had access to clean water *ad libitum*. The piglets were given dry creep feed starting on day 7 and *ad libitum* on day 10 after farrowing. The creep feed was provided in a round trough. The leftover feed from the trough was removed, weighed, and recorded before giving the new one to ensure that piglets got fresh feed, and to evaluate the feed intake of each litter.

Table 4

Nutrient content in the complete mixed feed use for the experiment

Nutrient Components	Gilt feed	Gestation feed	Lactation feed	Creep feed	Post-weaning feed
DM (%)	88.50	88.36	88.5	89.13	89.05
CP (%)	15.99	15.11	15.99	20.71	18.97
EE (%)	1.94	0.50	1.94	5.52	2.78
CF (%)	5.26	6.22	5.26	2.71	4.14
Ash (%)	8.48	8.18	8.48	4.65	5.26
AIA (%)	1.34	1.69	1.4	0.34	0.57

DM: dry matter; CF: crude fiber; CP: crude protein; EE: ether extract; ASH: ash; AIA: acid-insoluble ash.

3.2.3. Details of the experiment

3.2.3.1. Modification of optimal body conditions and age of *Moo Lath* gilts for first insemination/mating

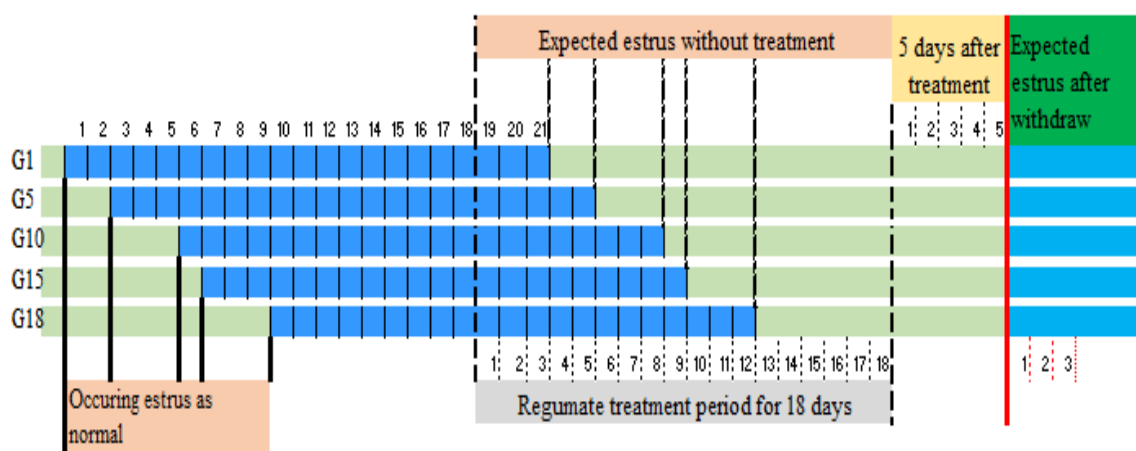
Thirty-six (36) gilts were reared for almost 4 months until they reached the optimal body weight and age as a requirement (> 50 kg and > 6.5 months, respectively). This

study aimed to evaluate the optimal age and body weight on the reproductive performance of *Moo Lath* pigs. To compare the performance of sows with those native sows raised by farmers in remote areas of Laos, which always have their first service as soon as the gilts exhibit their first oestrous. Typically, at days 120 and 180 of age, weighing approximately 21–30 kg. In this study, gilts were inseminated with body weight and age of over 36.60 kg and 195 d, respectively. These figures were significantly different from the minimum age and body weight of *Mangalica* gilts, mated for the first time, which should not be less than 270 d with a body weight not less than 90 kg (SZABÓ et al., 2013). One of our studies (non-published article) found farmers would allow *Mangalica* gilts to be mated for the first time when they were 330 to 398 d, with a mean body weight of about 100–120 kg.

3.2.3.2. Estrous synchronization and artificial insemination

The experiment aims to improve reproductive management to stimulate the gilts to come in heat simultaneously and increase more piglets per batch management for the *Moo Lath* pig production. The strategies of AR treatment were performed as described by BRUSSOW et al. (2008) and the company’s recommendation (MSD Animal Health, Walton in Milton Keynes, UK). All gilts in the synchronizing group (G1) were fed 5 ml of Altrenogest Regumate® (AR) per os at 7:00 am before the main feed for 18 consecutive days after their oestrous. AR was mixed into a small amount of feed and provided to each gilt in G1. It was monitored and ensured that gilts got their portion before offering a regular feed. Five days after withdrawal of AR, the gilts were expected to come to oestrous within 3 days (*Figure 3*).

Figure 3: Protocol for Altrenogest Regumate® treatment for Moo Lath gilts



Source: Modified based on MSD Animal Health, Milton Keynes, UK

All gilts from G1 and non-synchronization (G2) were inseminated three times during the oestrous period using the same *Duroc* semen, supported by UDA. Pig Farm. The AI was performed on the day of estrous detection (e.g., in the morning, late afternoon, and again on the following morning). The insemination was done by boar stimulation in the front corridor. The gilts in the control group (G3) were also mated three times, as described earlier, using a mature native boar. The supervision mating technique was used to mate each gilt in G3, the boar was taken out from the gilt soon after service.

3.2.3.3. Pregnancy determination

None of the gilts returned the oestrous cycle 21 days after insemination was considered pregnant. However, the current study diagnosed each gilt's pregnancy twice. First performed on day 28 and another on day 40 after insemination/mating to confirm the pregnancy using FarmScan[®] L70 Eye Muscles Veterinary Ultrasound as described by KOUSENIDIS et al. (2021). The transducer's operation points were at a 45° angle behind the abdomen at the height of the second nipple. Mineral coupling gel was used to improve the transition of the ultrasound wave.

3.2.3.4. Assessment of sow's body conditions

The body conditions of the sows were assessed by palpating the sows' backs and visualizing using the scale 1 to 5 scoring principle (1 = thin and 5 = fat). The body conditions of sows were assessed and recorded for the first time before insemination, on day 110 d of gestation, and weekly during their lactation period. The body weight of the sows was weighed using the 300 kg digital scale that was set up on the experimental farm. Each sow was measured backfat thickness (BF) using FarmScan[®] L70 Eye Muscles Veterinary Ultrasound. The operation point of the BF measurement is the P2 position, 6–8 cm away-down from the back middle at the last rib, with the mean of the right and left side being the value of BF, as described by ROONGSITTHICHAJ and TUMMARUK (2014). Mineral coupling gel was used to help the transmission of the ultrasound wave.

3.2.3.5. Farrowing and lactation management

Each sow was provided approximately 5 kg of rice straw on day 110 to build a nest for her farrowing. Weaker piglets were supported in drinking the colostrum (*Picture 2*), whereas the vigorous piglets were assisted in tearing the placental membrane and

drying shortly after birth. All piglets had their specific ear-notching marked on the 1st or 2nd days after farrowing. The male piglets were castrated on day 10 after farrowing with local anaesthesia, and preventive antibiotics were used right after the surgery. On days 1 or 2 after farrowing, piglets had their teeth clipped but not their tails docked. All piglets were administered 1 ml of iron injection between 3–7 days of age.



Picture 2: Stockman assisted the weaker piglets in sucking colostrum after birth

3.2.3.6. Weaning and post-weaning management

The piglets were weaned either on days 28, 35, 42, 49, or 56 after farrowing. The weaning was performed in the late afternoon to reduce stress from the hot weather during the daytime. Weaned piglets were transferred to nursing pens, with about 8–20 piglets per pen "3 x 4 m, or 12 m²", with around 5 cm of bed-deep saw dust (*Picture 3*). They were fed the same post-weaning feed at the nursery pen until 2nd week after weaning before they were sold out. The post-weaning feed was mixed with the creep feed five days before weaning to ensure the piglets were familiar with the feed during the weaning phase.



Picture 3: Piglets in the nursery pen grouped based on their body weight

3.2.3.7. Growth performance of piglet measurement and diarrhoea assessment

The weight gain of piglets was individually recorded weekly, which started from the day of farrowing and continued through the suckling period and two weeks of the nursery after weaning. The assessment of piglets' diarrhoea was the daily observation of their faeces using the faecal score principle (scale of 1 to 4) described by ALLTECH (N/A), where 1–2 is considered solid and well-form, while a scale of 3–4 is considered diarrhoea. The faecal score evaluation was performed every morning after recognizing of changing form in faeces. The number of diarrhoea piglets was recorded as individual litter for the suckling and nursing periods.

3.2.3.8. The optimal age of starting creep feed on the growth performance of piglets

115 piglets from 16 sows of their second parities were used in this study and were divided into 3 groups (CF7, CF10, and CF14) based on different days of starting creep feed (7, 10, and 14 days of age). All piglets were provided creep and post-weaning feed twice a day (7 AM and 5 PM). The data were recorded from the day of farrowing as birth weight and weekly until weaning (at day 35) and 2 weeks post-weaning. This study aims to evaluate the effects of different ages of starting creep feed to *Moo Lath* piglets on their growth performance, both suckling and early post-weaning periods.

3.2.3.9. Study on the sex proportion of piglets and their growth performance

This study involved 20 sows of their second parities of *Moo Lath* sows, with 149 piglets involved, to evaluate the difference in sex ratio and the effects of sex on the growth performance of piglets until weaning at 35 and 2 weeks of their post-weaning. All male piglets were castrated on day 10 after farrowing. From day 7, after farrowing, all piglets were fed *ad libitum* with the same creep and post-weaning feed. The body weight of piglets was recorded from the day of farrowing as birth weight (BW), then recorded weekly until weaning and 2 weeks after weaning.

3.2.3.10. Examination of bacterial infection in piglets

A total of 20 faecal samples (1–2 ml) of 20 diarrhoea piglets were collected from the anus of each piglet using a pipette to ensure no contamination by other objects. The samplings were done in two periods, pre-weaning and post-weaning, 10 for each. The sampling was performed at 7:00 am using a sterilized pipette and placed in a sterilized

sample bottle soon after collection. Soon after the samples were collected, all sample bottles were sent to be stored until diagnosed at the National Animal Health Laboratory, Department of Livestock and Fisheries. All kinds of possible infected bacteria were checked, and the total bacteria from each sample were counted and recorded (using culture test and biochemical test techniques).

3.2.3.11. Effects of dried green banana on reducing post-weaning diarrhoea

Seventy-five (75) piglets were used in this study to compare the effectiveness of supplementation with 10% of dried green banana (*Musa Acuminata*) in the piglet diet 3 days before and after weaning (6 days in total). Diarrhoea piglets within two weeks of post-weaning were observed and individually recorded for each diarrhoea piglet.

3.2.3.12. Study on the age and body condition at puberty and first mating of crossbreed *Moo Lath* x *Duroc* gilts

18 CMD gilts from our first experiment were selected soon after weaning. Each gilt was separated and kept in an individual pen after the onset of puberty based on birth weight (< 0.7 ; $\geq 0.7-0.8$; and > 0.9 kg) to evaluate the age at puberty and first mating, including the body condition of the first mating of CMD gilts, including litter size and their offspring birth weight. 15 mature purebred *Moo Lath* (PML) gilts reared by local farmers were also involved in this study to compare the morphologies at first mating between CMD and PML gilts.

3.3. Statistical analysis

The SPSS statistical version 26 (2019) was used to analyze the data. One-way ANOVA was used to evaluate the body condition of sows, litter size, growth performance of piglets, piglets' mortality, and effects of weaning periods on the performance of sows and piglets. The independent-sample T-Test was used to compare of sex ratio and sex effects on the growth performance of piglets. The same as the effects of supplementing green dried banana on post-weaning piglets' diarrhoea, and the morphology comparison between the CMD and PML gilts. The Bivariate Pearson Correlation Analysis was used to assess the correlation coefficients between reproductive parameters. The significant differences in the mean between groups were checked using the LSD test. A significant level of 0.05 ($P < 0.05$) was used as the significant difference.

4. RESULTS AND DISCUSSIONS

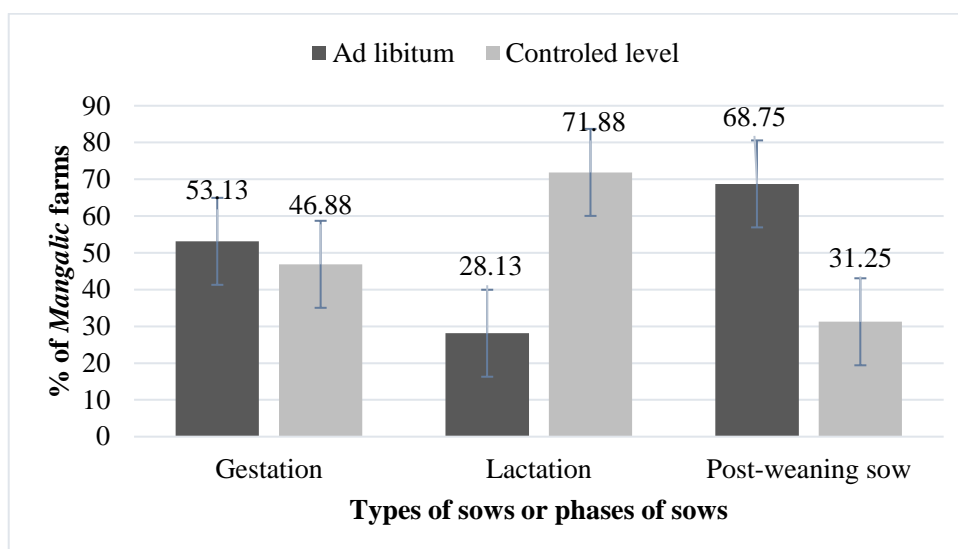
4.1. Reproductive management in Hungarian and Lao indigenous pig farms

4.1.1. Gilt and sow management

Mangalica gilts are always kept in the grower and finisher group in a straw-bedded barn with a small outdoor access area until they reach the optimal age and body weight for first mating. It is usually around 330–420 d to attain 100–120 kg body weight. There was no significant difference in the mean age and body weight at first service ($p > 0.05$) of sows between clustered farms. However, farmers in cluster C (> 100 sows) tended to allow the gilts to be bred earlier (394 d), with a body weight of about 107 kg. Meanwhile, farmers in cluster A (< 30 sows), allowed gilts to have first service a bit late (403 d), with a body weight of about 110 kg. These findings are similar to those of EGERSZEGI et al. (2003), and EGERSZEGI et al. (2018), which recommended the proper age at first mating of *Mangalica* gilts should be between 330–360 d. It also supports the findings of RADOVIĆ et al. (2019), who reported that the mean first parturition of *Mangalica* sows was approximately 519 d of age. During the grower and finisher stages, gilts were fed *ad libitum* in over 59%, and nearly 39% of the other participating farms fed them twice daily. Over 75% of participating farms produced their feed for pigs, and only 25% used commercial feed, mainly in cluster C farms.

Weaned sows were kept in the group after they were detected as pregnant. Nearly 90% of informants housed the gestating sows in a group in open barns with limited paddock access. One crucial issue to consider is the sows' feeding regime. More than 53% of informants fed the sows *ad libitum*, while nearly 47% fed them at a restricted level (Figure 4). This point might differ from many researchers' recommendations; gestation sows should be provided with a controlled diet to maintain optimal body conditions, especially in the first 4 weeks of gestation (JOHNSTON, 2010). Otherwise, it might influence or negatively impact embryos' survival and fetus development and may cause dystocia (SHANNON, 2005; MUSSER et al., 2006). Although increasing the feeding level between days 40 to 80 is necessary for gilts to deposit the optimum amount of fat for their lactation (CERISUELO et al., 2008).

Figure 4: Feeding regime of sows used by Hungarian *Mangalica* pig farms



Unfortunately, indigenous pig farms have not been developed yet in Laos. Therefore, getting information from Lao rural pig-raising households under traditional extensive systems to compare the gilts and sows management of what Hungarian *Mangalica* farms operate or do, is quite challenging. It is impossible to describe gilts and sows management standards because farmers cannot control breeding due to raising systems. Gilts will be mated soon after puberty, between 120 to 150 days of age. In many cases, gilts are mated before 25 kg of body weight. One of our findings (Xaylath et al., 2021) showed that over 87.80% of farmers allowed gilts to be mated soon after puberty due to not separating between gilts and boars.

4.1.2. Breeding management

Mangalica sows had the WEI between 4–8 d, covering 43.75% and around 56.25%, with over 8 d after weaning. This finding was similar to the WEI of Lithuanian native pigs, with about 9.34 ± 1.12 days (KARVELIENE et al., 2008). Our results confirm the conclusions of SOEDE et al. (2011), who found that the WEI of sows ranged between 4 and 7 d, depending on the lactation phase. For instance, LEVIS (1997) found sows had WEI at day 11 for those weaned within 8 to 10 d, compared to day 6 for those with 23–25 d of lactation.

Natural mating remains the primary breeding method used in most *Mangalica* farms, covering 75%. Only 16% used AI, and 9.38% used both natural mating and AI. AI is used primarily on farms with > 100 sows. Over 56.26% of participating farms utilized

Duroc to cross with pure *Mangalica* (PM) sows for marketing purposes. This strategy would be positive for Lao farmers to improve Lao indigenous pigs. Artificial insemination (AI) is only an advanced technique performed in some Hungarian *Mangalica* farms at the time of the study, with 9 out of 32 participating farms reported they used AI in the breeding program. Oestrous control, synchronization, or other hormone treatment in the gilts was not found in any *Mangalica* farms. However, RATKY et al. (2001) attempted to synchronize Swallow-bellied *Mangalica* using Regumate, followed by injections of 750, 1000, or 1250 IU PMSG to increase the ovulation rate before 3 days of ovulation. Gilts, followed by injections of 1,000 and 1,250 IU PMSG, showed a higher ovulation rate (24.20 ± 3.60 and 21.00 ± 2.30) than 750 IU (13.70 ± 2.70).

There is not much evidence regarding improving breeding for Lao indigenous pig breeds. Based on our findings, most farmers seem not to consider the optimal body weight and age at the first mating of the gilts. Around 87.80% of farmers allowed gilt to be bred at the first oestrous. Again, this is because most farmers cannot control the breeding gilts, which they free under free-ranging conditions without the limitation areas. Sometimes, the pig owners did not know even when their gilts or sows had been mated. It is hard to consider or find a better solution to improving the better management of pig breeding under current rural conditions in Laos, unless farming systems (e.g. housing and feeding systems) have been developed.

4.1.3. Farrowing management

The pregnant sows were separated from their herd and kept in an individual pen in the farrowing unit 5–7 days before the expected farrowing date. The sows were kept in the specific farrowing pen until weaning (average of 6.17 weeks, ranging from 4–8 weeks). Calming is a critical consideration that stockmen pay attention to during farrowing and lactation to reduce the pain and stress for the sow and piglets.

The mentioned approaches did not find any indigenous pig producers (from our study) considered or performed in Northern Laos. Over 85% of farmers did not know when their sows would deliver piglets. Approximately 54% of farmers did not keep sows in pens before the farrowing, and around 53% of sows gave birth in the nearby forest. From this point, there is a high potential for Lao researchers or concerned organizations to improve farrowing management of the indigenous pigs based on pig barn improvement.

4.1.4. Overall reproductive performance of Hungarian and Lao indigenous pigs

4.1.4.1. Reproductive performance of *Mangalica* sows

There was no significant difference in the lifespan of *Mangalica* sows, with an average of 5.42 years ranging from 3 to 8 years. However, the farms in clusters A and B had marginally longer use of sows than those in cluster C (5.76, 5.25, and 4.50 years, respectively). Overall, there was no difference in the reproductive performance of *Mangalica* sows among clustered farms. On the other hand, it significantly differed in specific types of *Mangalica* (pure (PM) vs CM). CM had almost every reproductive parameter higher than PM. The longest period of gilt development was in farms that produced pure SM, with a mean age at first mating was 450 d, while BM, RM, and CM were 429, 400, and 418 d, respectively. CM had a larger ($p < 0.05$) litter size (6.43) and birth weight (1.19), compared to PM, especially BM (*Table 5*). In addition, CM also had a slightly larger ($p < 0.05$) litter per year (1.46) compared to 1.03 in RM, 1.13 in SM, and 1.20 in BM. However, CM seems to be culled earlier than PM, especially SM.

Table 5

Reproductive performance of different types of *Mangalica* sows

Parameters	Types of <i>Mangalica</i>				p-value
	BM	SM	RM	CM	
Number of farms	7	4	3	18	
First mating/AI, days	429	450	400	418	0.647
Weight at first mating, kg	117.86 ^a	110.00 ^{ab}	103.33 ^b	108.61 ^b	0.008
Litter size	5.31 ^a	6.13 ^{ab}	6.07 ^{ab}	6.43 ^b	0.217
Birth weight, kg	0.88 ^a	0.96 ^{ab}	1.10 ^{ab}	1.19 ^b	0.135
Lactation period, weeks	8.86 ^a	6.50 ^{ab}	6.83 ^{ab}	5.72 ^b	0.157
Weaning weight, kg	8.07	7.50	8.00	7.73	0.959
Pre-weaning mortality	1.87	1.31	1.43	1.15	0.516
Litter per year	1.20 ^{ab}	1.13 ^{ab}	1.03 ^a	1.46 ^b	0.068
Lifespan, year	6.07 ^a	7.25 ^a	5.33 ^{ab}	4.79 ^b	0.006

^{a,b}: Mean in the same row with the same superscripts do not differ ($p > 0.05$)

The average suckling period differed significantly ($p < 0.049$) between clustered farms. Particularly the sows in clusters A and C farms (6.54 vs 5.21 w), while the cluster B farms were 5.87 w. The mean weaning age of most HM farms practising now was 6.17 w. This figure might align with the EU regulation that does not allow organic pig

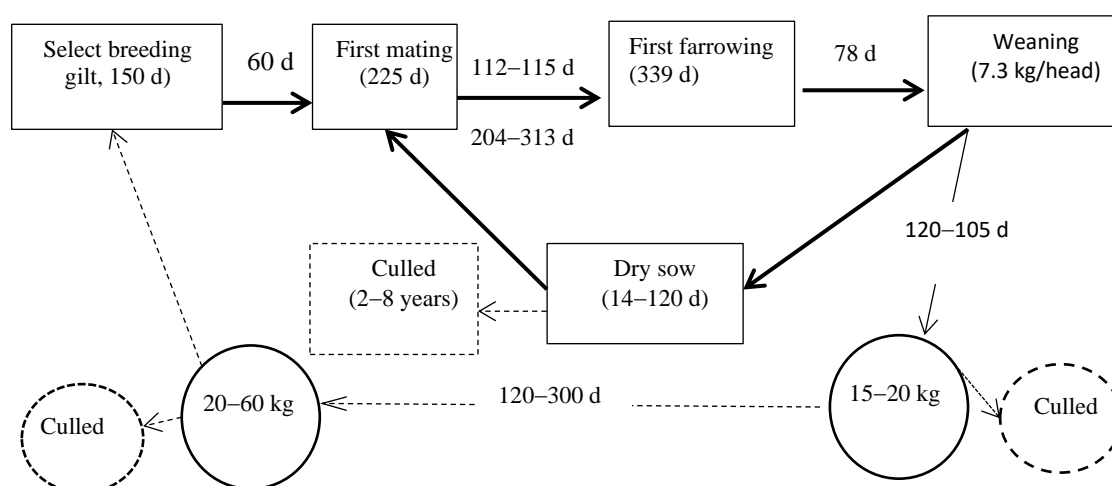
producers to wean piglets earlier than 8 w, and not less than 4 weeks for commercial production (Council Directive 2008/120/EC). These numbers differ from most commercial pig farms in Laos, where the weaning is often disrupted 3 w after farrowing.

4.1.4.2. Overall reproductive performance of Lao indigenous pigs

Lao indigenous gilts reach puberty roughly at 211 ± 41 d (ranging from 120–330 d), almost twice younger than *Mangaica* gilts. This finding might support the report of KEONOUCH et al. (2011), which indicated the mean first oestrous of Lao native pig breeds was between 173 to 388 d of age. It might be slightly higher than the record of NAFRI (2020); the mean first oestrous of Lao native pig breeds was 178 d. The first farrowing ranged from 240–450 d, or approximately 339 ± 43 d. The farrowing interval between two parities was 204 to 313 d (*Figure 5*), depending on the sows' lactation and dried periods. Lao indigenous sows gave roughly 1.30 ± 0.53 litter per year, ranging between 0.7 to 2, with an average litter size of about 7.60 ± 1.77 . Similarly, STUR (2002) discovered that *Moo Lath* sows gave 1–2 litters with 6–8 piglets per litter. KEONOUCHANH et al. (2011) also reported that *Moo Lath* sows had 1–1.5 litters per year under the traditional raising system. These figures were smaller than *Mong Cai* Vietnamese pig sows gave 2.1–2.2 litters per year, with an average of about 11–12 piglets per each (DUYEN and THUY, 2011). Our findings were slightly different from PHENGVILAYSOUK et al. (2017), who discovered that sows reared by smallholders in Northern Laos had a mean litter per year and litter size between 1.4–1.8 and 7.0–7.6, respectively. The mean birth weight and weaning weights were around 0.72 ± 0.23 kg and 7.30 ± 2.12 kg, with a suckling period of about 11.21 ± 3.38 w. These findings were also slightly bigger than PHENGVILAYSOUK et al. (2018), who found only 0.6 kg of BW and 7 kg of WW with a weaning age of about 1.5 w, nearly twice as shorter than the traditional extensive raising system.

The mean WEI of native pig breeds reared by small-scale farmers in Northern Laos was 48.34 ± 27 d. This figure differed from modern sows, in which more than 70% always came to the heat within 4–6 d post-weaning (STEVENSON and BRITT, 1981; MICHAEL and CHATHERINE., 1993). The precise causes of this variation are still unknown, but the flawed recording system and poor management, including feeding conditions during lactation, could be blamed.

Figure 5: Reproductive and productive cycle of Lao indigenous pigs



4.1.4.3. Stockmanship

For various reasons, the stockmen are concerned with farrowing management and assistance to minimize stillbirth and mortality rates during farrowing (KIRKDEN et al., 2013). The stockman is always considered a key component in influencing reproductive performance in modern pig production farms (KRAELING and WEBEL, 2015). Therefore, the skill and attitudes of stockmen need to be trained by the farm manager in all relevant activities (KIRKDEN et al., 2013). Identifying the farrowing behaviour and properly handling piglets are the first two primary elements that stockmen need to be competent in performing tasks in HM pig farms, covering 58% out of the five skill requirement indicators. While identifying the proper time to let the gilts or sows be mate/inseminated, which covered 20%; estimating and detecting the oestrous cycle of sows covered 18%; and identifying or diagnosing the pregnancy of sows was only 4%. Unfortunately, no scientific research or work report currently mentions anything regarding the necessary skills of the stockmen in Laos to compare with these findings. This is of great concern that most indigenous pig production in Laos is still at the household levels, mainly for household consumption only.

4.1.4.4. Comparison of the reproductive performance of Hungarian and Lao indigenous pig breeds

The ages at first mating varied between *Mangalica* and *Moo Lath* sows (360–423 d vs. 225–245 d). *Moo Lath* sows seem to produce a slightly larger litter size (7.60–7.75)

than *Mangalica* sows, which range from 5.58–6.12. Considering the number of ovulations in *Mangalica* gilt was 10.60 ± 3.10 (BRUSSOW et al., 2004), while only 8.80 ± 2.90 in *Moo Lath* gilts (RATKY et al., 2013). It was estimated that *Moo Lath* gilt might have a bit higher fertility than *Mangalica* gilt, so it had a slightly larger litter size. Both, Hungarian and Lao indigenous pig producers use a long lifespan of sows compared to modern pig breeds, where sows were often culled after their 6th parities or earlier. Based on the completed difference in breeds and raising environment, more scientific studies are required to compare reproductive physiology and their performance between Hungarian and Lao native pig breeds. Anyway, throughout the research period, we can summarize some reproductive performance figures of Hungarian and Lao indigenous pig breeds, as demonstrated in *Table 6*. The comparative data on their reproductive physiologies have already been shown in *Table 3*, which was conducted by BRÜSSOW et al. (2004); RATKY et al. (2013).

Table 6

The reproductive performance between *Mangalica* and *Moo Lath* Lao pig breeds

Parameters	<i>Mangalica</i>		<i>Moo Lath</i>	
	NAMB (2013)	Farmers (Survey 2020)	Extensive rearing	Farm experiment
Age at first mating, day	360	423	225	245
Weight at first mating, kg	100	110	37.50	49.59
Age at first farrowing, day	619	497	330	354
Weight at first farrowing, kg	-	-	50.56	75.99
Litter per year	1.41	1.32	1.31	-
Litter size	5.58	6.12	7.60	7.75
Birth weight, kg	-	1.09	0.73	0.64
Suckling period, week	3	6	11	(4–8)
Weaning weight, kg	4.70	7.80	7.30	3.48–5.92
Lifespan of sow, year	-	5.42	4.66	-

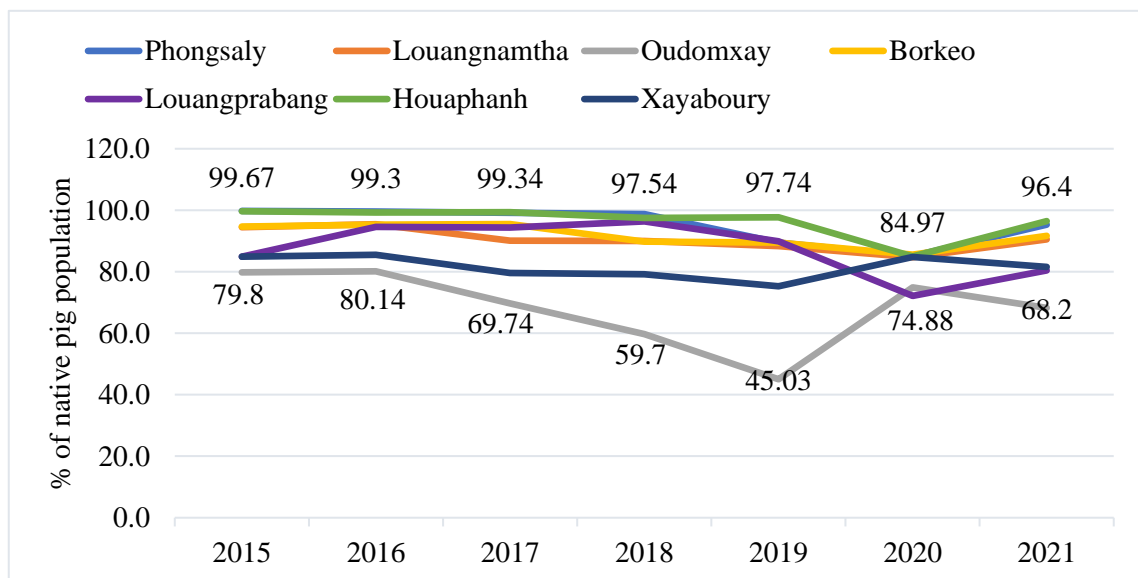
4.2. Constraints on indigenous pig development in Laos

4.2.1. Overall trend of the indigenous pig population in Northern Laos

Native pig populations in Northern Laos gradually decreased, from 91.20% in 2015 to 81.70% in 2020. However, it increased by almost 5% in 2021 compared to 2020 after

African Swine Fever (ASF) pandemic. This decline might also concern new investments in commercial pig farms of Chinese companies in larger provinces in Northern Laos, such as Louangnamtha, Oudomxay, and Louangprang, from the second half of 2016. MATSUMOTO et al. (2021) reported that the pig population of smallholders in Laos dramatically dropped after the first case of ASF was confirmed in July 2019. This caused the native pig population to decline by almost 5% in 2019 compared to 2018 or nearly 10% compared to 2015. Especially, Oudomxay decreased by almost 15%, and 7% in Louangprabang province (*Figure 6*). However, the overall trend of the native pig population in Northern Laos increased by almost 5% from 2020 to 2021, except in Oudomxay and Xayaboury provinces decreased by 6.68 and 3.18%, respectively.

Figure 6: General trend of native pig population in Northern Laos



4.2.2. Effects of raising systems on the reproductive performance of native pigs

Three types of the traditional pig-rearing systems in Laos include a free scavenging rearing system (FRS), semi-scavenging (SRS), and confinement rearing system (CRS; *Picture 4*). FRS showed higher litter size ($p < 0.001$), with about 8.5 per litter, while the CRS and SRS, with an average of about 7.36 and 7.54, respectively (*Table 7*). In contrast, FRS had a lower ($p < 0.000$) litter per year (0.87) compared to CRS and SRS (1.45 and 1.41). The lactation period might affect the WW in the rearing system, as the CRS had a shorter duration of about 10.18 w with a lower WW of around 6.74 kg. Meanwhile, the FRS and SRS had a longer 11.64 vs. 11.98 w and had a higher WW of about 7.76 vs. 7.57

kg. The lifespan of sows and boars between rearing systems was an interesting issue to note, where the FRS had the most extended use of sows (5.8 years), and the 2nd-longest of boars use (3.5 years).



Picture 4: (A) semi-scavenging (pigs usually keep in the nighttime and during the main season of agriculture production); **(B) free scavenging system** (pigs are freed to roam around throughout the year)

These findings differed from other theories and research when many parameters of the reproductive performance of sows in the FRS were better than those in the CRS and SRS, particularly the litter size, BW, and WW. The exact reasoning is still unclear, but feeding and scavenging could be the first consideration that made a difference. These are due to no difference in feed ingredients among the three types of rearing systems mentioned. Farmers fed their pigs once in the morning and again in the evening with local feed sources, mainly cassava roots, rice bran, kitchen waste, and seasonal forest vegetation (HUYNH et al., 2006; PHENGSAVANH et al., 2010). One of the reasons might be that farmers could not buy high-quality feedstuffs or commercial feed for their pigs (STUR et al., 2002; KAENSOMBATH et al., 2012). At the same time, pigs in the FRS could consume the whole day, including scavenging and receiving feed from owners.

Table 7

Reproductive performance of indigenous pigs based on rearing systems

Parameters	Pig rearing systems			Mean±SD	p-value
	CRS	FRS	SRS		
Families (n)	64	41	59		
Selection age, day	148 ^a	157 ^a	178 ^b	161±55	0.009
Puberty age, day	205	213	275	211±41	0.331
First mating age, day	225	224	226	225±43	0.961

Table 7

Reproductive performance of indigenous pigs based on rearing systems (cont.)

Parameters	Pig rearing systems			Mean±SD	p-value
	CRS	FRS	SRS		
First farrowing age, day	339	338	340	330±43	0.961
Litter size, head	7.36 ^a	8.50 ^b	7.22 ^a	7.60±1.77	0.001
Litter per year	1.45 ^a	0.87 ^b	1.41 ^a	1.29±0.53	0.000
Birth weight, kg	0.70 ^a	0.79 ^a	0.69 ^b	0.72±0.23	0.085
Suckling duration, week	10.19 ^a	11.64 ^b	11.98 ^b	11.21±3.38	0.006
Weaning weight, kg	6.74 ^a	7.76 ^b	7.57 ^b	7.30±2.12	0.023
Pre-weaning mortality, %	15.91	13.00	16.93	15.45±12.41	0.839
Stillborn	0.20	0.06	0.12	0.14±0.41	0.206
Weaning estrus interval, day	46	48	50	48.34±27.04	0.664
Lifespan of sows, year	4.03 ^a	5.80 ^b	5.54 ^c	4.66±1.38	0.000
Lifespan of boars, year	3.81 ^a	3.50 ^a	2.76 ^b	3.36±1.33	0.000

^{a,b,c}: Mean in the same row with different superscripts differ significantly ($p < 0.05$); CRS = Confinement rearing system; FRS = Free scavenging rearing system; SRS = Semi-scavenging rearing system.

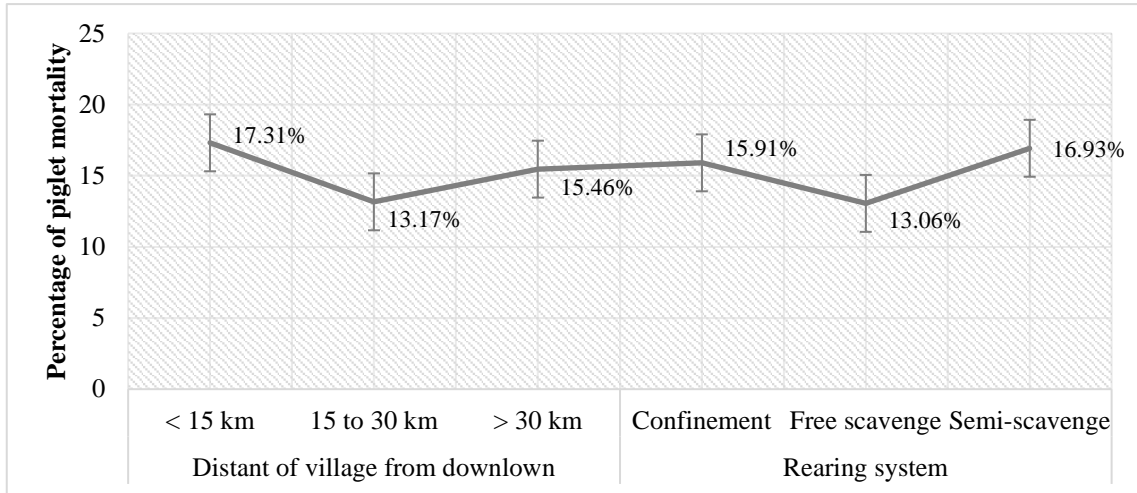
4.2.3. Effects of village's location and rearing systems on native piglet mortality

The pre-weaning mortality (PWM) was 15.45%, and no significance was observed between village locations or rearing systems. This finding was lower than PHENGSAVANH et al. (2010) conducted in the same region, which recorded almost 50% of PWM, and the study by CHITTAVONG et al. (2012) carried out in central Laos discovered approximately 20%. Our finding was lower than the report of KEONOUCHANH et al. (2012), which found between 27 and 32% of PWM in the villager's experiments on the local pig-improving system in Northern Laos. It was also slightly lower than the finding of NAKAI (2008) reported 16% of PWM of indigenous pigs traditionally reared by smallholders in Northern Thailand. In addition, our results were interesting when piglets from the FRS had the lowest PWM, about 13%, compared to 15.91% in the CRS and 16.93% in the SRS (*Figure 7*). One of presuming is farmers may lose in monitoring their sows for the first 3 d post-parturition.

Another interesting note is that the distance of villages' location did not influence piglet mortality. However, compared to piglets from clusters between 15 and 30 km (13.17%) and beyond 30 km (15.46%), the PWM of piglets born from sows raised by farmers living less than 15 km from the towns was slightly higher (17.31%). These figures

may be contrary to the findings of LEMKE et al. (2006), who found that preweaning mortality of native sows raised by smallholders in northern Vietnam ranged from 12–26%, whereas about 28–33% for those raised far away from towns.

Figure 7: The piglet mortality based on village clusters and rearing systems



Most farmers in the FRS cluster reported that their sows gave birth in the nearby forest. Some of them were not even aware that their sows had already given birth to the piglets until the sows brought their piglets back home. Farmers may not know how many piglets died before they were discovered in this case. Due to their weakness, lack of immunity, and susceptibility to being crushed by a sow, especially during the first 3 d post-parturition (DEVILLERS et al., 2011). Around 56% of mortality was estimated due to improper management during farrowing and lactation, which caused piglets to be crushed by sow and starvation. Approximately 54.26% of farmers did not keep their sows in pen before farrowing.

Additionally, more than 53.66% of farmers allow sows to give birth to piglets in the nearby forest. Therefore, most piglet mortality might occur due to poor management, especially during farrowing and early post-weaning due to new transit and improper feeding. As CAMPBELL et al. (2013) described that the early post-weaning was a critical aspect to consider for piglets' survival and growth performance because transit can increase stress, and new feed can change the function intestine of the new weaners.

4.2.4. Correlation of reproductive characteristics of indigenous pigs in Laos

The age at puberty strongly predicted a positive correlation to the first mating and first farrowing ages. Farmers cannot control the first mating of gilts, and virtually all let

the gilts be bred as soon as they attain puberty due to gilts and boars living together. On the other hand, the suckling period is estimated to negatively impact litter per year and birth weight but has a strongly positive correlation to weaning weight. The WEI was also expected to correlate with litter per year (*Table 8*). Due to the weaning procedures gradually occurring between 12 to 17 w in the traditional extensive system (COLSON et al., 2006), in some cases, farmers even do not know when it happened.

Table 8

Correlation between reproductive parameters of native pigs under small-scale conditions

	AP	AFM	AFF	LS	LPY	BW	SP	WW	MBW	WEI
AP		0.817**	0.817**	0.053	0.042	-0.010	0.048	0.015	0.137	-0.031
AFM	0.817**		1.000**	0.043	0.039	-0.030	-0.036	-0.078	0.188*	0.118
AFF	0.817**	1.000**		0.043	0.039	-0.030	-0.036	-0.078	0.188*	0.118
LS	0.053	0.043	0.043		0.021	0.232**	-0.144	-0.015	0.129	-0.124
LPY	0.042	0.039	0.039	0.021		0.142	-0.228**	-0.182*	0.126	-0.353**
BW	-0.010	-0.010	-0.030	-0.030	0.232		-0.224**	-0.171*	-0.26	-0.027
SP	0.048	-0.036	-0.036	-0.144	-0.228**	-0.224**		0.554**	-0.034	-0.090
WW	0.015	-0.078	-0.078	-0.015	-0.182*	-0.171*	0.564**		-0.138	-0.127
MBW	0.137	0.188*	0.188*	0.129	0.126	-0.026	-0.034	-0.138		0.010
WEI	-0.031	0.118	0.118	-0.124	-0.353**	-0.027	0.090	-0.127	0.010	

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); AP: Age of puberty; AFM: Age at first mating; AFF: Age at first farrowing; LS: Litter size; LPY: Litter per year; BW: Birth weight; SP: Suckling period; WW: Weaning weight; MBW: Mortality before weaning; WEI: Weaning oestrous interval.

4.2.5. Impacts of seasonal agriculture production on the reproductive performance of indigenous pigs in Laos

Almost 51% of farmers reported sows farrowed during the main season of agriculture production (MA) between June and September, approximately 24% farrowed after harvesting (AH) between October and December, and around 25% farrowed during the non-seasonal agriculture production (NA). Similarly, in the past, HM pigs and European wild boars mated in the autumn and gave birth to piglets 4 months later. In August and September, they might farrow the second time (WEBSTER, 2011; EGGERSZEGI et al., 2003; EGGERSZEGI et al., 2018). STASIAK et al. (2006) reported that the indigenous *Pulawska* pigs' fertility was higher in winter and autumn compared to other seasons. The same research team also noted that the mean length of dry *Pulawska* sows in the summer months was significantly higher than others.

It is challenging to respond to the difference ($p < 0.038$) in the mean litter per year of local pigs in Laos with regard to agricultural production seasons. Sows farrowed in the MA had the largest annual litter, followed by those farrowed in the NA and AH (1.40, 1.20, and 1.18, respectively). However, there was no difference ($p > 0.05$) in the mean litter size, birth weight, WW, and PWM of piglets among different seasons related to agricultural production. But the piglets born during the MA and AH had a marginally higher birth weight (0.73 and 0.77 kg) than those farrowed during the NA (0.68 kg). In contrast, piglets born in the MA and AH had a slightly higher mean PWM (1.23 and 1.14 heads) than those born in the NA (1.10). During these two seasons, sows were kept in pens and fed with low-quality local feed resources, which may cause one of the PWM due to starvation and be crushed by the sow due to poor management.

4.2.6. Chronic problems on reproductive performance and pig development in Laos

The chronic constraints on the reproductive performance of local pigs in Laos may include one or more of the following: (1) the quality of piglets from farrowing to weaning is very low, including weight gain and health conditions. (2) breeding cannot be controlled due to the rearing system (*Picture 5*). Gilts are bred from their first oestrous (120 to 150 d) due to gilts, and boars are not separated. (3) the farming system has not been developed yet, thus challenging to improve reproductive performance due to difficulty in management. And, (4) pigs grow with small body weight till their sexual maturity age, and it is rare to weigh > 100 kg. Therefore, improving the farming system and modifying the optimal body weight of gilts for their first mating should be the priority to enhance the development of native pig production in Laos.



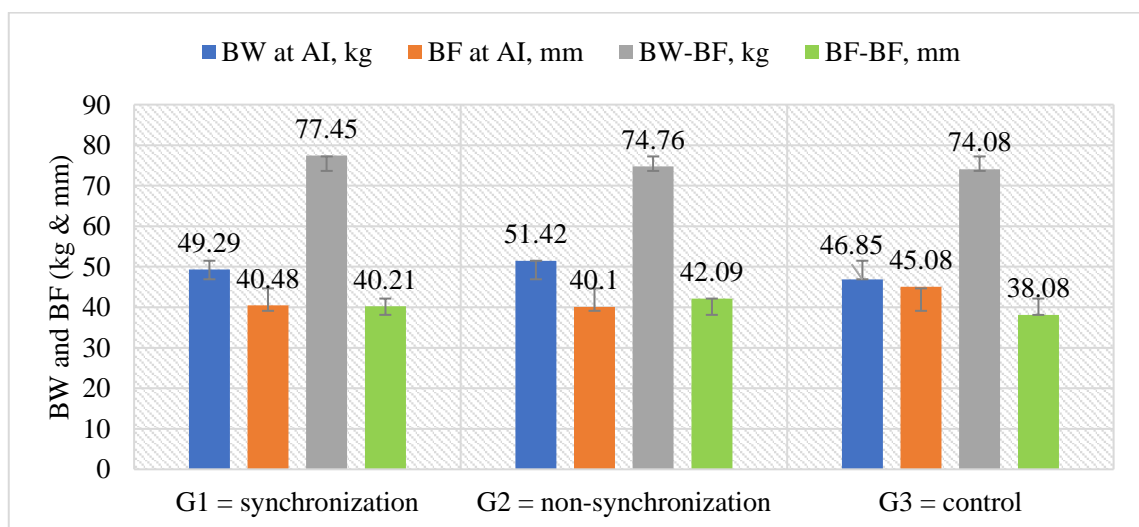
Picture 5: Uncontrolled breeding among native pigs in the traditional extensive system in rural areas of Laos (gilts did not reach 30 kg, within 5 months of age)

4.3. New strategies for improving the reproductive performance in *Moo Lath* pigs

4.3.1. Modification of the optimal body condition of *Moo Lath* gilts for first service and farrowing

The mean body weight of gilts before insemination was not significantly different ($p = 0.446$) in the studied groups. However, the body weight (BW) of the gilts in non-synchronization (G2) was slightly heavier (51.42 ± 8.81 kg) compared to 49.29 ± 6.88 kg in synchronization (G1) and 46.85 ± 3.75 kg in the control group (G3). Gilts in G3 had the thickest backfat (BF) before insemination (45.08 ± 3.81 mm), but it did not differ ($p = 0.079$) compared to those in G1 and G2 (40.48 ± 5.60 and 40.10 ± 4.79 mm). Conversely, gilts in G2 showed a thicker mean BF (42.09 ± 5.23 mm) before farrowing, compared to 40.23 ± 5.45 mm in G1 and 38.08 ± 8.17 mm in G3 (Figure 8). The average BW and BF at insemination and first farrowing were approximately 49.57 ± 7.20 kg, 41.12 ± 4.78 mm, and 75.99 ± 7.33 kg, 40.48 ± 5.87 mm, respectively. These figures did not meet our initial target of BW modification, expected to have the gilts with an average of over 50 kg at first mating. But, it was bigger than the findings of KEONOUCHANH et al. (2011), and NAFRI (2020) noted the mean weight at first mating of *Moo Lath* was about 39 kg, with BF of about 31–35 mm. The genetic limitations of *Moo Lath* gilts, in which a mature sow weighed between 47 and 61 kg (KEONOUCHANH et al., 2011), could be a factor that blocked our target for BW modification for the first insemination.

Figure 8: The body condition of the sows from the first insemination to farrowing

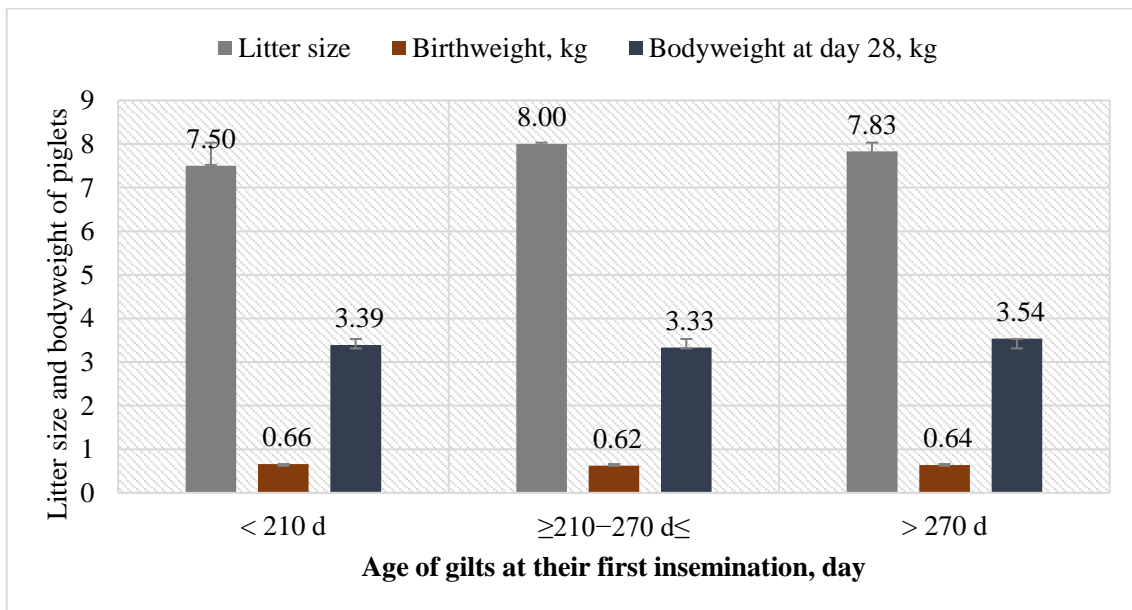


BW; BF at AI: body weight and backfat at insemination; BW-BF; BF-BF: body weight and backfat before farrowing.

4.3.2. Effects of first insemination age on reproductive performance of *Moo Lath* gilt

Age at first insemination of gilts was older than the initial target, and some gilts had already come to their fourth oestrous. That is why we decided to inseminate gilts before the expected body weight at first insemination. The average age of sows for this study was roughly 245 ± 40 d (ranging from 195 to 315 d) at first insemination and 339 d at first farrowing. There was no significant difference ($p = 0.656$) in the mean litter size and birth weight related to the age of the gilts at insemination/mating. However, the sows with age < 210 d had the smallest litter size (7.50) compared to those sows with between 210 to 270 d (8.00) and with > 270 d (7.83) at first insemination (Figure 9). In contrast, the gilts with age < 210 d at first insemination had slightly heavier birth weight (0.66 kg) compared to those born from the sows with that age between 210 and 270 d (0.62 kg), and the sows with > 270 d (0.64 kg) at first service.

Figure 9: Litter size and growth performance of piglets based on the age of gilts at first insemination or mating



< 210; ≥210–270; >270 d: age of the gilts at first insemination.

The ages of gilts at first insemination also did not show significant differences in the mean growth performance of piglets on day 28 after farrowing. Similarly, the age at first insemination did not significantly influence the stillbirth, mummified piglets, and mortality within 3 days after farrowing. Based on the present findings, further research related to *Moo Lath* gilts' age and body weight at first service is necessary. Regarding the

present results, we highlight that *Moo Lath* gilts can be mated between 195 and 240 days of age. This concept might support the report of KEONOUCHNAH et al. (2011), which indicated that the first mating of *Moo Lath* gilts was 195 days, weighing about 39 kg.

This finding is different from the traditional extensive pig-rearing system in the rural areas of Laos. Farmers rarely consider the optimum body weight or the age of gilt for the first mating. As found in our survey in northern Laos, about 88.7% of farmers told their gilts were bred soon after first oestrous, ranging from 120–150 d due to the gilts and boars were freely live together. As a result, *Moo Lath* sows produced a small litter size, poor quality piglets, low growth rate, and high mortality. In contrast, in modern pig farming, the gilts always have their first mating after the second or third oestrous cycle, with an optimum age of 233–253 d (MALANDA et al., 2019). Because the gilts need some periods (at least 210–240 d) to develop and establish the readiness of their uterine (LIBAL and WAHLSTROM, 1974), especially the maturity of the ovary. Nevertheless, the gilts' optimal body weight and age at first service may depend on different breeds. For instance, *Mangalica* gilts should have their first mating/insemination between 227–360 d of age and live weight between 100–120 kg (SZABÓ et al., 2013). Our survey also found the current operation in many HM farms, and gilts were bred at first service between 330 and 390 d, with a body weight of 108-114 kg.

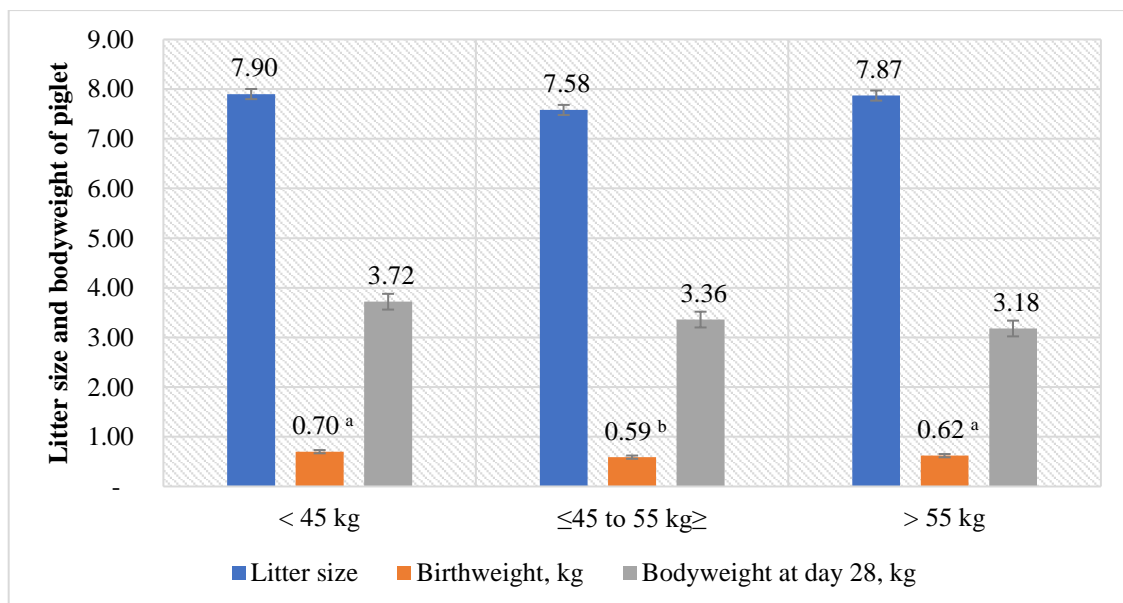
Considering the present results, the age at first mating relates to litter sizes and the birth weight of piglets. Instead of waiting until they are over 240 d old, *Moo Lath* gilts could be considered for their first mating between 210 to 240 d of age. Due to the limitation of supported data. Comprehensive scientific research about the optimal age of *Moo Lath* gilts for their first mating related to reproductive performance and longevity of sows is required. As SILVA et al. (2016) reported that indigenous pigs in Vietnam had their first farrowing at 252 d, while only 192 d old in Sri Lanka.

4.3.3. Effects of body weight of *Moo Lath* gilts on their reproductive performance

There was no difference in the mean litter size ($p = 0.799$) between groups based on the body weight of *Moo Lath* gilts at first insemination. Additionally, *Figure 10* shows that sows with a live weight of less than 45 kg at first insemination produced the largest litter size (7.90) compared to those sows with a live weight of between 45 to 55 kg (7.58) and those more than 55 kg (7.87). On the other hand, the birth weight of the piglets born from the sows with body weight ≤ 45 to $55 \text{ kg} \geq$ was lower (0.59 kg) than those born from

sows with body weight < 45 kg, and > 55 kg (0.70 and 0.62 kg, respectively). In contrast, the birth weight and growth performance on day 28 of the piglets born from sows with body weight < 45 kg were slightly significantly heavier than the other two groups. From this point, it may be presumed that the optimal body weight of *Moo Lath* gilts at first insemination could be considered a bit less than 45 kg. This assumption supports the findings of WILSON (2007) and KEONOUCHANH et al. (2011), who reported that the body weight of *Moo Lath* gilts at first mating was 30 kg and 39 kg, respectively. In one of our recordings (*Figure 12*), nearly 7% of total mortality was mummified, occurring only in a litter size greater than 8. Therefore, the optimal weight of *Moo Lath* gilts at first mating should be reconsidered, especially the capacity of their uterus.

Figure 10: Comparison of body weight at first insemination influences litter size and piglet performance



< 45 kg; ≤45 to 55 kg; > 55 kg: body weight of gilts at first insemination. ^{a,b}: Mean with the same letters do not differ ($p > 0.05$).

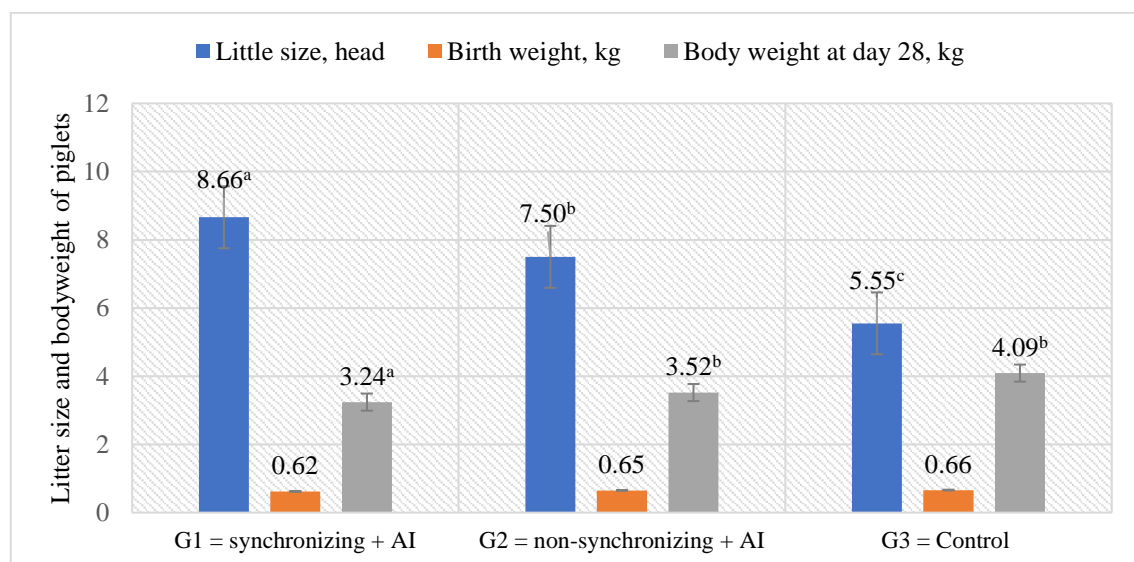
4.3.4. Effects of ES and AI on the reproductive performance of *Moo Lath* gilts

Using Altrenogest Regumate[®] for estrous synchronization (ES) might be an interesting new management method to increase the litter size of the local primiparous sows in Laos. *Figure 11* shows the primiparous sows in the synchronizing group (G1) had a larger litter size (8.66, $p < 0.001$), more than 1.16 piglets compared to 7.50 in the non-synchronizing group (G2), and more than 3.11 piglets (5.55) in the control group (G3). This finding was more than 1.16 piglets compared to crossbred piglets born from

Moo Lath sows x *Mong Cia* boar, with an average litter size of about 7.5 (MANIVANH et al., 2017). It also had more than 0.76 piglets compared to purebred *Moo Lath* sows with supplement feed and water during gestation (PHENGVILAYSOUK et al., 2018). It was bigger, nearly 4.26 piglets compared to purebred *Moo Lath* sows that were raised and fed with local feed sources in Northern Laos, with a mean litter size was only 4.4 (KEONOUCHANH et al., 2012). From this, it can be concluded that feeding and proper management during gilt development and gestation increase *Moo Lath* litter size.

Conversely, the studied groups had no significant difference in birth weight ($p = 0.804$). This might result from the limited space of *Moo Lath* gilts' uterus; it was crowded with contained more than 8 embryos. Likely, modern hyper-prolific sows are not expected to get a litter size of more than 16 per litter due to their uterus capacity and functional teats (WARD et al., 2020).

Figure 11: Litter size and growth performance of piglets between groups

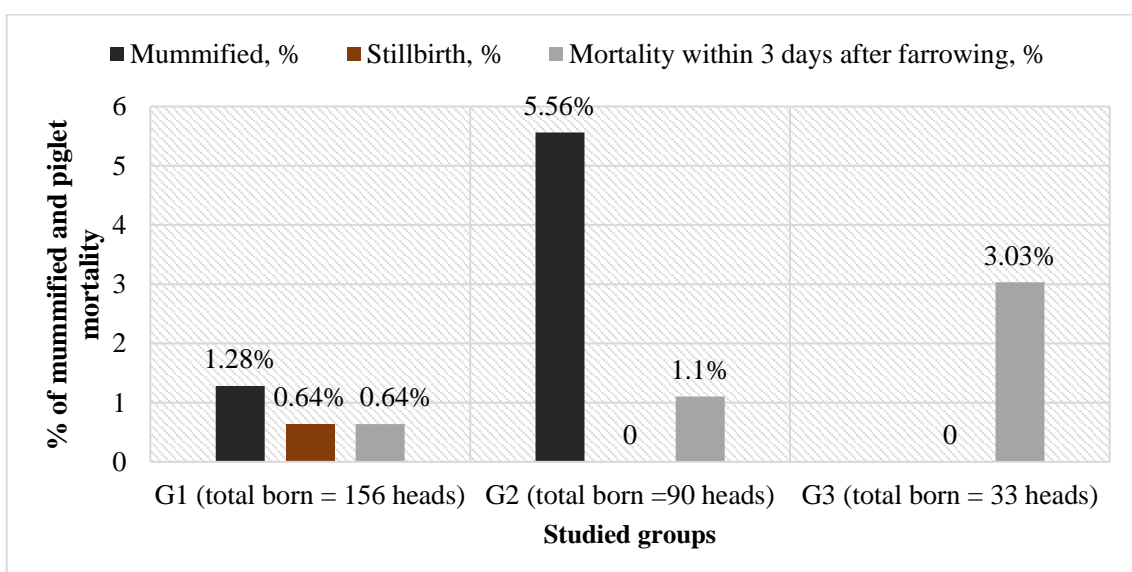


At the same time, the smallest ($p < 0.013$) mean body weight of piglets on day 28 after farrowing was found in the piglets from G1 (3.24 kg), compared to 3.53 kg born from G2 and 4.09 kg in G3. The significant difference in the growth performance of piglets in G1, G2, and G3; might be associated with the sows' milk production ability, as sows in G1 had nearly two and over three piglets than G2 and G3 sows. Unfortunately, the data regarding the amount of milk produced by *Moo Lath* sows is limited. Thus, further studies on the milk production and milk quality of *Moo Lath* are required. However, our findings showed a heavier birth weight mean (0.62 kg) than 0.46 kg, as reported by MANIVNAH et al. (2017). But this was very similar to the findings of

PHENGVILAYSOUK et al. (2018). Who noted that the average birth weight of *Moo Lath* piglets born from the sows with sufficient water supply during gestation was about 0.6 kg. Again, this might be because our and his team's approaches were similar in management. It can be assumed that feeding and managing gestating sows should be a primary consideration in improving the reproductive performance of the *Moo Lath* pigs.

Interestingly, mummified piglets were delivered only in G1 and G2, but G3 did not. It was observed that it mainly occurred in the gilts with a litter size ≥ 8 . As shown in *Figure 12*, sows in G2 had approximately 5.56% of mummified piglets and 1.28% in G1. This might be associated with the body weight of gilts at first insemination, only 49.29 kg (G1) and 51.42 kg (G2), and *Moo Lath* gilts' uterus capacity might accommodate only less than 8 fetuses. Meanwhile, G1 gilts had a mean litter size of about 8.66 and 7.50 in G2. Therefore, the uterus might not have enough space to carry more than 8 fetuses, which seldom occurs in the *Moo Lath* gilts. This hypothesis may support the observation of TUMMARUK and KESDANGSAKONWUT (2014), who found that the weight of the uterus corresponded with the body weight of the gilts but not with their age. Similar findings were made by BORGES et al. (2005), who discovered that sows with more than 12 piglets per litter had a higher chance of mummification than those with less than 10 piglets. However, RAGUVARAN et al. (2017) reviewed several reasons associated with mummified piglets, i.e. limitation of uterine space, placenta development, litter size, diseases, etc.

Figure 12: Comparison of mummified and piglets' mortality between groups



4.3.5. Pregnancy diagnosis using real-time ultrasonography

Pregnancy diagnosis using ultrasonography is novel for pig production in Laos, especially in small-scale farms. However, some commercial pig farms (in Laos) diagnose pregnancy in sows using ultrasound at weeks 5 and 7 after insemination/mating. With the results of using FarmScan® L70 Eye muscles Veterinary Ultrasound, we could identify 17 gilts, or 94.44%, from AR treatment had already got pregnant by day 28, and 1 gilt, or 5.55%, not confirmed pregnancy until day 40 after insemination. This gilt was exposed by a mature boar and re-inseminated again by day 43 after her first serviced day. However, the real reasons for this gilt's unsuccessful conception remain obscure, but ultrasound assisted us in diagnosing and identifying the non pregnant gilt on time. In contrast, all the non-synchronizing and the control group gilts were also diagnosed as pregnant in the first ultrasound scan performed on day 28 after insemination.

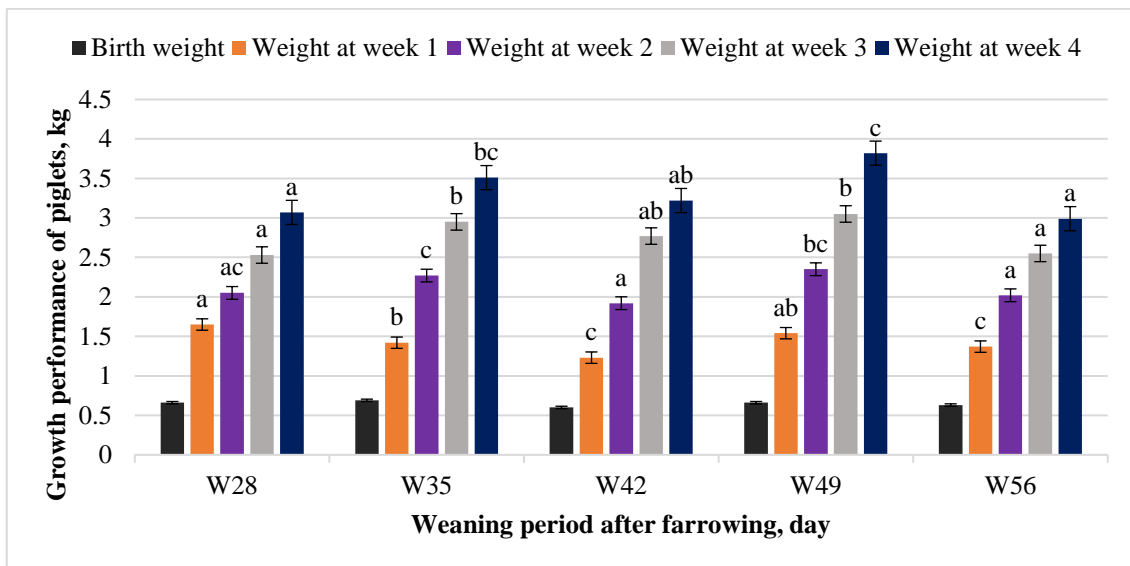
4.3.6. Effects of weaning age on growth performance of *Moo Lath* piglets

Thirty litters of CMD piglets, covering 231 piglets, were used in this study. The piglets were divided into 5 weaning groups: W28, W35, W42, W49, and W56, which weaned on days 28, 35, 42, 49, and 56 of age. To evaluate the effects of weaning age on the growth performance of piglets, including during suckling and post-weaning periods. There was no significant difference in the birth weight of the piglets ($p = 0.106$), with an average of 0.65 ± 0.15 kg. In contrast, the growth performance of piglets from weeks 1 to 4 after farrowing was significantly different ($p < 0.001$) between the studied groups (*Figure 13*). However, there was no difference in the body weight of piglets on day 28 in groups W28, W42, and W56 (3.07, 3.22, and 2.99 kg, respectively), but they were different between groups W35 and W49 (3.51 and 3.82 kg, respectively).

The average daily gain (ADG) of piglets in the first four weeks in this study varied between 107–136 g. These figures might not differ from the findings of PHENGVILAYSOUK et al. (2018), who reported *Moo Lath* piglets had an ADG of around 133 g within 6.43 w of the suckling period. Our result was nearly 1.59 times bigger than the crossbred piglets (*Moo Lath* x *Mong Cia* Vietnamese), with an ADG of about 86 g in week 4 of age (MANIVANH et al., 2017). Similarly, in one of our findings in Northern Laos, *Moo Lath* piglets got an ADG of approximately 95 g, with suckling periods of roughly 11.14 w. The present results might be slightly higher than the growth

rates of piglets raised by small-scale farmers in Northern Vietnam, which range from 67–123 g/d during the first 60 days of life (LEMKE et al., 2006). But it was smaller by 3 times compared to exotic pig breeds (Large White and Landrace) raised by small and large commercial farms in central and southern Laos. One of our findings showed that the piglets had an ADG of approximately 399 g, with a suckling period of about 4.02 w. The difference in the growth performance of piglets in the first four weeks of suckling was significant among the studied groups. A good explanation for this issue might be related to the ability of feed intake and resistance to diarrhoea infection of each piglet, especially between the 2nd to 3rd week of age when they started eating the solid creep feed.

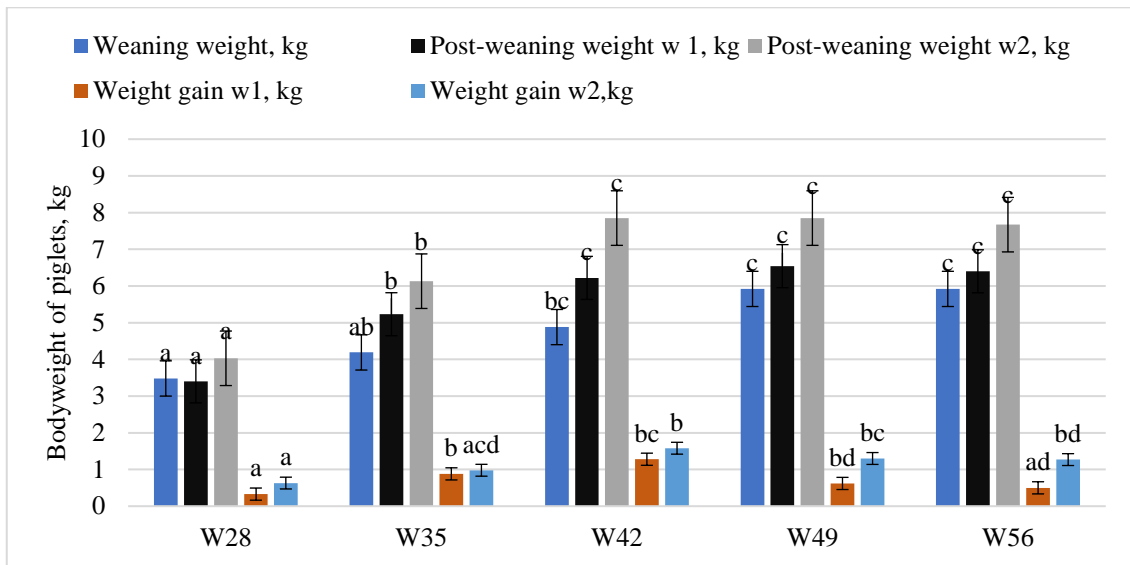
Figure 13: Live weight of piglets in the first four weeks of age



W28, W35, W42, W49, and W56: piglets were weaned on days 28, 35, 42, 49, and 56, respectively. ^{a,b,c:} Mean with the same superscripts do not differ ($p > 0.05$).

Figure 14 shows no significant difference in the mean WW of piglets in groups W28 and W35 (3.48 and 4.19 kg, respectively). Similarly, groups W35 and W42 found no difference in the WW of piglets. There was also no difference in the mean WW of the piglets in groups W42, W49, and W56 (4.88, 5.92, and 5.92 kg, respectively). The mean body weight of piglets during the 1st and the 2nd post-weaning weeks did not differ in groups W42, W49, and W56, but it differed compared to W28 and W35. Piglets from group W42 gained the highest weight gain ($p < 0.040$) in 1st week after weaning (1.28 kg), whereas piglets from groups W28 and W56 gained substantially less (0.33 and 0.50 kg). In contrast, in the 2nd week, piglets in groups W42, W49, and W56 gained 1.58, 1.30, and 1.27 kg, respectively, almost double the weight gain in groups W28 and W35.

Figure 14: Post-weaning growth performance of piglets as affected by weaning age



W28, W35, W42, W49, W56: the group of piglets were weaned at days 28, 35, 42, 49, and 56, respectively. a,b,c: Mean with the same superscripts do not differ ($p > 0.05$).

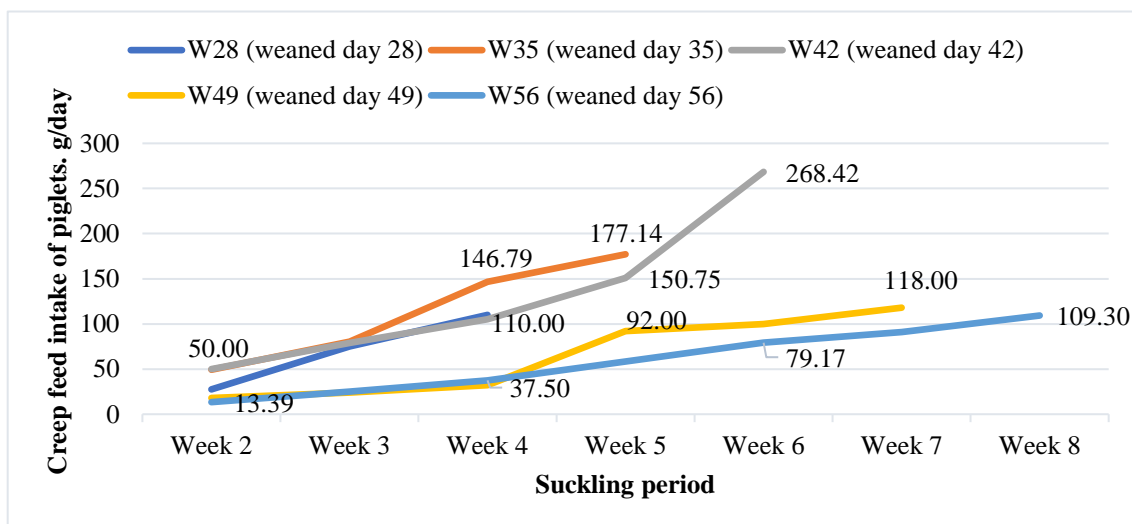
In the first two weeks after weaning, the ADG of piglets in the present study was about 139 and 164 g per day, respectively. The mean weight gain of piglets in the 1st post-weaning week did not differ between groups W28 and W56. It was presumed that weaning age did not influence post-weaning growth performance much, but management did. It relates much to weaning procedures and early weaning management (BLAVI et al., 2021). Usually, weaning creates more stress for new weaners and reduces their feed consumption (CAMPBELL et al., 2013). In contrast, the weight gain of piglets in groups W42, W49, and W56 for the 2nd post-weaning week increased almost 3 times compared to groups W28 and W35 (Figure 14). This finding supports the report of (VAN DER MEULEN et al., 2010; LEIBBRANDT et al., 1975), which described that increasing weaning age could improve feed intake and weight gain for post-weaned piglets.

4.3.7. Effects of weaning age on post-weaning feed intake of *Moo Lath* piglets

As mentioned above, growth performance and creep feed intake of piglets in this study were influenced by diarrhoea and the ability to recover after diarrhoea of the piglets. Between days 7 and 21 of suckling, most piglets were infected by bacteria and got diarrhoea, particularly after consuming solid creep feed on day 7 and chewing rice straw on the floor. Figure 15 shows the overall piglets had an average creep feed intake of about 32 g/day/piglet in the second week after farrowing. From weeks 5 to 6, the piglets consumed more creep feed, ranging from 92 to 268 g/day/piglet. Unfortunately, we could

not find any relevant study on the creep feed intake of *Moo Lath* piglets to compare with our findings. It was nearly three times less than (modern breeds) reported by MIDDELKOOP et al. (2020), which experimented at Wageningen University & Research, the Netherlands. The creep feed consumption of piglets from days 7 to 42 of the suckling period varied between 13 to 268 g/day. Our findings are also different from BRUININX et al. (2004), which found that piglets' intake of creep feed from day 11 to 28 of the suckling period varied from 24 to 690 g/day. Although, the authors used different pig breeds (Dutch Ld x Finnish Ld x Great Ysh) from our study (*Moo Lath* x *Duroc*). Another reason might be that most piglets faced serious diarrhoea from week 6 of suckling, especially in group W56, in which 5 out of 51 piglets died due to this consequence. And, it was observed that the feed consumption of piglets slowed down from week 6 of lactation.

Figure 15: Comparison of the creep feed intake of piglets between groups

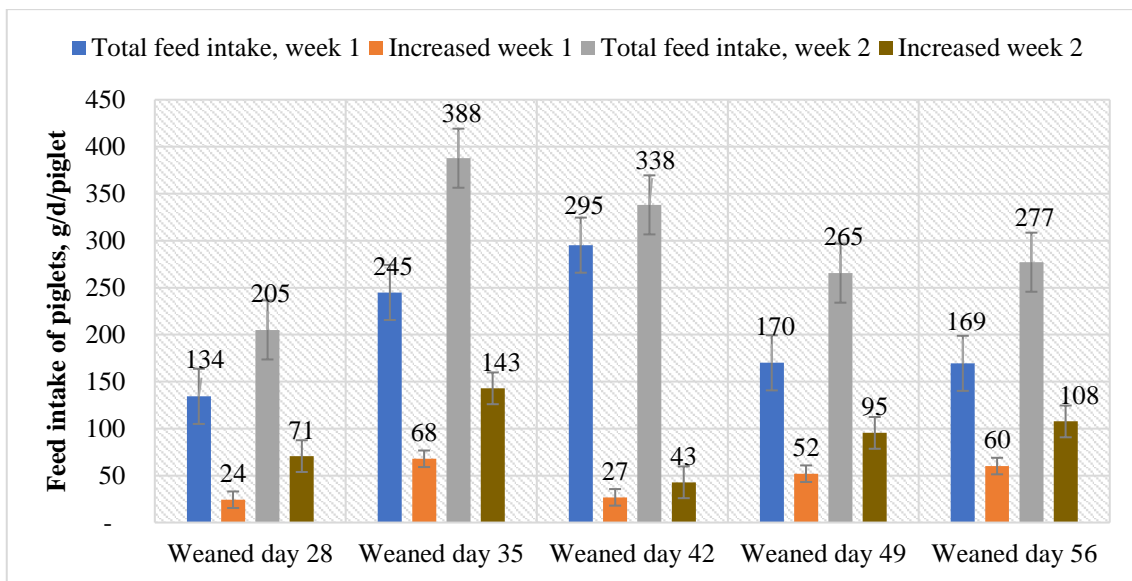


Due to the present study was influenced by diarrhoea infection in both suckling and post-weaning periods. The average feed intake of piglets one week before weaning was approximately 165 g/day, ranging between 110 to 283 g/day. Their creep feed consumption was highly diverse, which might be one factor influencing the intake of creep feed by diarrhoea infection.

Figure 16 demonstrates the feed consumption of post-weaning piglets based on weaning age. The total feed intake in the 1st post-weaning week varied from 134–295 g daily. These findings might not differ from the report of MAVROMICHALIS (2018). Who claimed that, in case of good management, piglets weaned between 19 to 23 d

ingested feed in the 1st post-weaning week, ranging from 200–250 g per day or up to 300 g. Our findings were nearly two times lower than the report of MIDDELKOOP et al. (2019b), who stated the feed consumption of piglets between days 0–5 after post-weaning ranged from 286–324 g per day. In our case, we found piglets in group W28 had the lowest total feed consumption per day, while the highest was found in group W42. Interestingly, the total feed intake of piglets from groups W49 and W56 in the 1st post-weaning week was lower than those in groups W35 and W42.

Figure 16: The total feed intake of post-weaning piglets (g/day/piglets)

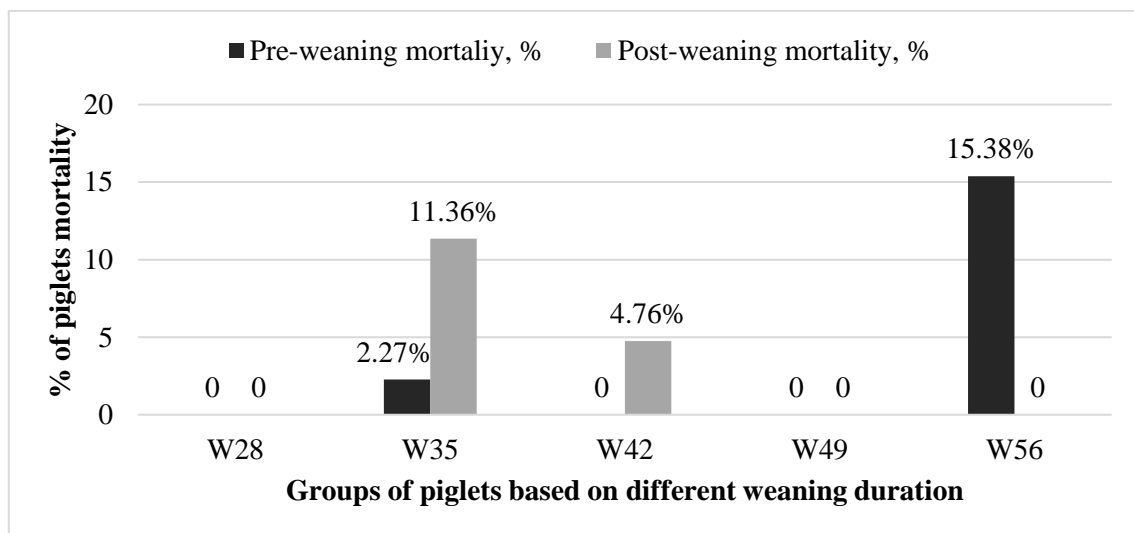


Although, in the second week of post-weaning, the piglets from each group consumed feed almost double compared to their first week. Still, the piglets from groups W49 and W56 consumed less feed than those from groups W35 and W42 (265 and 277 vs. 388 and 338 g, respectively). In contrast, the piglets from group W42 consumed feed increased by only 27 g in week 1 and 43 g in week 2 of post-weaning, different from other groups. Meanwhile, the piglets from group W35 had the highest feed intake, and it increased from the 1st and 2nd week after weaning. From this point, it might be said that the weaning age did not influence the total feed consumption of the piglets during 1st post-weaning week, but the proper management did. As found in this study, some piglets got chronic diarrhoea from week 2 of suckling and became worst after week 6 when the piglets were bigger while the lactating pen retained the same space. This is because of improper pen design, which is difficult to clean.

4.3.8. Effects of weaning age on *Moo Lath* piglet mortality

The average mortality of piglets in this study was approximately 6.93% of live-born piglets (231 piglets), including 3.90% in pre-weaning mortality and 3.03% in post-weaning mortality. When specifically observed, *Figure 18*, the highest pre-weaning mortality was found in the piglets from group W56, with around 15.38%, died between weeks 7 and 8 of the suckling period and approximately 2.27% in group W35. In contrast, the highest post-weaning mortality was found in piglets from group W35, with about 11.36% of total live born and 4.76% in piglets from group W42. This study did not observe any piglets mortality in group W28 and piglets in group W49.

Figure 18: Comparison of piglet’s mortality based on different weaning duration



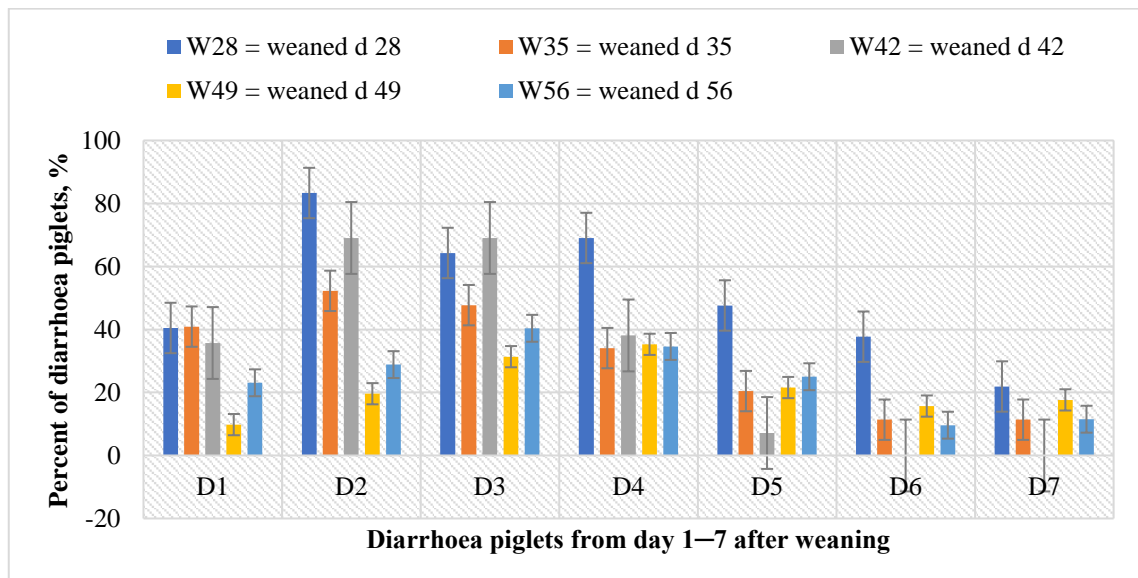
W28, W35, W42, W49, and W56: Weaned piglets at days 28, 35, 42, 49, and 56, respectively.

These findings were significantly different compared with the traditional extension of the pig-rearing system in rural areas of Laos, in which the preweaning mortality ranged from 20–50% (PHENGSAVANH et al., 2010; CHITTAVONG et al., 2012; KEONOUCHANH et al., 2012; MANIVANH et al., 2017). And, it was slightly lower than one of our findings, which was approximately 11.24% of pre-weaning mortality of piglets in small and large commercial farms in central and southern Laos. Again, improper pig barn design, which made cleaning more difficult, should be blamed for the current piglet mortality in this study. Thus, improving the proper pig barn for *Moo Lath* sows might be more cost-effective than other expenditures. As SHRESTHA et al. (2003) indicated a high chance of increasing the performance of Nepalese Pakhribas pigs under small farmers’ conditions by improving pig housing.

4.3.9. Effects of weaning age on diarrhoea infection of post-weaning *Moo Lath* piglets

Early post-weaning diarrhoea infection was a severe issue that blocked the growth performance of piglets in the present study, particularly on days 2 to 3 after weaning. However, in general, there was no difference ($p = 0.401$) in the percentage of diarrhoea piglets in the studied groups. But there was a significant difference ($p < 0.05$) when specifically checked each day within the first post-weaning week, especially days 2 and 3. *Figure 19* shows approximately 83.33% on day 2 and 64.29% on day 3 of the total piglets in group W28 got diarrhoea. Meanwhile, groups W49 (19.6 and 31.37%) and W56 (28.85 and 40.39%) were less infected. Though, the percentage of diarrhoea explored in the piglets between groups W28 and W42 did not differ and was very close to each other on days 2 and 3. But, the piglets in group W42 appeared to recover faster. Almost all piglets from each studied group had no new diarrhoea after day 10 of weaning. A good reason to address this issue might be that all piglets had already become familiar with their new environment in the nursery pen and were no longer stressed from abrupt weaning in week 2. Another consideration might be that the nursery pen has enough space (12 m^2) for the new weaners compared to the lactating pen, which is only 3 m^2 . Due to currently no scientific studies regarding the barns and pens of *Moo Lath* pig in Laos. Therefore, future studies in housing and pens related to *Moo Lath* piglets' performance are required to clarify this unclear information.

Figure 19: Comparison of the diarrhoea piglets' percentage.



D1, D2, D3, D4, D5, D6, D7: day 1, 2, 3, 4, 5, 6, and day 7 after weaning.

Bacteria-infected piglets in all studied groups were mainly caused by *Escherichia coli* (ssp.) infection covering 100%, *Enterobacter* (ssp.) 80%, and *Klebsiella* (ssp.) covering 40% of total diarrhoea piglets. Due to the scarcity of data on piglet diarrhoea in Laos, it was difficult to find any evidence to compare these findings. According to the actual observation, the appropriate lactating pen should be taken into consideration to improve or prevent diarrhoea in *Moo Lath* piglets. As used in the present study of about 1.5 x 2 m or 3 m² per sow, it seemed insufficient space for a *Moo Lath* sow to raise 8–9 piglets with over 5 weeks of lactation.

Briefly, the improper housing design that makes it difficult in cleaning procedures may be blamed for the piglets' diarrhoea infection in this study. Additionally, it managed the restricted space for piglets, especially after their first six weeks when they needed more space. Therefore, optimal housing should be the priority for further studies to address diarrhoea infection and improve the growth performance of *Moo Lath* piglets.

4.3.10. Effects of supplementing dried green banana in the diet on reducing *Moo Lath* piglets' post-weaning diarrhoea

To study the effects of supplementing 10% dried green banana in the piglets' diet 3 days pre-and post-weaning on reducing diarrhoea in piglets. 75 piglets were used in the study and divided into 2 groups (30 piglets = supplement, and 45 piglets = not supplementing dried meal green banana in diet. Approximately 79.29% of total piglets in group B got diarrhoea infection after weaning, and 57.14% occurred within the 1st post-weaning week. Meanwhile, 40% of group A piglets got diarrhoea in the 1st-week and no new infection in the 2nd week. However, based on the current findings, we are unable to determine the precise causes of this variation or how piglets' biology altered as a result of ingesting diets that included dried green bananas. But the tannins or tannic acid contained in the unripe banana (119.2 mg/g sample; ISHAK et al., 2020) might play a role in inhibiting or mitigating bacterial activities in the intestine of the piglets. This hypothesis might support the findings of GIRARD et al. (2018) discovered that 50% of post-weaning piglets had reduced diarrhoea and duration by supplementing with 1% chestnut extract containing 54% hydrolyzable tannins. From this point, the optimal proportion and duration of providing dried green bananas to post-weaning *Moo lath* piglets still need further studies due to the other side effects of tannic acid. It can decrease animal feed intake, growth rate, and protein digestibility (CHUNG et al., 1998).

4.3.11 Effects of lactation length on *Moo Lath* primiparous sow's body conditions and post-weaning performance

This study involved 30 *Moo Lath* primiparous sows, and divided into 5 weaning groups: W28, W35, W42, W49, and W56, weaned on days 28, 35, 42, 49, and 56, respectively. Each group contained 6 sows, and each was kept in pen (1.5 x 2 m) in the opened band with a concrete floor. The study was divided into two phases: 1st phase started from day 110 of gestation (before farrowing) until weaning, and 2nd started from weaning to 1st service of each sow. *Table 9* shows the mean body weight of gilts before farrowing was 76.22±9.09 kg, and the heaviest (89.08 kg) was found in sows group W56. Meanwhile, the thinnest BF of gilts before farrowing was observed (41.52 mm) in group W42. There was no significant difference in the loss of body weight ($p = 0.894$) and BF ($p = 0.511$) of the sows after farrowing between the studied groups. Similarly, there was no difference ($p = 0.179$) in weight loss at weaning time, while BF ($p < 0.003$) was. It was more severe in the late weaning sows, especially in sows weaned on days 49 and 56.

Table 9

The BW and BF thickness of the sows changes from farrowing to weaning.

Parameters	Weaning age (day)					Mean±SD	P-value
	W28	W35	W42	W49	W56		
No. of sows	6	6	6	6	6		
BWF, kg	70.46 ^a	74.08 ^a	75.38 ^a	72.12 ^a	89.08 ^b	76.22±9.09	0.000
BFF, mm	48.62	45.95	41.52	46.87	52.05	47.00±6.69	0.082
WLF, kg	11.99	13.38	13.08	12.36	11.17	12.39±3.93	0.894
BFLF, mm	5.22	8.62	9.82	4.58	6.64	5.63±3.34	0.511
BWW, kg	58.46 ^a	60.70 ^a	62.30 ^a	59.75 ^a	77.90 ^b	63.82 ±10.31	0.001
BFW, mm	43.40 ^{ace}	37.33 ^e	31.70 ^b	42.28 ^{ace}	45.61 ^{dc}	40.06±7.63	0.005
BWLW, kg	17.51	23.98	17.73	20.99	24.58	20.95±6.54	0.179
BFLW, mm	5.96 ^a	8.66 ^{ab}	8.01 ^{ab}	12.38 ^{bc}	15.14 ^c	8.10±7.01	0.034

W28, W35, W42, W49, W56: sows weaned on days 28, 35, 42, 49, and 56, respectively. BWF, BFF: body weight and backfat of sow before farrowing; WLF, BFLF: weight and backfat lost 1 week after farrowing; BWW, BFW: body weight and backfat at weaning; BWLW, BFLW: body weight and backfat lost at weaning. ^{a,b,c,d}: Means in the same row with the same superscripts do not differ ($p > 0.05$).

The largest body weight loss (24.58 kg) at weaning was found in group W56 sows; the smallest (17.51 kg) was observed in group W28 sows. Similarly, the largest BF loss

($p < 0.034$) was observed in the group W56 sows (15.14 mm). This differs significantly ($p < 0.05$) with group W28 sows (5.96 mm). Conversely, it was not the case ($p > 0.05$) if compared to sows from groups W35, W42, and W49 (8.66, 8.01, and 12.38 mm, respectively). Group W35 sows had the most significant weight loss of around 32%, while 25% in W28, 24% in W42, 29% in W49, and 28% in sows from group W56. In contrast, BF loss was observed in over 29% of sows from group W56, 27% in W49, 19% in W35 and W42, and over 12% in sows from group W28. Group W56 sows lost over 7 kg of body weight compared to those in group W28. Over 9 mm of BF was lost at the weaning in the group W56 sows compared to those in group W28. From this point, it might be said that the lactation length influenced the body conditions of *Moo Lath* primiparous sows.

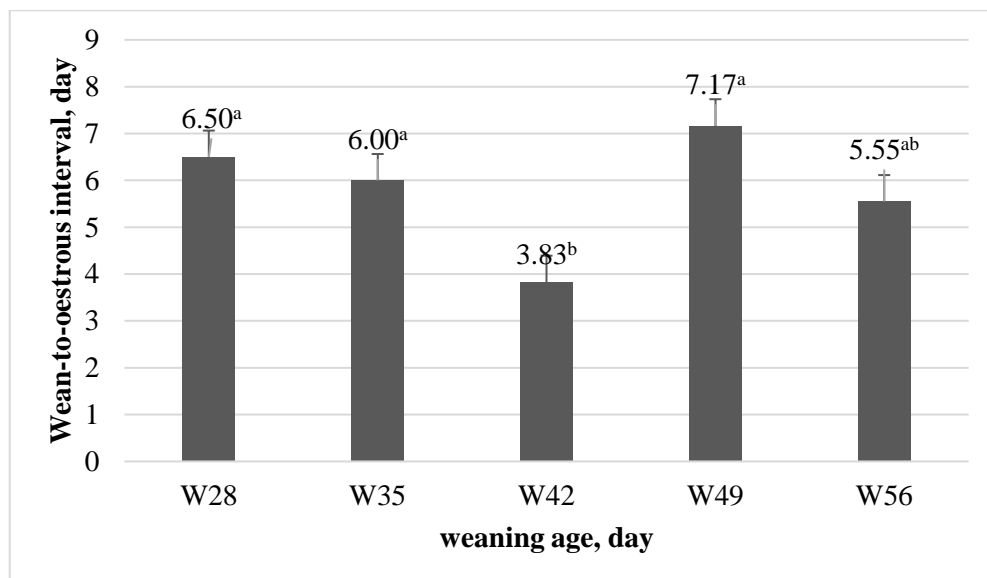
However, currently a lack of data on the body conditions of *Moo Lath* primiparous sows related to their reproductive performance. According to the direct observation, we suspected that (but need to clarify by an intensive study) *Moo Lath* sows did not seem to have much milk left after day 42 of lactation. This observation might correspond to KYRIAZAKIS and WHITTEMORE (2006) and NEILL and WILLIAM (2010), who explained that modern sows reach their peak of milk production on day 21 after farrowing when they can produce milk between 10 to 12 kg/day. By the way, the amount of milk production was controlled by the genetics of the individual's breed (QUESNEL et al., 2015), and influenced by the energy level supplied (NOBLET and ETIENNE, 1986).

The present results show that the body weight of *Moo Lath* primiparous sows gradually decreased from week 4 (12%) and became more severe after week 7 (26%) of lactation. But, this loss did not find an adverse result on the first service conception of sows after weaning, opposite to THAKER and BILKEI (2005) and COZANNET et al. (2018). Who found that modern sows with a body weight loss between 19 to 25 kg or around 10% during lactation risk losing conception for the first service after weaning. Another consideration concerns the lactation pen (3 m²) used in this study, which may be insufficient for a *Moo Lath* lactating sow with 7 or 8 piglets. Especially when they are older than 6 w, it was estimated that piglets created more stress on the sow. It might be one of the reasons why the body conditions of sows were found to be more severe in weeks 7 and 8 of lactation. Therefore, the appropriate design of the lactation pen dimensions still needs further intensive study related to lactation length of *Moo Lath* sow.

The present results found that the weaning-to-oestrous interval (WEI) of *Moo Lath* primiparous sows varied between 3 and 9 d after weaning, averaging about 5.80 ± 1.76 d

(Figure 20). There was a significant difference ($p < 0.007$) in the WEI of sows between the studied groups. The sows in group W49 had the longest mean WEI, while the shortest was observed in group W42 (7.17 vs. 3.83 d). The reason for a significant difference in WEI between sows from groups W28, W35, W49, and W56 was unclear in this study. In contrast, it was different in the WEI of the sows from group W42 compared to those in groups W28, W35, and W49. However, this study did not differ in the first service conception rates after weaning. We recommend further studies regarding lactation length on *Moo Lath* sows' reproductive performance are required due to our findings might be contrary to LEVIS (1997), who reported the longer length of lactation decreased farrowing rate and decreased consequence of litter size.

Figure 20: Comparison of the WEI of *Moo Lath* primiparous sows due to the weaning age



W28, W35, W42, W49, W56: sows weaned on days 28, 35, 42, 49, and 56, respectively. ^{a,b}: Means with the same superscripts do not differ ($p > 0.05$).

Sows in group W42 had the shortest mean WEI (3.83 d), while sows in group W49 had the longest (7.17 d). It might be because most sow's uterus is already well-established after 28 d post-partum, as described by KYRIAZAKIS and WHITTEMORE (2006). On the other hand, in this study, those sows with weaning on day 49 post-partum were at the point facing more serious body conditions. It would be reasonable to point out that sows need more time to repair their body conditions. As THAKER and BILKEI (2005) discovered, when sows lose around 16–20% of their body weight during lactation, their WEI increases by 1 to 2 d compared to those lost < 5%. More adversely, the primiparous

sows would increase the WEI up to 31.75 d if their backfat thickness was thinner than 18 mm or lost more than 21% during lactation (ŠKORJANC et al., 2008).

4.3.12. The optimal age for creep feeding on growth performance of *Moo Lath* piglets

One hundred and fifteen (115) piglets from 16 litters were used in this study and were divided into 3 groups (CF7, CF10, and CF14) based on different days of introducing the creep feed (7, 10, and 14 d after farrowing). This study aimed to evaluate the effects of different starting of creep feed to *Moo Lath* piglets on their growth performance, including the suckling and early post-weaning periods. The difference in the mean birth weights ($p < 0.000$) of piglets between groups (CF7= 0.65, CF10 = 0.52, and CF14 = 0.69 kg, respectively). It might be one of the most important reasons for responding to a significant difference in the growth performance of piglets in the 1st and 2nd weeks ($p < 0.000$). *Table 10* showed an interesting point to note: piglets in group CF10 gained 1.52 times more in week 3 (2.68 kg) compared to their 2nd week (1.77 kg), while piglets in group CF7 gained 1.31 times (2.08 kg) and 1.30 in group CF14 (2.27 kg). The ADG was roughly 155 g per day in group CF7 piglets, 145 g in CF10, and 140 g in CF14 piglets. It means that a delay of 3 to 4 days of providing creep feed would affect or slow down the growth performance of *Moo Lath* piglets by around 5 to 10 g per day. With this result, we strongly recommended promoting a creep feed for *Moo Lath* piglets from day 7 to 10 after farrowing. This suggestion supports the recommendation of several authors (EASTWOOD, 2018; YAN et al., 2011; LEE and KIM, 2018), who advised that creep feed should be provided to piglets from 1-week post-farrowing.

In contrast, there was a significant difference in post-weaning weight in weeks 1 & 2 ($p < 0.014$ and $p < 0.001$). Interestingly note is, the most significant weight gain in the 1st-week of post-weaning ($p < 0.000$) was found in group CF7 piglets (1.02 ± 0.61 kg), compared to 0.38 ± 0.33 kg in group CF10, and 0.88 ± 0.72 kg in group CF14 piglets. However, the group CF14 piglets gained (0.98 ± 0.77 kg) slightly better ($p = 0.079$) in 2nd post-weaning week, compared to 0.95 ± 0.51 kg in group CF7 and 0.69 ± 0.23 kg in CF10. On average, the group CF7 piglets gained approximately 146 g per day in the 1st post-weaning week, around 54 g in CF10, and 126 g in CF14. Meanwhile, the group CF7 piglets gained around 136 g per day in the 2nd post-weaning week, 99 g in CF10, and around 140 g in CF14. These findings were 2 times less than the ADG of modern pig breeds, in which many authors reported that the suckling and early post-weaner piglets

always gained ranged from 250–300 g per day or more (HEO et al., 2018; MUNS and MAGOWAN et al., 2018).

Table 10

The growth performance of piglets based on different ages of giving the creep feed

Parameters	Day of giving creep feed after farrowing			p-value
	CF7	CF10	CF14	
Number of piglets, head	53	48	48	
Birth weight, kg	0.65±0.16 ^a	0.52±0.06 ^b	0.69±0.15 ^a	0.000
Body weight week 1, kg	1.52±0.30 ^a	0.90±0.22 ^b	1.42±0.32 ^a	0.000
Body weight week 2, kg	2.08±0.37 ^a	1.77±0.31 ^b	2.27±0.54 ^c	0.000
Body weight week 3, kg	2.77±0.37	2.68±0.59	2.96±0.81	0.162
Body weight week 4, kg	3.57±0.68	3.58±0.76	3.51±1.27	0.942
Weaning weight, kg	4.66±1.02	4.36 ±0.87	4.19±1.66	0.241
Post-weaning weight week 1, kg	5.66±1.05 ^a	4.74±0.83 ^b	5.22±1.81 ^{ab}	0.014
Post-weaning weight week 2, kg	6.63±1.14 ^a	5.43±0.82 ^b	6.20±1.82 ^a	0.001
Weight gain week 1, kg	1.02±0.61 ^a	0.38±0.33 ^b	0.88±0.72 ^a	0.000
Weight gain week 2, kg	0.95±0.51	0.69±0.23	0.98±0.77	0.079

CF7, CF10, CF14: group of piglets the given creep feed at day 7, 10, and 14 after farrowing. ^{a, b, c}: Mean in the same row with the same superscripts do not differ ($p > 0.05$).

4.3.13. The sex ratio, birth weight, and growth performance of *Moo Lath* piglets

This study covered 20 litter of the second parities of *Moo Lath* sows, with 149 piglets. Approximately 50.26% of piglets were born as males, and the other 49.74% were females. There was no difference ($p = 0.171$) in birth weight between male and female piglets (0.63±0.14 vs 0.62±0.16 kg). Opposite to the findings of EMERY et al. (2018) reported that male piglets were born marginally heavier than females (1.54 vs 1.36 kg). The pre-weaning and weaning weight of male and female piglets was also not different ($p > 0.05$). However, *Figure 21* shows the average weaning weight of male piglets was slightly higher than females (4.26±1.22 vs 4.23±1.13 kg). Interestingly, the female piglets had a marginally higher ($p > 0.05$) body weight at 1st and 2nd week of post-weaning (4.83 vs 4.75 kg and 5.82 vs 5.56 kg, respectively). Similarly, the weight gain of female piglets in the 1st and 2nd week was also slightly higher than male piglets (0.55 vs 0.48 kg and 0.98 vs 0.79 kg, respectively). These findings were contrary to KEONOUCHANH (2018), which reported that NongTaenh black sows (CMD x CMD) gave birth to about

40% of males and 60% of female piglets. The same author also reported that the average birth weight of male piglets was around 1.17 kg, while the females were about 1.16 kg. It was also different from BOCIAN et al. (2012), who found that the two hybrids (Poland LW x Poland LD) gave birth to 54.89% of females and 45.11% of male piglets.

Figure 21: The growth performance of Moo Lath piglets based on different sex



This study found the ADG from day 1 to 35 of male and female piglets was approximately 116 g per day. This figure is slightly bigger than NongTaeng black pig, which was around 99 g per day (KEONOUCH, 2018). However, the growth performance of female piglets after weaning was slightly higher. For example, the ADG of female and male piglets in their 1st post-weaning week was 78.57 vs 58.57 g, while about 140 and 113 g per day in the 2nd post-weaning week. Approximately 6.67% of total piglets' mortality, including 3.08%, occurred in pre- and 3.59% in post-weaning periods. Around 4.10% of total mortality was female piglets. The actual causes of this mortality were unknown or unclear to provide the correct response. As these results, additional research on different sex proportions of *Moo Lath* piglets regarding their growth performance, including fattening and the piglets' mortality, is required.

4.4. Effects of birth weight on age at puberty and first mating and reproductive performance of crossbred CMD gilts

Eighteen (18) crossbred *Moo Lath* x *Duroc* (CMD) gilts were selected from our first experiment. They were divided into three groups based on birth weight after puberty. Group A (gilts born with <0.7 kg), group B (gilts born $\geq 0.7-0.9$ kg \leq), and group C (gilts

born with >0.9 kg). This study aims to evaluate the effects of birth weight on the ages at puberty and first mating, including the body condition of the CMD gilts. 15 purebred *Moo Lath* (PML) gilts were also used in this study to compare their morphologies. *Table 11* shows the birth weight of CMD gilts did not influence ($p = 0.126$) their age at puberty, with an average of about 137.47 ± 10.07 d (ranging from 122–158 d). The gilts in group A showed puberty slightly earlier than those in groups B and C (131.86 ± 8.32 , 142.75 ± 13.57 , and 142.00 ± 3.56 d, respectively). Similarly, there was no significant difference in the mean body weight ($p = 0.826$) at puberty (31.35 ± 5.44 kg). The birth weight was not apparent whether it influenced body weight at puberty. The gilts in group A had 30.62 ± 5.09 kg of mean body weight at puberty, while those in group B had 32.85 ± 8.63 kg, and gilts in group C had 31.13 ± 2.73 kg.

In contrast, the birth weight of CMD gilts might influence the BF at puberty and first mating ($p < 0.039$ and 0.031 , respectively). The larger birth weight gilts showed a thicker backfat at puberty than those with smaller birth weights. Gilts in group C had a significantly thicker BF than those in group A at puberty and first mating (44.69 vs. 35.14 mm and 42.93 vs. 36.60 mm, respectively; *Table 11*). However, the optimal body condition and age of CMD gilts at first mating are not clear, but in this study, gilts were bred by a local boar at their 3rd or 4th oestrous cycling. The mean age at first mating was 193.27 ± 16.71 d (168–229 d), with a body weight of about 39.69 kg and 38.18 mm of backfat thickness.

Table 11

Ages at puberty and first mating and body condition of CMD gilts

Parameters	Gilts based on birth weight			Mean±SD	p-value
	A	B	C		
Number of gilts	7	6	5		
Age at puberty, day	131.86	142.75	142.00	137.47 ± 10.07	0.126
Body weight at puberty, kg	30.62	32.85	31.13	31.35 ± 5.44	0.826
Backfat at puberty, mm	35.14 ^a	43.28 ^b	44.69 ^b	39.86 ± 7.12	0.039
Age at first mating, day	195.57	198.00	184.50	193.27 ± 16.71	0.493
Body weight at first mating, kg	36.60	41.85	42.93	39.69 ± 5.91	0.162
Backfat at first mating, mm	32.66 ^a	41.35 ^{ab}	44.66 ^b	38.18 ± 8.29	0.031

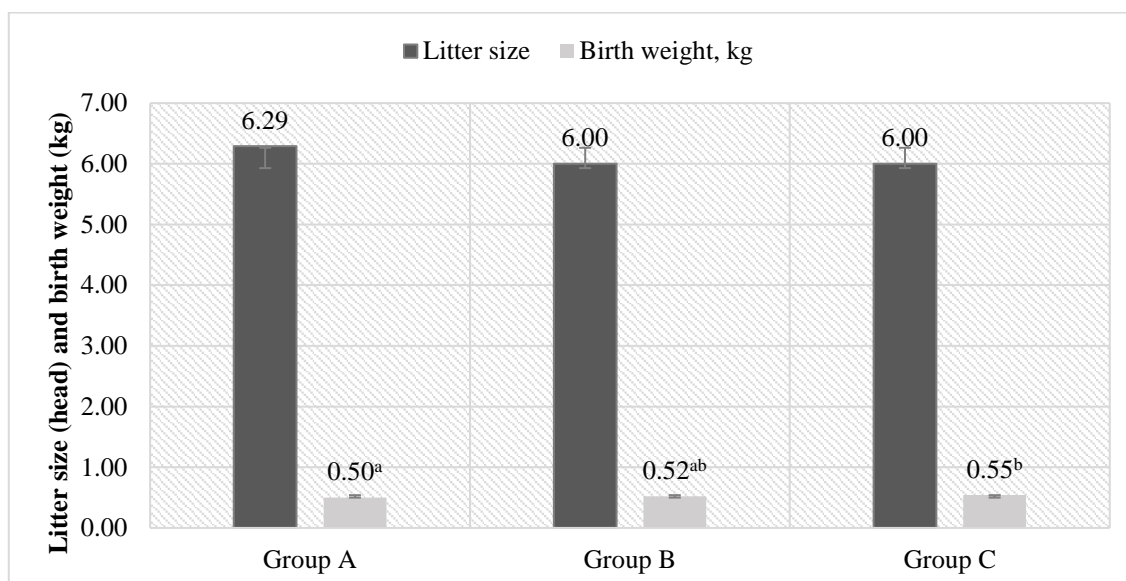
A, B, C: groups of gilts based on their birth weight with < 0.7 , $\geq 0.7-0.9$, and > 0.9 kg, respectively. ^{a,b,c}

Means in the same row with the same letters do not differ ($p > 0.05$).

These findings might not differ from PML reared by small-scale farmers in rural Laos, with about 195 d, ranging from 180–210 d, with around 39 kg of live weight at first mating (KEONOUCHANH et al., 2011). It might be slightly younger than NongTaeng back pig (CMD x CMD), which obtained puberty at 203 d (73.60 kg) and 226 d (80.30 kg) at first mating (NAFRI, 2020). The age at first mating of CMD gilts was also lower than other indigenous pig breeds in the ASEAN countries. For instance, the *Mong Cai* Vietnamese pig obtained puberty at 210 d (ranging from 180–240 d) with a body weight of about 35 kg (DANG-NGUYEN et al., 2010). It might be higher than native pig breeds reared by small-scale farmers in Timor East, where gilts reached puberty at 179 d and 275 d for their first mating (NORONHA et al., 2017). *Xishuangbanna* pigs in Southwestern China, which might be one of the *Moo Lath* ancestors, reached their first farrowing at the age of about 435 d (RIEDEL et al., 2014). This means it might be older, over 2 times the age at first mating, compared to our study. In contrast, it differed from European indigenous pig breeds, especially in the optimal age for their first mating. For example, Hungarian *Mangalica* gilts obtained puberty at approximately 210–240 d (EGERSZEGI et al., 2018), but most farmers would not allow them to be bred before 270 d of age or less than 90 kg of live weight at first mating (SZABÓ et al., 2013). Spanish Iberia pigs are another famous European indigenous pig breeds, which came to its first farrowing around 398 d, ranging from 300–495 d (NIETO et al., 2019).

The birth weight of CMD gilts did not influence their litter size ($P = 0.826$). However, *Figure 23* shows the mean litter size of gilts in group A was 6.29 ± 0.76 , marginally larger than those in groups B and C (6.00 ± 0.82 and 6.00 ± 1.16 , respectively). These figures might be opposite to the report of MAGNABOSCO et al. (2016), who concluded that gilts with less than 1 kg of birth weight produced less in the total born piglets than those born with heavier birth weight. On the other hand, the birth weight of CMD gilts influenced the birth weight of their offspring ($P < 0.042$). The mean birth weight of piglets born from the gilts in group C was 0.55 ± 0.33 kg, which was slightly heavier than those born from the gilts in groups A and B (0.50 ± 0.03 kg and 0.52 ± 0.3 kg, respectively). Although, there was no much difference in the birth weight of piglets born among the groups. But the growth performance or daily weight gain from birth to weaning might be more substantially different, as de ALMEIDA et al. (2014) described.

Figure 23: Comparison of the litter size and birth weight based on the gilts' birth weight

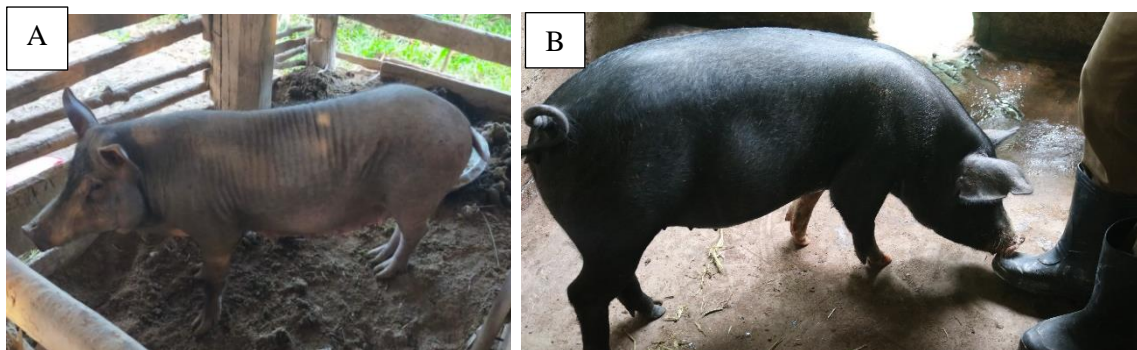


Group A, B, C: groups gilts based on their birth weight with < 0.7 , $\geq 0.7-0.8 \leq$, and > 0.9 kg, respectively. ^{a,b}: Means with the same superscripts do not differ ($p > 0.05$).

The unclear influence of the birth weight of piglets in this study was assumed to be associated with two factors. The first factor *Moo Lath* sows hardly produced piglets with over 1 kg of birth weight; it usually varies from 0.5 to 0.7 kg. The second component could be associated with the body weight of the CMD gilts at first mating, with an average weight of 39.69 ± 5.91 kg in this study. Especially, the mean body weight of gilts at first mating in group A was only 36.60 kg. The capacity of their uterus might not have enough space to hold six or seven fetuses, which birth weight might have an impact. Due to a lack of information regarding Lao indigenous pig breeds or CMD gilts. All studies related to the performance of Lao indigenous pigs, including the CMD gilts and sows, are required.

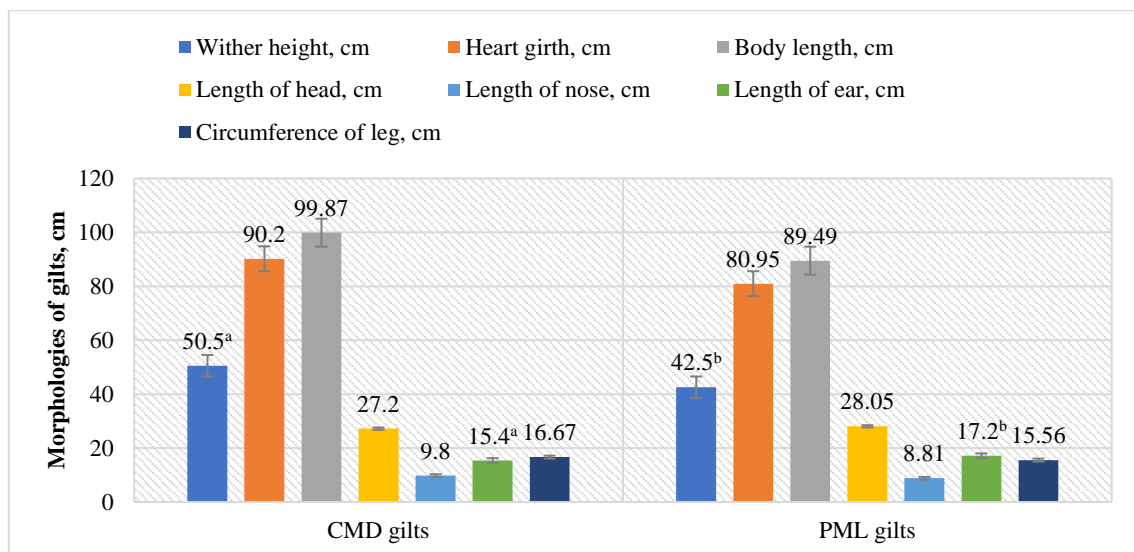
Figure 24 indicates the CMD gilt has a significantly taller ($p < 0.026$) wither height than PML gilts (50.53 ± 4.80 vs 42.55 ± 11.16 cm). The average body length and heart girth of CMP gilts at first mating are longer ($p > 0.05$) than the PML gilts (99.87 ± 8.65 and 90.20 ± 8.36 cm vs 89.49 ± 9.74 and 80.95 ± 9.24 cm, respectively). The average body length and heart girth of CMD gilts at first mating are longer, almost 10 cm, than the mature PML gilts. However, the present results were also not much different from Nong Taeng black pig (CMD x CMD), with an average wither height at first mating of about 61.33 cm and a body length of approximately 83.17 cm (KEONOUCHANH, 2018). But the body weight at first mating of CMD was significantly smaller, almost twice times compared to Nong Taeng black pig (39.86 vs 80.33 kg). The precise reason for this difference still

needs more scientific studies to approve it. But, the difference between the age at first mating might be one of the pre-assumption when our team allowed the gilts to be mated at 193 days while Nong Taeng black pig was 226 days. Nevertheless, we observed a longer body length and heart girth of the CMD than PML gilts (*Picture 6*) and MPL sows raised by local farmers, with an average of about 92.5 and 93 cm, respectively (KEONOUCHANH et al., 2011).



Picture 6: General appearance of the PML (A) and CMD (B) gilts

Figure 24: Comparison of the morphology of the CMD and PML gilt at their first mating



CMD: crossbred *Moo Lath* x *Duroc*; PML: purebred *Moo Lath*. ^{a,b}: Mean with the same superscripts do not differ ($p > 0.05$).

4.5. Lesson learnt of the farm operation and marketing strategies of Hungarian *Mangalica* to improve Lao indigenous pig breeds

It appears obvious that effective farm management and marketing strategies are essential for animal farms' profitability and sustainability. And, Hungarian *Mangalica*

farms model is a good illustration of successful farm operations to be adopted to improve indigenous pig development in Laos, particularly:

- 1) **On-farm-processing products:** Instead of exclusively selling live animals, each Hungarian *Mangalica* farm offers roughly ten different products that can add value to their products.
- 2) **On-farm feed production:** Approximately 75% of Hungarian farmers use self-mixed feed on farms, which creates more potential for farmers to reduce their feed costs. Laos also has a high potential for pig feedstuff production, such as maize and dried cassava. Currently, most Lao farmers have not used much of these potentials. Suppose Lao farmers had been more trained in utilizing the excellent adaption of the indigenous pig breeds on using the highest possibilities of self-mixed feed on farms. It will be a great opportunity to develop Lao indigenous pig breeds, particularly feed security for pigs, which is always a high cost in all aspects of pig production.
- 3) **Set up any organization to respond to improving indigenous pigs in Laos:** The National Association of Mangalica Breeders is a prominent actor in breed conservation and purebred breeders supplier, which farmers use in their breeding program, especially for marketing strategies. Currently, no actor has been working on Lao indigenous pig breeds conservation, which leads to high risks of losing the genetic diversity of purebred Lao indigenous pigs as in other neighbouring countries in the region. So, it should be one consideration in improving research and development for the better reproductive performance of Lao indigenous pig breeds.
- 4) **Modern extensive housing system:** Improving the pig housing system with a combination of an extensive and intensive model, like Hungarian *Mangalica* pig farms, could be more cost-effective and sustainable in developing Lao indigenous pigs. A housing system with free-running areas where pigs can freely do their natural behaviours. This approach may suit Lao indigenous pig producers, not only in rural areas where farmers use the traditional extensive system to raise pigs. But it could also benefit pig producers in urban due to the high potential in marketing strategies.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Mangalica gilts had over twice older at first mating than *Moo Lath* gilts. The conception rate of *Mangalica* gilts was expected to be lower than *Moo Lath* gilts. That can be considered based on the higher ovulation rates in *Mangalica* sows, but they produced nearly 2 piglets per litter less than in *Moo Lath* gilts. Keeping purebred for cross-breeding for marketing strategies seems to be the best technique/strategy of most current Hungarian *Mangalica* pig farms.

The traditional extensive pig rearing systems did not influence the reproductive performance of the indigenous pig breeds rearing by small-scale farmers in Laos. However, the proper management of both pre-and post-farrowing did. The main current problems of Lao indigenous pig production in Laos include the farming system not yet developed that blocking in improving the better reproductive performance; poor piglets' quality from farrowing to post-weaning; low rate of growth performance, with small body size at maturity due to a lack of proper management in breeding.

Utilizing the Altrenogest Regumate[®] (AR) in oestrous synchronization and artificial insemination can improve the litter size of *Moo Lath* gilts, but the birth weight, as well as the weight at day 28 of crossbred *Moo Lath* x *Duroc* (CMD) piglets, was not. The capacity of gilts' uterine horns, small body weight at first insemination, and *Moo Lath* sows' milk production are to be blamed for addressing these issues.

The weaning age did not influence the growth performance of *Moo Lath* piglets in the 1st post-weaning week, but the 2nd post-weaning week did. Lactation length significantly affected the body condition of primiparous *Moo Lath* sows that began from week 4, and got worse from week 7 of their lactation. But, the lactation length did not influence or play a negative severe on the weaning-to-oestrous interval and the 1st conception of primiparous *Moo lath* sows.

The dimensions of the lactating pen and pig barn design play a vital role in preventing and minimizing piglets' diarrhoea and the severe body condition of *Moo Lath* sows. On the other hand, supplementing dried green bananas in the piglet diet for 3 days pre and post-weaning can benefit in reducing diarrhoea in post-weaning piglets.

The optimal age at first service of *Moo Lath* gilts was between 210 and 240 days, with a body weight of nearly 45 kg, and the mean backfat approximately 41.12 mm. With

these conditions, *Moo Lath* gilts can have a mean body weight of around 75 kg and 40.48 mm of backfat at first farrowing. And with these body conditions, *Moo Lath* primiparous sows can rear their litters of about 7 to 8 heads up to 5 or 6 weeks with good body conditions.

The birth weight of the F-1 crossbred *Moo Lath* x *Duroc* (CMD) gilts did not influence the age at puberty and first mating, including their body weight, while the backfat thickness did. The CMD gilts can be bred for the first time at about 193.27 days old on their 3rd or 4th oestrous cycle, with a mean body weight of about 39.69 kg and a backfat thickness of approximately 38.18 mm. The birth weight of the CMD gilts did not influence their litter size; however, it influenced the birth weight of their offspring. In the case of the CMD gilts, under good management, have the mean body length, heart girth, and height at wither at first mating around 100, 90, and 51 cm, respectively. These are nearly 10 cm longer, wider and taller than pure-breed *Moo Lath* gilts raised by local farmers.

5.2. Recommendations

Most Lao farmers still raise indigenous pigs in the traditional extensive system, and none operate their farms commercially. Therefore, a modern semi-extensive Hungarian *Mangalica* model should be a favourable option to adapt in improving Lao indigenous pig breeds. Pig barn improvement and better feed relevant to management can increase the number of surviving market-weight offspring. These two things should be a priority to be considered in improving the reproductive performance of indigenous pig breeds in Laos.

Proper management during and early post-weaning must be considered to combat diarrhoea in piglets. The adequate size/dimensions of the lactating pen and daily sanitation are two factors that need to be considered to prevent piglets' diarrhoea, including the severe body condition of *Moo Lath* sows during their lactation. Lao farmers should recognize that *Moo Lath* piglets should be weaned between 5 and 6 weeks to achieve the economic outcome. Similarly, the optimal age of *Moo Lath* gilts at first mating should not be less than 210 days, reaching their 3rd or 4th oestrous cycling, and body weight should not be less than 40 kg.

However, AI is a new method for Lao indigenous pig producers. But this study proved that it could improve litter size of *Moo Lath* gilts and piglets' quality. Therefore,

AI should be a pivotal option to improve and develop better quality piglets and improve the reproductive performance of Lao indigenous pig breeds, especially the market strategies.

A crucial point that should be urgently addressed is to save the genetic diversity of Lao indigenous pig breeds. The association or community association regarding gene improvement for Lao indigenous pig breeds should be established to preserve the diverse genetics of indigenous pig breeds in Laos. The National Association of Mangalica Breeders in Hungary should be the best model that Lao can learn from. One of our studies in Northern Laos found it hard to identify the pure indigenous pig breeds in the study areas. Most local pig breeds have already been crossbred with various breeds, including Chinese and Vietnamese pig breeds. More severe cases were found in Houaphanh province, where most *Moo Lath* pigs were crossbred with *Mong Cai* Vietnamese.

To improve the reproductive performance of the entire Lao indigenous pig breed development procedures. All research on the effects of nutrition on gilt and sow reproductive performance, including piglet performance, are still required. All fields related to the reproductive biology of native pig breeds and their performance, especially body weight, meat and fat quality of Lao indigenous pig breeds, are required. All research on housing and feeding technologies in improving Lao indigenous pig breeds' reproductive performance is necessary.

6. NEW SCIENTIFIC RESULTS

- 1) The litter size of Moo Lath primiparous sows can be increased by two or three piglets if assisted reproductive techniques are used.
- 2) The capacity of Moo Lath primiparous sows' uterus is not more than 8 fetuses.
- 3) The optimal body weight of Moo Lath gilts at first mating is between 40-45 kg when the age of the gilts is 210-240 days, and the backfat thickness is between 30-40 mm.
- 4) Supplementing 10% dried green banana (*Musa Acuminata*) can be beneficial to reduce diarrhoea incidence post-weaning piglets.
- 5) For Moo Lath sows, the body weight loss duration of lactation is between 17.50 and 24.58 kg, and loss of backfat thickness of about 5.97–15.14 mm did not have a severe negative impact on the weaning-to-oestrous interval and first conception after weaning.

7. RESULTS APPLICABLE IN PRACTICE

1. Combining the traditional pig-raising system in rural areas of Laos with modern extensive as the current Hungarian *Mangalica* pig-raising system in Hungary should be a high chance to improve the reproductive performance and pig quality production in Laos. This is because Laos, particularly in the rural areas, has more potential to apply the modern extensive pig-raising system. Therefore, traditional extensive pig-raising still domains in rural Laos, but it needs the proper management methods to operate sustainably for rural development based on Lao economic strategy.
2. Lactating pen, with areas of about 2 x 1.5 m, or 3 m² can be used for only 5 to 6 weeks of lactation for a *Moo Lath* sow with about 7–8 piglets. This means that farmers need to consider increasing the proper size of the lactating pen for *Moo Lath* when the suckling period needs to be extended beyond 6 weeks. Otherwise, it will harm the welfare and health of both sows and piglets.
3. The optimal age of *Moo Lath* at first mating is between 210 and 240 days when they come to the 3rd and 4th oestrous cycle and attain a body weight of about 40 kg. With these figures, the gilts have the optimum body condition for lactating her 7–8 piglets until 5 or 6 weeks after farrowing.
4. Utilizing artificial insemination techniques could be a high chance of improving the reproductive performance of Lao indigenous pig breeds as well as meat quality.
5. Applying dried green bananas to treat diarrhoea in piglets for both pre-and post-weaning is an excellent option for native pig farmers, which not need higher skill to operate it. Moreover, there is plenty of banana (*Musa Acuminata*) in Laos, especially in rural areas. In this regard, the farmers do not need more expenditure on purchasing bananas for their piglets.

8. SUMMARY

The Hungarian *Mangalica* pig breed has a long history of successful evolution and is well-known for its unique curly hair and flavorful flesh. Its marbled meat and fat products can be sold at three times higher than common lean meat produced by modern pig breeds. Similarly, Lao indigenous pig breeds, especially *Moo Lath*, are well-known in Laos. Unfortunately, the quality of *Moo Lath* pig, including its reproductive performance and meat quality, has not been improved yet. Additionally, several factors affected the *Moo Lath* pig population, such as market preferences for lean meat and increased crossbreeding with other breeds due to no organization being responsible for their gene conservation.

The chronic problems of Lao indigenous pig breeds in the traditional extensive rearing system include (1) poor quality of piglets from farrowing to weaning, weight gain and health conditions. (2) uncontrolled breeding based on the traditional extensive rearing system. The gilts are bred from 120 or 150 days of age as soon as after the first puberty due to gilts and boars being together. (3) The farming systems are not developed yet, which is a serious challenge for improving reproductive performance due to difficulty in management. (4) pigs grow at a low rate (< 300 g per day), with a small body size till they attain sexual maturity, and it hardly weighs > 100 kg. And, (5) gilt and sow produce a small litter size with high pre-weaning mortality: 20–50%.

With successful experience in farm operation, gene conservation, and marketing strategies of HM pigs. And, these success stories should be adopted to improve the other regions' indigenous pig breeds, including Lao indigenous pig breeds. Therefore, this research was carried out with the following specific objectives:

1. to evaluate and identify the reproductive management methods in *Mangalica* pig farms to be adopted to improve indigenous pig breeds in Laos.
2. to evaluate the efficiency of utilizing estrous synchronization (ES) and artificial insemination (AI) with *Duroc* semen in improving the quality of the reproductive performance of *Moo Lath* gilts.
3. to evaluate the effects of weaning age on the growth performance of piglets and body conditions of *Moo Lath* primiparous sows.
4. to evaluate the effects of supplementing dried green banana to reduce diarrhoea in post-weaning piglets.

5. to examine the bacteria-infected post-weaning diarrhoea in *Moo Lath* piglets. (so-called by-products)
6. to study the effects of birth weight on age at puberty and first mating and reproductive performance of crossbred *Moo Lath* x *Duroc* gilts.

We found that the optimal age at first mating of *Mangalica* (330–398 d) is twice that of *Moo Lath* gilts (210–240 d). The conception rate of *Mangalica* gilts was suspected to be lower than *Moo Lath* compared to their litter size of 5.58–6.12 vs. 7.60–7.75. Meanwhile, the ovulation rate of *Mangalica* gilts was higher than *Moo Lath* (10.60 vs. 8.8). Proper housing management and self-feed production are two components that are found necessary to improve reproductive performance in most HM pig farms. On-farm processing (unique or traditionally processed products) and market fairs might be the critical success of *Mangalica* farms' operation in Hungary.

The reproductive performance of *Moo Lath* sows in the traditional extensive rearing system was not significantly different between rearing systems. However, this study found that the free-scavenging rearing system (FRS) had a marginally better litter size and birth weight than confinement (CRS) and semi-scavenging rearing systems (SRS). Similarly, the pre-weaning mortality did not differ in both village locations and rearing systems. The FRS had the lowest mortality, with around 13%, compared to 15.91% in the CRS, and 16.93% in the SRS. Approximately 56% of the total piglets' mortality was caused by poor management during farrowing and lactation, which resulted in piglets being crushed by a sow and starvation. This was proved by more than 54.26% of farmers did not keep their sows in a pen during their farrowing. Furthermore, 53.66% of farmers did not know when their sows would farrow, and most of their sows gave birth to piglets in the nearby forest. So, proper farm management might be considered a priority in improving the overall productivity of indigenous pigs in Laos.

The use of Altrenogest Regumate® in ES and AI using *Duroc* semen can improve the litter size of *Moo Lath* primiparous sows. Gilts in the ES group had a larger litter size, with about 1.16 piglets than gilts in the non-synchronized group, more than 3.16 piglets than those in the control group. But the F1-crossbred piglets' birth weight and growth performance on day 28 were not improved. The age and body weight at first insemination did not influence the reproductive performance of *Moo Lath* gilts in the present study. Anyway, the optimal age at the first service of *Moo Lath* gilts is between 210 and 240

days, with a body weight of nearly 45 kg. However, CMD gilts can reach puberty at about 137.47 days ranging from 132–143 days. Approximately 193.27 ± 16.71 days at first mating, with a body weight of about 39.69 ± 5.91 kg and 38.18 ± 8.29 mm of BF.

The lactation length had an adverse effect on the body conditions of the *Moo Lath* primiparous sows, which began in lactation week 4 and worsened by week 7. In the present study, the sows' body condition alterations did not negatively impair the WEI and first-service conception of sows after weaning. There was no difference in the weaning weight between *Moo Lath* piglets weaned at days 28 and 35. Likewise, the piglets weaned at days 35 or 42 showed no difference. Similarly, in this study, there was no difference in weaning weight among weaning at days 42, 49, and 56. However, the weaning age did not influence the weight gain of *Moo Lath* piglets in the 1st-week after weaning. But, in the 2nd post-weaning week, piglets with longer suckling periods gained nearly 3 times the weight gain compared to those with shortened periods.

Preventing diarrhoea infection in piglets was the most challenging in this study. Supplementing 10% dried green banana (*Musa Accuminata*) to the piglet diet for 3 days pre-and post-weaning can reduce diarrhoea in post-weaning piglets by over 40% compared to the non-supplemented group.

We could not observe much difference in the growth performance of male and female piglets. However, the female had a slightly higher daily weight gain in both 1st-week (54.29 g) and 2nd week (163 g) post-weaning, while male piglets got only 50 g in the 1st-week and 108 g per day in the 2nd week.

In brief, Lao farmers should keep in mind that *Moo Lath* piglets should be weaned between 5 and 6 weeks to achieve the best economic return. Similarly, the optimal age of *Moo Lath* gilts at first mating should not be less than 210 days. Meanwhile, the body weight should not be less than 40 kg with their 3rd or 4th oestrous cycling. Lactating pen or pig barn should be urgently considered for better reproductive performance of *Moo Lath* gilts and sows.

9. REFERENCES

1. AHERNE, F. X., KIRKWOOD, R. N. (1985): Nutrition and sow prolificacy. *Journal of Reproduction & Fertility Supplement*. 33, 169–183.
2. ALLTECH (N/A): Guide to diarrhea in pigs. How to monitor and find solutions (poster). Available at: [https://www.alltech.com/sites/default/files/2021-02/Guide% 20to% 20Pig% 20Diarrhea% 20Poster.pdf](https://www.alltech.com/sites/default/files/2021-02/Guide%20to%20Pig%20Diarrhea%20Poster.pdf). (Accessed: 26 August 2022)
3. ATHORN, R., PLUSH, K. (2019): Best practice gilt management for fertility and longevity. Australian Pork Limited. Available: https://australianpork.com.au/sites/default/files/2021-06/2019-09_Best_Practice_Gilt_Management_for_Fertility_and_Longevity.pdf (Accessed: 5 December 2022)
4. ALTHOUSE, G. (2015): Sow and gilt management, University of Pennsylvania. Available: <https://www.msdevetmanual.com/management-and-nutrition/management-of-reproduction-pigs/sow-and-gilt-management>.
5. ALMEIDA, F. R. C. L., NOVAK, S., FOXCROFT, G. R. (2000): The time of ovulation in relation to estrus duration in gilts. *Theriogenology*. 53 (7), 1389–1396.
6. ANDERSON, L. L., (2009): Reproductive Biology of Pigs. Iowa State University Animal, https://doi.org/10.31274/ans_air-180814-838
7. AZARPAJOUH, S. (N/A): 9 genetic factors related to pre-weaning mortality. *Pig Progress*. Available online: <https://www.pigprogress.net/pigs/genetics/9-genetic-factors-related-to-pre-weaning-mortality/>. (Access on 20 March 2023)
8. BAZER, F. W., THATCHER, W. W., MARTINAT-BOTTE, F., TERQU, M. (1988): Sexual maturation and morphological development of the reproductive tract in Large White and prolific Chinese Meishan pigs. *Journal of reproduction and fertility*. 83, 723–728.
9. BENE, E., NEMETH, S., KALMAN, A., KENSZTHELYI, S., BERCZI, I. E., BOLDOG, V., PALL, Z. (2016): The Hungarian Agriculture and Food Industry in Figure. Hungarian Chamber of Agriculture. Pp. 21–25, <https://www.nak.hu/kiadvanyok/kiadvanyok/1605-nak-mmesz2016enweb/file>
10. BLAVI, L., SOLÀ-ORÍOL, D., LLONCH, P., LÓPEZ-VERGÉ, S., MARTÍN-ORÚE, S. M., PÉREZ, J. F. (2021): Management and Feeding Strategies in Early Life to Increase piglet performance and welfare around weaning. *Animals*. 11(2), 1–43.
11. BOLET, G., MARTINAT BOTTE, F., LOCATELLI, A., GRUAND, J., TERQUI, M., BERTHELOT, F. (1986): Components of prolificacy in hyperpolific Large White sows compared with the Meishan and Large White breeds. *Genetics Selection Evolution*. 18, 333–342.

12. BORGES, V. F., BERNARDI, M. L., BORTOLOZZO, F. P., WENTZ, I. (2005). Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. *Preventive veterinary medicine*, 70(3-4), 165-176.
13. BOULET, S., QUESNEL, H., QUINIOU, N. (2008): Management of high prolificacy in French herds: Can we alleviate side effects on piglet survival? *Advance in pork production*. 19, 213–220.
14. BOCIAN, M., JANKOWIAK, H., CEBULSKA, A., WIŚNIEWSKA, J., FRĄTCZAK, K., WŁODARSKI, W., KAPELAŃSKI, W. (2012): Differences in piglets sex proportion in litter and in body weight at birth and weaning and fattening results. *Journal of Central European Agriculture Production*. 13 (3), 475–482.
15. BRÜSSOW, K.-P., EGRSZEGI, I., RÁTKY, J., SOÓS, F., GARCIA CASADO, P., TUCHSCHERER, A., TOTH, P. (2004): Organometric data of the reproductive tract in cycling and early pregnant Hungarian Mangalica pigs, *Archives Animal Breeding*. 47, 585–594.
16. BRÜSSOW, K.-P., SCHNEIDER, F., TUCHSCHERER, A., EGRSZEGI, I., RÁTKY, J. (2008): Comparison of luteinizing hormone, leptin and progesterone levels in the systemic circulation (Vena jugularis) and near the ovarian circulation (Vena cava caudalis) during the oestrous cycle in Mangalica and Landrace gilts. *Journal of reproduction and development*. 54 (6), 431–438.
17. BRUININX, E., SCHELLINGERHOUT, A., BINNENDIJK, G., PEET-SCHWERING, C., SCHRAMA, J., DEN HARTOG, L., BEYNEN, A. (2004): Individually assessed creep food consumption by suckled piglets: Influence on post-weaning food intake characteristics and indicators of gut structure and hind-gut fermentation. *Animal Science*. 78 (1), 67–75.
18. CAMPBELL, J. M., CRENSHAW, J. D., POLO, J. (2013): The biological stress of early weaned piglets. *Journal of Animal Science and Biotechnol*. 4:19.
19. CEDE, P., BILKEI, G. (2004): The effect of modified eros centre, outdoor raising or conventional group housing on breeding gilts and its effects on reproductive performance over four parities, *Theriogenology*. 61(1), 185–194.
20. CERISUELO, A., SALA, R, GASA, J., CHAPINAL, N., CARRIÓN, D., COMA, J., BAUCCELLS, M. D. (2008): Effects of extra feeding during mid-pregnancy on gilts productive and reproductive performance. *Spanish Journal of Agricultural Research*. 6(2), 219–229.
21. CHITTAVONG, M., LINDBERG, J. E., JANSSON, A. (2012): Feeding regime and management of local Lao pigs in Central Lao PDR. *Tropical Animal Health and Production*. 45(1), 149–155.

22. CHUNG, K. T., WONG, T. Y., WEI, C. I., HUANG, Y. W., LIN, Y. (1998): Tannins and human health: a review. *Critical Reviews in Food Science and Nutrition*. 38(6), 421–64.
23. COLSON, V., ORGEUR, P., FOURY, A., MORMÈDE, P. (2006): Consequences of weaning piglets at 21 and 28 days on growth, behaviour and hormonal responses. *Applied Animal Behaviour Science*. 98(1–2), 70–88.
24. COUNCIL DIRECTIVE 2008/120/EC (2008): Official Journal of the European Union. Available at: <http://data.europa.eu/eli/dir/2008/120/oj> [Accessed on 16 August 2022]
25. COZANNET, P., LAWLOR, P. G., LETERME, P., DEVILLARD, E., GERAERT, P.A., ROUFFINEAU, F., PREYNAT, A. (2018): Reducing BW loss during lactation in sows: a meta-analysis on the use of a nonstarch polysaccharide-hydrolyzing enzyme supplement. *Journal of Animal Science*. 96 (7), 2777–2788.
26. DANG-NGUYEN, T. Q., TICH, N. K., NGUYEN, B. X., OZAWA, M., KIKUCHI, K., MANABE, N., RATKY, J., KANAI, Y., NAGAI, T. (2010): Introduction of various Vietnamese indigenous pig breeds and their conservation by using assisted reproductive techniques. *Journal of reproduction and development*. 56(1), 31–35.
27. De ALMEIDA, M., BERNARDI, M.L., MOTTA, A.P., BORTOLOZZO, F.P., WENTZ, I. (2014): Effect of birth weight and litter size on the performance of landrace gilts until puberty. *Acta Scientiae Veterinariae*. 42(1), 1-8.
28. DEVILLERS, N., DIVIDICH, J. L., AND PRUNER, A. (2011): Influence of colostrum intake on piglet survival and immunity. *Animal*. 5(10), 1605–1612.
29. DEBRECÉNI, O., BUČKO, O., KOMOVÁ, P. (2016): Effect of feeding system in relationship to fattening and production parameters from Mangalica breed. *Research pig breeding*. 10 (2), 1–28.
30. DEPARTMENT OF LIVESTOCK AND FISHERIES. (2020): Statistic of livestock and poultry in Laos from 2014–2019.
31. DOUGLAS, S. L., EDWARDS, S. A., KYRIAZAKIS, I. (2014): Management strategies to improve the performance of low birth weight pigs to weaning and their long-term consequences. *Journal of Animal Science*. 92(5), 2280–2288.
32. DOVE, C. R. (2009): Farrowing and lactation in the sow and gilt. The University of Georgia, Cooperative extension. Colleges of agriculture and environment science & Family and consumers science. <https://athenaeum.libs.uga.edu/bitstream/handle/10724/12025/B872.pdf>
33. DUYEN, T.T.B. AND THUY, PH.-CH.-TULIEM. (2011): Mong Cai pig conservation and development in Vietnam. International Seminar on the Utilization of Native Animals for Building Rural Enterprises in Warm Climate Zone, Muñoz, Nueva Ecija (Philippines), 19-

- 23 Jul 2010. p. 73-83. <https://agris.fao.org/agris-search/search.do?recordID=PH2011000204>, last accessed on 4/11/2021
34. EASTWOOD, L. (2018): Creep feeding to improve piglet performance. OMA FRA Factsheet. 18, 3. Online: <http://www.omafra.gov.on.ca/english/livestock/swine/facts/18-003.htm> (last accessed on 2 October 2022).
 35. EGBUNIKE, G. N., AND STEINBACH, J. (1977): Effects of season and litter size on gestation length in swine. *Nigerian Journal of Animal Production*. 4(1), 43–52
 36. EGRSZEGI, I., RATKY J., SOLIT, L., BRUSSOW, K.P. (2003): Mangalica - an indigenous swine breed from Hungary (Review). *Arch. Tierz., Dummerstorf*. 46(3), 245–256.
 37. EGRSZEGI, I., BRÜSSOW, K-P., SARLÓS, P., MANABE, N., RÁTKY, J. (2018): Reproductive capacity of Mangalica pigs–What is the reality? *Archivos de Zootecnia*. 81–86
 38. EINARSSON, S., ROJKITTIKHUN. T. (1993): "Effects of nutrition on pregnant and lactating sows." *Journal of Reproduction and Fertility Supplement*. 48, 229–239.
 39. ELZE, K., SCHNURRBUSCH, U., MEHLHORN, I., RITTENBACH, P., RUMMER, H. J., FREYSOLDT, C. (1975): Studies on improving the fertility of aged sows. 3. Results of histological studies on puerperal involution and regeneration processes in the endometrium of lactating sows and sows after extremely early weaning. *Arch Exp Veterinarmed*. 29(5), 689–99.
 40. EMERY, A. L., SIEFERT, D. Q., MOORE, C. K., HARRELSON, F. W., HARRELSON, P. L. (2018): Effect of gestation length on litter size and piglet birth weight. *Celebration of Student Scholarship Posters Archive*. 20. https://scholarworks.moreheadstate.edu/student_scholarship_posters/20
 41. EPPRECHT, M., WEBER, A.K., BERNHARD, R., KEOKA, K., SAPHANGTHONG, T., MANIVONG, V., INGXAY, P., VONGSAMPHANH, P., BOSONI, N., HANEPHOM, S., VANMEEXAI, P., KAUNGBOUNHIENG, A., SISOUVANH, H., KOUNTHIKOUMMAN, S., XAICHOUNORXOA, K., XAICHOUNORXOA, P., INGALL, M., NANHTHAVONG, V., LU, J., NORASINGH, I., WIESMANN, U., AND BREU, T. (2018): Atlas of agriculture in the Lao PDR.. Centre for Development and Environment (CDE), University of Bern, Switzerland, and Ministry of Agriculture and Forestry (MAF), Lao PDR, with Bern Open Publishing (BOP). <http://dx.doi.org/10.7892/boris.116598>.
 42. ESTIENNE, M. (2009): Using artificial insemination in swine production: Detecting and synchronizing estrus and using proper insemination technique. Virginia cooperative extension. Virginia state university. VCE Publications. 414, 414–038, <https://www.pubs.ext.vt.edu/414/414-038/414-038.html>.

43. FAHMY, M. H, FRIEND, D. W. (1981): Factors influencing, and repeatability of the duration of farrowing in Yorkshire sows. *Canadian Journal of Animal Science*. 61, 11–22.
44. FLOWERS, W.L. (2020): Chapter 16 - Reproductive management of swine. *Animal Agriculture*, Academic Press. Pp: 283–297. <https://doi.org/10.1016/B978-0-12-817052-6.00016-1>
45. GAÁL, B. (2019): More Mangalica pork eaten in Japan than in Hungary. *Budapest Business Journal*, 29th August, 2019. <https://bbj.hu/budapest/gastronomy/food/more-mangalica-pork-eaten-in-japan-than-in-hungary>.
46. GEISERT, R. D., SCHMITT, R. A. M. (2002): Early embryonic survival in the pig: Can it be improved?, *Journal of Animal Science*. 80 (1), 54–E65.
47. GEISERT, R. D., SUTVOSKY, P., LUCY, M. C., BARTOL, F. F., MEYER, A. E. (2020): Chapter 15 - Reproductive physiology of swine. Editor: Fuller W. Bazer, G. Cliff Lamb, Guoyao Wu. *Animal Agriculture*, Academic Press, 2020, pp. 263–281, <https://doi.org/10.1016/B978-0-12-817052-6.00015-X>.
48. GIRARD, M., THANNER, S., PRADERVAND, N., HU, D., OLLAGNIER, C., BEE, G. (2018): Hydrolysable chestnut tannins for reduction of postweaning diarrhea: Efficacy on an experimental ETEC F4 model. *PLoS ONE* 13 (5): e0197878. <https://doi.org/10.1371/journal.pone.0197878>
49. GONZALEZ-ANOVER, P., ENCINAS, T., GOMEZ-IZQUIERDO, E., SANZ, E. LETELIER, C. A., TORRES-ROVIRA, L., PALLARES, P. SANCHEZ-SANCHEZ, R., GONZALEZ-BULNES, A. (2010): Advanced onset of puberty in gilts of thrifty genotype (Iberian Pig). *Reproduction in the domestic animal*. 45, 1003–1007.
50. HEINONEN, M., PELTONIEMI, O., VALROS, N. (2013): Impact of lameness and claw lesions in sows on welfare, health and production. *Livestock science*. 156(1-3), 2–9.
51. HINES, E. (2020): Swine reproductive herd management. Penn State Extension. Last update: June 29, 2020. Available: <https://extension.psu.edu/swine-reproductive-herd-management>
52. HEO, P. S., KIM, D. H., JANG, J. C., HONG, J.S., KIM, Y.Y. (2018): Effects of different creep feed types on pre-weaning and post-weaning performance and gut development. *Asian-Australas Journal of Animal Science*. 31(12), 1956–1962.
53. HOLT, H. R., INTHAVONG, P., BLASZAK, K., KEOKAMPHE, CH., PHONGMANY, A., BLACKSELL, S. D., DURR, P. A., GRAMHAM, K., ALLEN, J., DONNELLY, B., NEWBERRY, K., GRACE, D., ALONSO, S., GILBERT, J., UNGER, F. (2019): Production diseases in smallholder pig systems in rural Lao PDR. *Preventive Veterinary Medicine*. 162, 110–116.

54. HOLYOAKE, P.K., DIAL, G.D., TRIGG, T., KING, V.L. (1995): Reducing pig mortality through supervision during the perinatal period. *Journal of Animal Science*. 73(12), 3543–3551.
55. HUNTER, R. H. F. (1981): Sperm transport and reservoirs in the pig oviduct in relation to the time of ovulation. *Journal of Reproduction & Fertility*. 63, 109–117.
56. HUNGARIAN CENTRAL STATISTICAL OFFICE (2022): Agricultural Census. Online http://www.ksh.hu/docs/eng/agrar/html/tab11_5_1_1.html.
57. HUYNH, T.T.T., ARNINK, A.J.A., DRUCKER, A., VERSTEGEN, M.W.A. (2006): Pig production in Cambodia, Laos, Philippines, and Vietnam. *Asian Journal of Agriculture and Development*. 3, 69–90.
58. ISHAK, N. Ab., RAZAK, N., PAK DEK, M., SAMSU BAHARUDDIN, A. (2020): Production of high tannin content and antioxidant activity extract from an unripe peel of *Musa acuminata* (Cavendish) using ultrasound-assisted extraction (UAE). *Bio Resources*. 15(1), 1877-1893.
59. JARVIS, S., CALVERT, S. K., STEVENSON, J., VANLEEUEWEN, N., LAWRENCE, A., B. (2002): Pituitary-adrenal activation in pre-parturient pigs (*Sus scrofa*) is associated with behavioural restriction due to lack of space rather than nesting substrate. *Animal welfare*. 14(4), 371–384.
60. JIN, S. S., JUNG, S. W., JANG, J.C., CHUNG, W. L., JEONG, J. H., KIM, Y. Y. (2016): Effects of dietary energy levels on the physiological parameters and reproductive performance of gestating gilts. *Asian-Australasian Journal of Animal Sciences*. 29, 1004–1012.
61. JOHNSTON, L. (2010): Gestating swine nutrient recommendations and feeding management. Factsheet, Pork Information Gateway. University of Minnesota. Available: <https://porkgateway.org/resource/gestating-swine-nutrient-recommendations-and-feeding-management/>. Accessed on 17 November 2022.
62. KABARE, N. (1991): Genetic and environmental aspects of reproductive performance and pre-weaning growth of three pig breeds in large-scale herds in Kenya. MSc. Thesis. University of Nairobi, <http://erepository.uonbi.ac.ke/handle/11295/21552>.
63. KAENSOMBATH, L. (2012): Taro leaf and stylo forage as protein sources for pigs in Laos. Doctoral Thesis. Swedish University of Agricultural Sciences Uppsala. https://pub.epsilon.slu.se/9255/1/kaensombath_1_20121122.pdf
64. KARVELIENE, B., SERNIENE, L., RISKEVICIENE, V. (2008): Effect of different factors on weaning-to-first-service interval in Lithuanian pig herds. *Veterinary Medicine and Zootechnics*. 41, 64–69.

65. KEONOUCHANH, S., EGRSZEGI, I., RATKY, J., BOUNTHONG, B., MANABE, N., BRÜSSOW, K-P. (2011): Native pig (Moo Lat) breeds in Lao PDR. *Archives Animal Breeding*. 54, 606–600.
66. KEONOUCHANH, S., XAYPHA, S., KHAMPHAVONG, S. (2012): Improvement of local pig production system in Pha Oudom, Houn and Phonthong District. *Lao Journal of Agriculture and forestry*. 26, 129–142.
67. KEONOUCHANH, S., DENGKHOUNXAY, TH. (2017): pig production and pork quality improvement in Lao PDR. *Lao Journal of Agricultural and Forestry, NAFRI*. 36, 37–42.
68. KEONOUCHANH, S. (2018): KOPIA Project Final Report year 2016- 2018. The improved livelihood of farmers by chicken and pig raising in Mork district, Xiengkhuang Province. National Agriculture and Forestry Institute of Laos.
69. KILBRIDE, A.L., MENDEL, M., STATHAM, P., HELD, S., HARRIS, M., COOPER, S., GREEN, L. E. (2012): A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. *Preventive Veterinary Medicine*. 104(3–4), 281–291.
70. KIM, S. W., WEAVER, A. C., SHEN, Y. B., ZHAO, Y. (2013): Improving efficiency of sow productivity: nutrition and health. *Journal of Animal Science and Biotechnology*, 4:26, <http://www.jasbsci.com/content/4/1/26>. Last access on 7/11/2021.
71. KING, R. H.-WILLIAMS, I. H. (1984): The effect of nutrition on the reproductive performance of first-litter sows 1. Feeding level during lactation, and between weaning and mating. *Animal Science*. 38(2), 241–247.
72. KIRKDEN, R. D., BROOM, D. M., ANDERSEN, I. L. (2013): INVITED REVIEW: Piglet mortality: Management solutions. *Journal of Animal Science*. 91(7), 3361–3389.
73. KNOX, R.V., RODRIGUEZ ZAS, S. L. (2001): Factors influencing estrus and ovulation in weaned sows as determined by transrectal ultrasound. *Journal of Animal Science*. 79(12), 2957–2963.
74. KNOX, V.R. (2021): Sows and gilts management. Last full review/revision 2021. MSD Manual Veterinary Manual. Available: <https://www.msdsvetmanual.com/management-and-nutrition/management-of-reproduction-pigs/sow-and-gilt-management>. (Accessed: 15 October 2022)
75. KNOX, V.R. (2022): Breeding management of pigs. Last review/revision Oct 2021. MSD Manual Veterinary Manual. Available: <https://www.msdsvetmanual.com/management-and-nutrition/management-of-reproduction-pigs/breeding-management-of-pigs>.
76. KOKETSU, Y., TANI, S., IIDA, R. (2107): Factors for improving reproductive performance of sows and herd productivity in commercial breeding herds. *Porcine health management*. 3:1.

77. KOUSENIDIS, K., GIANTSIS, L., KARAGEORGIU, E., AVDI, M. (2021): Swine ultrasonography numerical modeling for pregnancy diagnosis and prediction of litter size. *International Journal of Biology and Medical Engineering*. 15, 29–35.
78. KRAELING, R. R., WEBEL, S.K. (2015): Current strategies for reproductive management of gilts and sows in North America. *Journal of Animal Science and Biotechnologies*. 6:3.
79. KUNAVONGKRIT, A., HEARD, T. W. (2000): Pig reproduction in South East Asia. *Animal reproduction science*. 60(61), 527–533.
80. KUNDU, M. S., PERUMAL, P., RAVI, S. K., SNEHA SAWHNEY, BHATTACHARYA, D., KUNDU, A. (2020): Evaluation of reproductive and production performance of Nicobari pig under humid tropical island ecosystem. *Indian Journal of Animal Science*. 90(7), 1048–1053.
81. KYRIAZAKIS, I., WHITTEMORE, C.T. (2006): *Whittemore’s Science and Practice of Pig Production*. Blackwell Publishing, Book, Third Edith, 2006. P. 107–108.
82. LANGENDIJK, P. (2021): Latest Advances in Sow Nutrition during Early Gestation. *Animals*. 11(6): 1720.
83. Lao National Statistics Bureau 2000–2022: *Statistic Yearbook 2000–2021*. Ministry of Planning and investment. Vientiane Capital, Laos. Available: <https://www.lsb.gov.la/en/home/>
84. LI, Q., YUAN, X., CHEN, Z., ZHANG, A., ZHANG, Z., ZHANG, H., LI, J. (2018): Heritability estimates and effect on lifetime reproductive performance of age at puberty in sows. *Animal Reproduction Science*, 195, 207-215.
85. LAWLOR, P.G., LYNCH, P.B. (2007): A review of factors influencing litter size in Irish sows. *Irish Veterinary Journal*. 60, 359.
86. LEE, S. I., KIM, I. H. (2018): Creep feeding improves growth performance of suckling piglets. *Brazilian Journal of Animal Science*. 47:e20170081.
87. LEIBBRANDT, V.D., EWAN R.C., SPEER V.C., ZIMMERMAN DEAN R. (1975): Effect of weaning and age at weaning on baby pig performance. *Journal of Animal Science*. 40(6), 1077–1080.
88. LEMKE, U., KAUFMANN, B., THUY, L., EMRICH, K., VALLE ZÁRATE, A. (2006): Evaluation of smallholder pig production systems in North Vietnam: Pig production management and pig performances. *Livestock Science*, 105(1-3), 229-243.
89. LEVIS, D.G., ZIMMERMAN, D.R., AHLSCWEDE, W.T., REESE, D.E., BRUMM, M.C. (1989): *Swine reproductive management*. University of Nebraska-Lincoln. <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=5649&context=extensionhist>
90. LEVIS, G. (1997): Effect of lactation length on sow reproductive performance. University of Nebraska–Lincoln. Available online: <https://core.ac.uk/download/pdf/17231797.pdf>

91. LIBAL, G.W., WAHLSTROM, R.W. (1974): Age of breeding and reproductive performance of gilts. *Animal science reports*. South Dakota State University. http://openprairie.sdstate.edu/sd_swine_1974/9
92. LEIGH, A. O. (1981): Factors affecting the gestation period of pigs in Nigeria. *Tropical Animal Health and Production*. 13(2), 87–93.
93. LIU, Z.-X., WEI, H.-K., ZHOU, Y.-W., PENG, J. (2018): Multi-level mixed models for evaluating factors affecting the mortality and weaning weight of piglets in large-scale commercial farms in central China. *Animal Science Journal*. 89(5), 760–769.
94. MAES, D., LOPEZ RODRIGUEZ, A., RIJSSELAERE, T., VYT, P. VAN SOOM, A. (2011): Artificial insemination in pigs. *Artificial insemination in farm animals*, pp.79-94.
95. MAF (2015): Agriculture development strategy to 2025 and vision to the year 2030. Ministry of Agriculture and Forestry of Laos. Access date 21 April 2021. <https://www.maf.gov.la/wp-content/uploads/2016/01/MDS-2025-and-Vision-to-2030-Eng.pdf>
96. MAF (2020): Agricultural Statistics Year Book 2019. Ministry of Agriculture and Forestry, Department of Planning and Finance, Vientiane. Online: <https://alipsea.org/alipseaonlinelibrary/laos-agricultural-statistics-year-book-2019/>
97. MAGNABOSCO, D., BERNARDI, M.L., WENTZ, I., CUNHA, E.C.P., F.P. BORTOLOZZO, F.P. (2016): Low birth weight affects lifetime productive performance and longevity of female swine. *Livestock Science*. 184, 119-125.
98. MANIVANH, N., INTHAPANYA, S., SAVATHVONG, S., SCHILLER, J.M. (2017): Improving the reproduction of local pigs in Northern Lao PDR by crossing with Vietnamese Mong Cai pigs. *Lao Journal of Agriculture and Forestry*. 36, 17–32.
99. MALLMANN, A. L., BETIOLO, F. B., CAMILLOTI, E., MELLAGI, A. P. G., ULGUIM, R. R., WENTZ, I., BERNARDI, L. M., GONÇALVES, M. A.D., KUMMER, R., BORTOLOZZO, F. P. (2018): Two different feeding levels during late gestation in gilts and sows under commercial conditions: impact on piglet birth weight and female reproductive performance, *Journal of Animal Science*. 96(10), 4209–4219.
100. MALLMANN, A. L., CAMILOTTI, E., FAGUNDES, D. P., VIER, C. E., G MELLAGI, A. P., ULGUIM, R. R., BERNARDI, M. L., D ORLANDO, U. A., D GONÇALVES, M. A., KUMMER, R., BORTOLOZZO, F. P. (2019): Impact of feed intake during late gestation on piglet birth weight and reproductive performance: a dose-response study performed in gilts. *Journal of Animal Science*. 97(3), 1262-1272.
101. MALLMANN, A. L., OLIVEIRA, G. S., ULGUIM, R. R., G MELLAGI, A. P., BERNARDI, M. L., D ORLANDO, U. A., D GONÇALVES, M. A., COGO, R. J., BORTOLOZZO, F. P. (2020): Impact of feed intake in early gestation on maternal growth

- and litter size according to body reserves at weaning of young parity sows. *Journal of Animal Science*. 98(3).
102. MALANDA, J., BALOGH, P., & NOVOTNI DANKÓ, G. (2019): Optimal age of breeding gilts and its impact on lifetime performance. *Acta Agraria Debreceniensis*. 2, 15–20.
 103. MATSUMOTO, N., SIENGSANAN-LAMONT, J., HALASA, T., YOUNG, J.R., WARD, M.P., DOUANGNGEUN, B., THEPPANGNA, W., KHOUNSY, S., TORIBIO, J.A.L.M.L., BUSH, R.D., BLACKSELL, S.D. (2021): The impact of African swine fever virus on small holder village pig production: An outbreak investigation in Lao PDR. *Transboundary and Emerging Diseases*. Wiley. 68, 2897–2908.
 104. MAVROMICHALIS, L. (2018): Post-weaning feed intake target for piglets. *Feed Strategy*. Accessed date: 25 September 2022, <https://www.feedstrategy.com/blog/post-weaning-feed-intake-target-for-piglets/>
 105. MESSERLI, P., HEINIMANN, A., EPPRECHT, M., PHONESALY, S., THIRAKA, C., AND MINOT, N. (2008): *Socio-Economic Atlas of the Lao PDR – an Analysis based on the 2005 Population and Housing Census*. Swiss National Center of Competence in Research (NCCR) North-South, University of Bern, Bern and Vientiane: Geographica Bernensia., <https://www.researchgate.net/publication/234091807>
 106. MELLADO, M., GAYTÁN, L., MACÍAS-CRUZ, U., AVENDAÑO, L., MEZA-HERRERA, C., LOZANO, E. A., RODRÍGUEZ, A., MELLADO, J. (2018): Effect of climate and insemination technique on reproductive performance of gilts and sows in a subtropical zone of Mexico. *Austral Journal of Veterinary Science*. 50(1), 27–34.
 107. MIDDELKOOP, A., COSTERMANS, N., KEMP, B. (2019a): Feed intake of the sow and playful creep feeding of piglets influence piglet behaviour and performance before and after weaning. *Science Reproduction*. 9, 16140.
 108. MIDDELKOOP, A., VAN MARWIJK, M. A., KEMP, B., and BOLHUIS, J. E. (2019b): Pigs Like it varied; feeding behavior and pre-and post-weaning performance of piglets exposed to dietary diversity and feed hidden in substrate during lactation. *Frontiers Veterinary Science*. 6, 408.
 109. MIDDELKOOP, A., CHOUDHURY, R., GERRITS, W. J. J., KEMP, B., KLEEREBEZEM, M., BOLHUIS, J. E. (2020): Effects of creep feed provision on behavior and performance of piglets around weaning. *Frontiers Veterinary Science*. 7, 520035.
 110. MICHAEL, R.W. AND CATHERINE, E. D. (1993): The associations between weaning-to-estrous and sow efficiency. *Swine health and production*. 1(4), 10–15.
 111. MUSSER, R. E., DAVIS, D. L., TOKACH, M. D., NELSEN, J. L., DRITZ, S. S., GOODBAND, R. D. (2006): Effects of high feed intake during early gestation on sow

- performance and offspring growth and carcass characteristics. *Animal Feed Science and Technology*. 127, 187–199.
112. MUNS, R., NUNTAPAITOON, M., TUMMARUK, P. (2016): Non-infectious causes of pre-weaning mortality in piglets. *Livestock Science*. 184, 46–57.
113. MUNS, R., MAGOWAN, E. (2018): The effect of creep feed intake and starter diet allowance on piglets' gut structure and growth performance after weaning. *Journal of Animal Science*. 96(9), 3815–3823.
114. NAFRI (National Agriculture and Forestry Research Institute of Laos) (2020): Report: 20 years for livestock research and development in Laos. NAFRI. pp. 12–21.
115. NAKAI, S. (2008): Reproductive performance analysis of native pig smallholders in the hillside of northern Thailand. *Tropical Animal Health and Production*. 40(7), 561-566.
116. NIETO, R., GARCÍA-CASCO, J., LARA, L., PALMA-GRANADOS, P., IZQUIERDO, M., HERNANDEZ, F., DIEGUEZ, E., DUARTE, J. L., BATOREK-LUKAČ, N. (2019): Ibérico (Iberian) Pig. In M. Candek-Potokar, & R. M. N. Linan (Eds.), *European local pig breeds - diversity and performance. A study of project TREASURE*. IntechOpen. <https://doi.org/10.5772/intechopen.83765>
117. NEWTON, E.A., MAHAN, D.C. (1993): Effect of initial breeding weight and management system using a high-producing sow genotype on resulting reproductive performance over three parities. *Journal of Animal Science*. 71(5), 1177–86.
118. NEILL, C. R., WILLIAMS, N. H. (2010): Milk production and nutritional requirements of modern sows. *Nutrition*. Available: https://www.pig333.com/articles/milk-production-and-nutritional-requirements-of-modern-sows-i_4698/ . (Accessed: 15 October 2022)
119. National Assembly of Laos. Law of Livestock and Veterinary of Laos. Issue Number: 08/NA-LAOS. Available online: <https://na.gov.la/?lang=en> (accessed on 25 August 2022).
120. NOBLET, J., ETIENNE, M. (1986): Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets, *Journal Animal Science*. 63(6), 1888–1896.
121. NORONHA, A. M. C. G., NORONDHA, C. G., AGBISIT, A. M., AMOR, C., ESTRELLA, S., DIZON, J. T., COSTA, A. M. D., NARONDHA, G. (2017): Productivity of native pigs in subsistence farming and their roles in community development in Timor-Leste. Thesis (MS in Animal Science), University Library, University of the Philippines at Los Baños. Online <https://agris.fao.org/agris-search/search.do?recordID=PH2019000234>
122. NOWAK, B., MUCHA, A., MOSKA, M., KRUSZYŃSKI, W. (2020): Reproduction indicators related to litter size and reproduction cycle length among sows of breeds considered maternal and paternal components kept on medium-size farms. *Animals*. 10(7).

123. NUNTAPAITOON, M., TUMMARUK, P. (2018): Factors influencing piglet pre-weaning mortality in 47 commercial swine herds in Thailand. *Tropical Animal Health and Production*. 50, 129–135.
124. OBERMIER, D., EICKHOFF, M., MOTE, B. E., UITERMARKT, A., FROBOSE, H., BORG, B. (2021): 57 The impact of functional teat number on piglet survival and sow efficiency. *Journal of Animal Science*. 99 (Suppl 1), 149.
125. OLIVIERO, C., HEINONEN, M., VALROS, A., PELTONIEMI, O. (2010): Environmental and sow-related factors affecting the duration of farrowing. *Animal Reproduction Science*. 119(1-2), 85–91.
126. OLIVIERO, C., KOTHE, S., HEINONEN, M., VALROS, A., PELTONIEMI, O. (2013): Prolonged duration of farrowing is associated with subsequent decreased fertility in sows, *Theriogenology*. 79(7), 1095–1099.
127. PAPP, C. (2016): Breeding results for Mangalica breeds in 2016. National Association of Mangalica Breeds. Accessed date 21st April 2021. <http://www.moe.org.hu/tenyesztes/tenyesztesi-eredmenyek/>
128. PATTERSON, J., FOXCROFT, G. (2019): Gilt management for fertility and longevity. *Animals*. 9(434), 1–15.
129. PETROVIĆ, M., SAVIĆ, R., PARUNOVIĆ, N., RADOJKOVIĆ, D., RADOVIĆ, C. (2013): Reproductive traits of pigs of mangalitsa breed. Proceeding 8th International Symposium on the Mediterranean Pig, Slovenia, Ljubljana, October 10th–12th, 2013. *Acta agriculturae Slovenica*. 4, 89–92.
130. PHENGSAVANH, P., OGLE, B., STÜR, W., FRANKOW-LINDBERG, B. E., AND LINDBERG, J.E. (2010): Feeding and performance of pigs in smallholder production systems in Northern Lao PDR. *Tropical Animal Health and Production*. 42, 1627–1633.
131. PHENGSAVANH, P., OGLE, B., STÜR, W., LINDBERG, F. B. E., LINDBERG J. E. (2011): Small-holder pig rearing system in Northern Lao PDR. *Tropical Animal Health and Production*. 42, 27–33.
132. PHENGVILAYSOUK, A., JANSSON, A., PHENGSAVANH, P., IEMANN, T. T., PHENGVICHITH, V., LINDBERG, J. E. (2017): Sow and piglet management in smallholder and large-scale pig farms in the Northern part of Laos. *Livestock research for rural development*. 29, 201
133. PHENGVILAYSOUK, A., LINDBERG, J. E., SISONGKHAM, V., PHENGSAVANH, P., JANSSON, A. (2018): Effects of provision of water on reproductive performance of native Moo Lath pigs in Laos. *Tropical Animal Health and Production*. 50, 1139–1145.

134. PIETRUSZKA, A., DER, A., MATYSIAK, B. (2020): Analysis of gestation length and its influence on the reproductive performance of crossbred sows kept on a large-scale pig farm. *Scientific Annals of the Polish Society of Animal Production*. 16 (1): 29–36.
135. POZZI, P., ALBORALI, L. (2012): Reproductive diseases in sows (*Sus scrofa domestica*). *Israel Journal of Veterinary Medicine*. 67(1), 24–33.
136. PRUNIER, A., QUESNEL, H. (2000): Influence of nutritional status on ovarian development in female pigs. *Animal reproduction science*. (60–61), 185–197.
137. QUESNEL, H., FARMER, C., THEIL, P. K. (2015): Colostrum and milk production. *The Gestating and Lactating Sow*. 1st Edition, Edited by Famer, C. Chapter 8. Publisher: Wageningen Academic Publisher.
138. RADOVIĆ, Č., SAVIĆ, R., PETROVIĆ, M., GOGIĆ, M., LUKIĆ, M., RADOJKOVIĆ, D., & BATOREK-LUKAČ, N. (2019): Mangalitsa (Swallow-Belly Mangalitsa) Pig. In M. Candek-Potokar, & R. M. N. Linan (Eds.), *European Local Pig Breeds - Diversity and Performance. A study of project TREASURE*. IntechOpen. <https://doi.org/10.5772/intechopen.83773>
139. RAGUVARAN, R., SANGEETHA, P., PRABAKAR, G., JADHAV RAVINDRA, J. V. (2017): Stillbirth and mummification in swine: A review. *Agricultural research communication centre*. Available online: <http://arccarticles.s3.amazonaws.com/arcc/Galley-Proof-R-1625.pdf>.
140. RAJCSANYI, V. K. (2017). Changes in the livestock of Hungarian pig farming and its position in international trade (Part II). *European Scientific Journal, ESJ*. 13(7), 29.
141. RÁTKY, J., BRÜSSOW, K-P., SOLTI, L., TORNER, H., SARLÓS, P. (2001): Ovarian response, embryo recovery and results of embryo transfer in a hungarian native pig breed. *Theriogenology*. 56(5), 969–978.
142. RATKY, J., EGERSEGI, I., TOTH, P., KEONUCHAN, S., NAGAI, T., KIKUCHI, K., MANABE, N., BRUSSOW, H. P. (2013): Saving genetic resources of native pigs in occidental and oriental countries-practical examples of the characterization and utilization of native pigs in Hungary and Laos. *Journal of reproduction and development*. 59(5), 437–441.
143. RIEDEL, S., SCHIBORRA, A., HÜLSEBUSCH, C., SCHLECHT, E. (2014): The productivity of traditional smallholder pig production and possible improvement strategies in Xishuangbanna, South Western China. *Livestock Science*. 160, 151–162.
144. ROONGSITTHICHAI, A., TUMMARUK, P. (2014): Importance of backfat thickness to reproductive performance in female pigs. *Thai Journal of Veterinary and Medicine*. 44(2), 171–178.

145. SASAKI, Y., KOKETSU, Y. (2007): Variability and repeatability in gestation length related to litter performance in female pigs on commercial farms, *Theriogenology*. 68(2), 123–127.
146. SHANNON, M. (2005): Nutrition and feeding for optimum reproductive performance. S133 Animal Sciences Center, Columbia, MO 65211.
147. SHRESTHA, N. P., EDWARDS, S. A., ENGLISH, P. R., ROBERTSON, J. F. (2003): Factors affecting reproductive performance in Nepalese Pakhribas pig: Effects of Nutrition and Housing during Lactation. *Asian-Aust. Journal of Animal Science*. 16(5), 644–649.
148. ŠKORJANC, D., HOHLER, M., AND BRUS, M. (2008): Effect of backfat loss during lactation on weaning-to-oestrus interval of sows at gonadotropin application, *Archives Animal Breeding*. 51, 560–571.
149. SILVA, G. L. L. P.; THUY, L. T.; ABEYKOON, N. D.; HANH, N. T. H.; BETT, R. C.; OKEYO, M.; IBRAHIM, M. N. M. (2016): Comparative study of Indigenous pig production in Vietnam and Sri Lanka. *International Journal of Livestock Production*. 7(10), 84–93.
150. SOEDE, N. M., KEMP, B. (1997): Expression of oestrus and timing of ovulation in pigs. *Journal of Reproduction and Fertility. Supplement*. 52, 91–103.
151. SOEDE, M., LANGENDIJK, P., KEMP, B. (2011): Reproductive cycles in pigs. *Animal Reproduction Science*. 124(3–4), 251–258.
152. STASIAK, A., KASPRZYK, A., SAŁYGA, M. (2006): The effect of the season of farrowing on selected performance traits in Pulawska sows. *Animal science papers and reports*, 24, 87–91, Institute of Genetics and Animal Breeding, Jastrzębiec, Poland. <https://www.researchgate.net/publication/266884398>. Last access on 5/11/2021
153. STEVENSON, J. S., BRITT, J. H. (1981): Interval to estrus in sows and performance of pigs after alteration of litter size during late lactation. *Journal of animal science*. 53(1), 177–181.
154. STÜR, W., GRAY, D., BASTIN, G. (2002): Review of the livestock sector in the Lao People's Democratic Republic. *International Livestock Research Institute*., https://cgspace.cgiar.org/bitstream/handle/10568/21136/adb_livestock_review.pdf?
155. SUPAKORN, C., STOCK, J.D., GARAY, E., JOHNSON, A.K. AND STALDER, K.J. (2018): Lameness: a principle problem to sow longevity in breeding herds. *CABI Reviews*. pp.1–14.
156. SZABÓ, P., PAPP, C., TÓTH, P., VÁSÁRHELYI, B. (2003): Mangalica pig register. National Association of Mangalica Breeders. Debrecen, Hungary.
157. SZABÓ, P., PAPP, C., TÓTH, P., VÁSÁRHELYI, B. (2013): Mangalica pig register. National Association of Mangalica Breeders. Debrecen, Hungary.
158. THAKER, M.Y.C., BILKEI, G. (2005): Lactation weight loss influences subsequent reproductive performance of sows. *Animal Reproduction Science*. 88(3–4), 309–318.

159. THODBERG, K., JENSEN, K. H., HERSKIN, M. S. (2002): Nest building and farrowing in sows: relation to the reaction pattern during stress, farrowing environment and experience. *Applied Animal Behaviour Science*. 77(1), 21–42.
160. TUCKER, B. S., CRAIG, J. R., MORRISON, R. S., SMITS, R. J., KIRKWOOD, R. N. (2021): Piglet Viability: A review of identification and pre-weaning management strategies. *Animals: an Open Access Journal from MDPI*, 11(10).
161. TUMMARUK, P., KESDANGSAKONWUT, S. (2014): Uterine size in replacement gilts associated with age, body weight, growth rate, and reproductive status. *Czech Journal of Animal Science*. 59(11), 511–518.
162. UDOMCHANYA, J., SUWANNUTSIRI, A., SRIPANTABUT, K., PRUCHAYAKUL, P., JUTHAMANE, P., NUNTAPAITOON, M., TUMMARUK, P. (2019): Association between the incidence of stillbirths and expulsion interval, piglet birth weight, litter size and carbetocin administration in hyper-prolific sows. *Livestock Science*. 227, 128–134.
163. VALLE ZÁRATE, A., HAU, N.V, THUY, L.T. (2010): Reproductive performance of local pig breeds reared under smallholder conditions in Son La province, northwest of Vietnam. *Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia – Hanoi, 21-23 July 2010*, <https://projekte.uni-hohenheim.de/sfb564/uplands2010/presentations/186.pdf>
164. VAN DER MEULEN, J., KOOPMANS, S. J., DEKKER, R. A., HOOGENDOORN, A. (2010): Increasing weaning age of piglets from 4 to 7 weeks reduces stress, increases post-weaning feed intake but does not improve intestinal functionality. *Animals*. 4(10), 1653–1661.
165. VANDERHAEGHE, C., DEWULF, J., KRUIF, A., MAES, D. (2013): Non-infectious factors associated with stillbirth in pigs: A review. *Animal Reproduction Science*. 139(1–4), 76–88.
166. VAN DIJK, A., VAN RENS, B., VAN DER LENDE, T., TAVERNE, M. (2005). Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. *Theriogenology*. 64(7), 1573–1590.
167. VARLEY, M. A. (1989): Factors affecting the reproductive performance of sows. *The production of pig meat in Mediterranean Countries*. Paris: CIHEAM. pp: 101–106.
168. VILA, R. M., TUMMARUK, P. (2016): Management strategies in farrowing house to improve piglet pre-weaning survival and growth. *The Thai Journal of Veterinary Medicine*. 46(3), 347.
169. WARD, S. A., KIRKWOOD, R. N., PLUSH, K. J. (2020): Are larger litters a concern for piglet survival or an effectively manageable trait? *Animals*. 10(2), 309.

170. WEITZE, K. F., WAGNER-RIETSCHER, H., WABERSKI, D., RICHTER, L., KRIETER, J. (1994): The onset of heat after weaning, heat duration, and ovulation as major factors in AI timing in sows. *Reproduction in Domestic Animals*. 29(5), 433–443.
171. WHITE, B.R., MCLAREN, D.G., DZIUK, P.J., WHEELER, M.B. (1993): Age at puberty, ovulation rate, uterine length, prenatal survival and litter size in Chinese Meishan and Yorkshire females. *Theriogenology*. 40, 85–97.
172. WILSON, T. R. (2007): Status and prospects for livestock production in the Lao People's Democratic Republic. *Tropical animal health and production*. 39, 443–452.
173. WEBSTER, J. (2011): Management and welfare of farm animals. The UPAW farm handbook. 5th edition. Edited by Webster J. Wiley-Blackwell. Pp. 253–291.
174. XAYALATH, S. and SACKLORKHAM, S. (2010): Study the impact of villages' Pig Bank implementation in Khua and Samphanh districts, Phongsaly province, Laos. Thesis. Department of rural economic and food technologies; Faculty of Agriculture; National University of Laos.
175. XAYALATH, S., SACKLORKHAM, S., KAENSOMBATH, L. (2016): Study on the indigenous pig production system and its market potential for improving the livelihood of farmers in Lao Ngam district Saravanh province. Thesis. Division of post graduated; Faculty of Agriculture; National University of Laos.
176. YAN, L., JANG, H.D., KIM, I. H. (2011): Effects of varying creep feed duration on pre-weaning and post-weaning performance and behavior of piglet and sow. *Asian-Australasian Journal of Animal Sciences*. Asian Australasian Association of Animal Production Societies. 4,1601–1606.
177. YOUNG, L. G., KING, G.L (1981): Reproductive performance of gilts bred on first versus third estrus. *Journal of Animal Science*. 53(1), 19–25.

10. PUBLICATIONS ON THE TOPIC OF THE DISSERTATION



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Candidate: Somsy Xayalath
Doctoral School: Doctoral School of Animal Husbandry
MTMT ID: 10070656

List of publications related to the dissertation

Foreign language scientific articles in Hungarian journals (2)

1. **Xayalath, S.**, Rátky, J., Komlósi, I.: Reproductive performance of indigenous pig breeds in Southeast Asia.
Állatteny. takarm. 70 (1), 3-14, 2021. ISSN: 0230-1814.
2. **Xayalath, S.**, Balogh, E. E., Rátky, J.: The role of animal breeding with special regard to native pigs of food supply and rural development in Laos.
Agrártud. Közl. 1 (1), 149-154, 2020. ISSN: 1587-1282.
DOI: <http://dx.doi.org/10.34101/actaagrar/1/3771>

Foreign language scientific articles in international journals (4)

3. **Xayalath, S.**, Mujitaba, M. A., Ortega, A. D. S. V., Khangembam, R., Novotniné Dankó, G., Rátky, J.: Effects of birth weight on puberty and the reproductive performance of crossbred Moo Lath x Duroc gilts = A születési súly hatása az ivarérésre és a szaporodásbiológiai teljesítményre keresztezett Moo Lath x Duroc kocasüldőknél.
J. Cent. Eur. Agric. "Accepted by Publisher" (-), 1-11, 2023. ISSN: 1332-9049.
4. **Xayalath, S.**, Novotniné Dankó, G., Rátky, J.: Suckling duration affects sow body conditions and early post-weaning growth performance in Moo Lath piglets.
12 (2), 363-374, 2022. ISSN: 2066-6276.
DOI: <http://dx.doi.org/10.31924/nrsd.v12i2.112>
5. **Xayalath, S.**, Novotniné Dankó, G., Rátky, J.: The Role of Estrous Synchronization and Artificial Insemination in Improving the Reproductive Performance of Moo Lath Gilts.
Agriculture-Basel. 12 (10), 1-11, 2022. EISSN: 2077-0472.
DOI: <http://dx.doi.org/10.3390/agriculture12101549>
IF: 3.408 (2021)





6. **Xayalath, S.**, Novotniné Dankó, G., Balogh, P., Brüssow, K. P., Rátky, J.: Reproductive performance of indigenous Lao pigs reared by small-scale farmers in northern provinces of Laos.
Arch. Anim. Breed. 64 (2), 365-373, 2021. EISSN: 2363-9822.
DOI: <http://dx.doi.org/10.5194/aab-64-365-2021>
IF: 1.776

Foreign language conference proceedings (1)

7. **Xayalath, S.**, Rátky, J.: Gilts and sows reared by commercial farms in the central and southern Laos: Management and reproductive performance.
In: Conference Papers from the 1st Stipendium Hungaricum PhD Student Conference. Eds.: Kitti Érsek, Annamária Keresztes, Tempus Public Foundation, Budapest, 119-128, 2023.

List of other publications

Foreign language scientific articles in Hungarian journals (3)

8. **Xayalath, S.**, Mujitaba, M. A., Ortega, A. D. S. V., Rátky, J.: Opportunities and challenges for pig production in Vientiane Capital, Laos: a review.
Rev. Agric. Rural Dev. 11 (1-2), 3-8, 2022. ISSN: 2063-4803.
DOI: <http://dx.doi.org/10.14232/rard.2022.1-2.3-8>
9. **Xayalath, S.**, Mujitaba, M. A., Ortega, A. D. S. V., Rátky, J.: A review on the trend of livestock breeds in Laos.
Acta Agrar. Debr. 2021 (1), 227-237, 2021. ISSN: 1587-1282.
DOI: <http://dx.doi.org/10.34101/ACTAAGRAR/1/9047>
10. Ortega, A. D. S. V., Mujitaba, M. A., **Xayalath, S.**, Gutierrez, W., Soriano, A. C., Szabó, C.: Perspectives of the livestock sector in the Philippines: A review.
Acta Agrar. Debr. 2021 (1), 175-188, 2021. ISSN: 2416-1640.
DOI: <http://dx.doi.org/10.34101/actaagrar/1/9101>

Foreign language conference proceedings (1)

11. Ortega, A. D. S. V., **Xayalath, S.**, Lugata, J. K., Szabó, C.: Effects of heat stress-induced oxidative stress on the reproduction of sows and its alleviation by dietary antioxidants – a review.
In: XXV. Tavaszi Szél Konferencia 2022 : Tanulmánykötet I.. Szerk.: Molnár Dániel, Molnár Dóra, Nagy Adrián Szilárd, Doktoranduszok Országos Szövetsége, Budapest, 13-25, 2022.
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Foreign language abstracts (4)

12. Ortega, A. D. S. V., **Xayalath, S.**, Lugata, J. K., Szabó, C.: Effects of heat stress-induced oxidative stress on the reproduction of sows and its alleviation by dietary antioxidants: a review.
In: XXV. Tavasz Szél Konferencia 2022 : Absztraktkötet. Szerk.: Molnár Dániel, Molnár Dóra, Doktoranduszok Országos Szövetsége, Budapest, 72-73, 2022. ISBN: 9786158205481
13. **Xayalath, S.**, Rátky, J.: Opportunities and challenges for pig production in vientiane capital, Laos: a review.
In: 19th Wellmann International Scientific Conference : Book of Abstracts. Ed.: Orsoly Kiss, University of Szeged Faculty of Agriculture, Hódmezővásárhely, 95, 2022. ISBN: 9789633068601
14. **Xayalath, S.**, Rátky, J.: The role of estrous synchronization and artificial insemination in improving reproductive performance of moo lath primiparous sows.
In: XXV. Tavasz Szél Konferencia 2022 : Absztraktkötet / Molnár Dániel, Molnár Dóra, Doktoranduszok Országos Szövetsége, Budapest, 91, 2022. ISBN: 9786158205481
15. **Xayalath, S.**, Rátky, J.: Current management and reproductive performance of gilts and sows at small and large commercial farms in the central and southern Laos.
In: XXIV. Tavasz Szél Konferencia 2021 : Absztraktkötet. Szerk.: Molnár Dániel, Molnár Dóra, Doktoranduszok Országos Szövetsége, Budapest, 69, 2021. ISBN: 9786155586996

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The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

26 April, 2023



11. DECLARATIONS

DECLARATION

I hereby declare that I have prepared this dissertation in the framework of the Doctoral School of Animal Science, University of Debrecen, in order to obtain the doctoral (PhD) degree in Animal Husbandry.

Debrecen, 2023/...../.....

.....
Somsy Xayalath
PhD candidate

DECLARATION

I hereby declare that **Somsy Xayalath** PhD candidate, has carried out his work under my/our supervision between 2019 and 2023 within the framework of the Doctoral School of Animal Science, University of Debrecen. The findings of the dissertation represent the candidate's own ideas and independent work. I recommend accepting the dissertation.

Debrecen, 2023/...../.....

.....
supervisor
Prof. Dr. Jozsef Ratky
Professor

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