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Preweaning piglet mortality and colostrum consumption associated with parity number, season, newborn traits and dietary *L*-arginine supplementation in gestating sows

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A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Theriogenology
Department of Obstetrics Gynaecology and Reproduction
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มรกต นันทไพฑูรย์ : การตายก่อนหย่านมและปริมาณน้ำนมเหลืองที่ลูกสุกรได้รับสัมพันธ์กับลำดับท้อง ฤดูกาล คุณลักษณะของลูกแรกเกิด และการเสริม แอล-อาร์จินีนในอาหารแม่สุกรอุ้มท้อง (Preweaning piglet mortality and colostrum consumption associated with parity number, season, newborn traits and dietary *L*-arginine supplementation in gestating sows) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. น.สพ. ดร. เผด็จ ธรรมรักษ์, 187 หน้า.

การตายของลูกสุกรก่อนหย่านมเป็นส่วนหนึ่งที่สำคัญของระบบการสืบพันธุ์ที่มีผลต่อผลผลิตในอุตสาหกรรมการเลี้ยงสุกร องค์ความรู้ที่เกี่ยวกับปัจจัยที่มีผลต่ออัตราการตายของลูกสุกรก่อนหย่านมเป็นสิ่งที่สำคัญในการปรับปรุงสวัสดิภาพสัตว์ ลดการสูญเสียผลผลิตและเพิ่มผลกำไรในฟาร์มสุกร วัตถุประสงค์ในการศึกษาครั้งนี้เพื่อสำรวจปัจจัยที่มีผลต่ออัตราการตายของลูกสุกรก่อนหย่านมในฟาร์มสุกรของประเทศไทยในปัจจัยด้านลูกสุกร แม่สุกร และสิ่งแวดล้อม รวมทั้งได้ทำการศึกษาปัจจัยที่มีผลต่อปริมาณน้ำนมเหลืองที่ลูกสุกรได้รับร่วมไปด้วย นอกจากนี้ได้ทำการศึกษาถึงผลของการเสริมแอล-อะจินีนในอาหารแม่สุกรอุ้มท้องระยะท้ายต่อประสิทธิภาพของแม่สุกรและลูกสุกร การวิจัยเชิงวิเคราะห์แบบย้อนหลังได้ทำการนำข้อมูลที่จดบันทึกในระบบคอมพิวเตอร์ของฟาร์มมาวิเคราะห์เพื่อให้ทราบข้อมูลพื้นฐานของอัตราการตายของลูกสุกรก่อนหย่านมในประเทศไทยและทำการศึกษาปัจจัยที่มีผลต่ออัตราการตายของลูกสุกรก่อนหย่านมจากข้อมูล ผลการศึกษาพบว่า อัตราการตายของลูกสุกรก่อนหย่านมมีค่าเฉลี่ยอยู่ที่ 11.2% (ค่ามัธยฐาน = 9.1%) และมีค่าระหว่าง 4.8% ถึง 19.2% จากแต่ละฟาร์ม ครอกที่มีจำนวนลูกสุกรที่เลี้ยงระหว่าง 13 – 15 ต่อครอก (24.1%) มีอัตราการตายของลูกสุกรก่อนหย่านมสูงกว่าครอกที่มีจำนวนลูกสุกรที่เลี้ยงระหว่าง 1 – 7 (11.9%, $P < 0.001$) 8 – 10 (11.8%, $P < 0.001$) และ 11 – 12 (14.6%, $P < 0.001$) ตัวต่อครอก ครอกที่มีลูกสุกรน้ำหนักแรกเกิดต่ำ (18.8%) มีอัตราการตายของลูกสุกรก่อนหย่านมสูงกว่าครอกที่มีลูกสุกรน้ำหนักแรกเกิดปานกลาง (15.7%, $P < 0.001$) และครอกที่มีลูกสุกรน้ำหนักแรกเกิดสูง (12.1%, $P < 0.001$) สุกรสาวมีอัตราการตายของลูกสุกรก่อนหย่านมเพิ่มขึ้นจาก 12.1% เป็น 18.5% (+6.4%) เมื่ออุณหภูมิโดยรอบระหว่าง 0 – 7 วันหลังคลอดเพิ่มขึ้นจาก < 25.0 องศาเซลเซียส เป็น ≥29 องศาเซลเซียส ($P < 0.001$) อัตราการตายของลูกสุกรก่อนหย่านมในฟาร์มขนาดใหญ่มีค่าสูงกว่าฟาร์มขนาดเล็กและฟาร์มขนาดกลาง (13.6%, 10.6% and 11.2% ตามลำดับ; $P < 0.001$) การวิจัยเชิงวิเคราะห์แบบไปข้างหน้าได้ทำการศึกษาปัจจัยของคุณลักษณะของลูกแรกเกิด (ประกอบด้วย อัตราการเต้นของหัวใจ ระดับออกซิเจนในกระแสเลือด ความเข้มข้นของน้ำตาลในกระแสเลือด อุณหภูมิทางทวารหนักที่ 24 ชั่วโมงหลังเกิด ลำดับการเกิด เพศ สีผิว ลักษณะของสายสะดือ ระยะเวลาตั้งแต่เกิดจนสามารถยืนได้ และการช่วยให้เกิด) ที่ทำการประเมินทันทีหลังคลอดต่ออัตราการตายและอัตราการเจริญเติบโตของลูกสุกรก่อนหย่านม ผลการศึกษาพบว่า อัตราการตายของลูกสุกรก่อนหย่านมสูงขึ้นเมื่อระยะเวลาตั้งแต่เกิดจนสามารถยืนได้มีระยะเวลานาน สีผิวซีด อุณหภูมิทางทวารหนักที่ 24 ชั่วโมงหลังเกิดต่ำกว่า 37.0 องศาเซลเซียสและมีปริมาณน้ำนมเหลืองที่ได้รับต่ำกว่า 400 กรัม ($P < 0.05$) น้ำหนักแรกเกิดของลูกสุกร ความเข้มข้นของน้ำตาลในกระแสเลือดและจำนวนลูกสุกรแรกเกิดมีชีวิตต่อครอกสัมพันธ์กับอัตราการเจริญเติบโตของลูกสุกรที่ 7 และ 21 วัน ($P < 0.05$) นอกจากนี้ ลูกสุกรที่ได้รับปริมาณน้ำนมเหลืองที่ต่ำกว่า 400 กรัมและมีน้ำหนักแรกเกิดต่ำจะมีอัตราการเจริญเติบโตที่ต่ำ ($P < 0.001$) ครอกที่มีจำนวนลูกสุกรแรกเกิดมีชีวิตน้อยกว่า 12 ต่อครอก น้ำหนักแรกเกิดต่ำ เกิดในลำดับที่มากกว่า 9 หรือมีระยะเวลาตั้งแต่เกิดจนสามารถยืนได้มากกว่า 5 นาที จะได้รับปริมาณน้ำนมเหลืองในระดับต่ำ ($P < 0.001$) เมื่อเปรียบเทียบกับครอกที่มีจำนวนลูกสุกรแรกเกิดมีชีวิตมากกว่า น้ำหนักแรกเกิดสูงกว่าและมีระยะเวลาตั้งแต่เกิดจนสามารถยืนได้สั้นกว่า การเสริมแอล-อาร์จินีนในอาหารแม่สุกรอุ้มท้องระยะท้ายสามารถเพิ่มน้ำหนักลูกสุกรแรกเกิด ระดับออกซิเจนในกระแสเลือดของลูกสุกร สัดส่วนของจำนวนลูกสุกรแรกเกิดมีชีวิตต่อครอกและระดับความเข้มข้นของอิมมูโนกอบบูลิน จี ที่ 1 ชั่วโมงหลังคลอดในน้ำนมเหลือง ($P < 0.05$) อีกทั้งยังสามารถลดการตายของลูกสุกรแรกเกิดและมีแนวโน้มที่จะเพิ่มสัดส่วนของลูกสุกรที่มีน้ำหนักแรกเกิด 1.35 กิโลกรัมและลดการสูญเสียไขมันสันหลังในแม่สุกรระหว่างเลี้ยงลูกอีกด้วย จากผลการศึกษาทั้งหมดสามารถสรุปได้ว่า อัตราการตายของลูกสุกรก่อนหย่านมมีความเกี่ยวข้องกับ ลำดับท้อง สภาวะภูมิอากาศ ขนาดฟาร์ม คุณลักษณะของลูกแรกเกิดและปริมาณน้ำนมเหลืองที่ลูกสุกรได้รับ การเสริมแอล-อาร์จินีนในอาหารแม่สุกรอุ้มท้องระยะท้ายสามารถปรับปรุงประสิทธิภาพของแม่สุกรและลูกสุกรได้

ภาควิชา สูติศาสตร์-เธนุเวชวิทยาและวิทยาการสืบพันธุ์ ลายมือชื่อนิสิต ....

สาขาวิชา วิทยาการสืบพันธุ์สัตว์ ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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KEYWORDS: ARGININE, BIRTH WEIGHT, COLOSTRUM, PIG, PREWEANING MORTALITY

MORAKOT NUNTAPAITOON: Preweaning piglet mortality and colostrum consumption associated with parity number, season, newborn traits and dietary *L*-arginine supplementation in gestating sows. ADVISOR: PROF. PADET TUMMARUK, D.V.M., M.Sc., Ph.D., 187 pp.

Piglet preweaning mortality is one of the major reproductive components that affects herd productivity in the swine industry. Knowledge of factors that influence piglet preweaning mortality are important to improve animal welfare, to reduce production loss and to increase profits in commercial herds. The present study aimed to investigate factor influencing piglet preweaning mortality in commercial swine herd in Thailand in relation to piglet, sow and environmental factors. Moreover, influencing factors on piglet colostrum consumption were also determined. Additionally, effect of dietary *L*-arginine supplementation in late gestating sow on sow and piglet performances were investigated. From retrospective studies, the data from a computerized data-base system of the herds were analysed resulting in known basic knowledge of piglet preweaning mortality in Thailand and were determined factors which related piglet mortality. On average, piglet preweaning mortality was 11.2% (median = 9.1%) and varied among herds from 4.8% to 19.2%. Piglet preweaning mortality in the litter with 13 – 15 littermate pigs (24.1%) was significantly higher than the litter with 1 – 7 (11.9%, $P < 0.001$), 8 – 10 (11.8%, $P < 0.001$) and 11 – 12 (14.6%, $P < 0.001$) littermate pigs. The litters with a low BW_B had a higher piglet preweaning mortality rate (18.8%) than the litters with a medium (15.7%, $P < 0.001$) and a high BW_B (12.1%, $P < 0.001$). In primiparous sows, preweaning mortality was increased from 12.1% to 18.5% (+6.4%) when the temperature during 0 – 7 days postpartum increased from < 25.0 °C to ≥ 29 °C ($P < 0.001$). Piglet preweaning mortality in large sized herds was higher than among small and medium sized herds (13.6%, 10.6% and 11.2%, respectively; $P < 0.001$). From cohort studies, newborn traits (*i.e.,* heart rate, blood oxygen saturation, blood glucose concentration, rectal temperature at 24 h after birth (RT24h), birth order, sex, skin color, integrity of the umbilical cord, time from birth until first attempts to stand and birth intervention) measured soon after birth on piglet preweaning mortality and growth were measured. We found that high piglet preweaning mortality positively was found in piglet with high time from birth until first attempts to stand, pale skin color, piglet with RT24h below 37.0 °C and piglets with colostrum consumption less than 400 g ($P < 0.05$). Piglet BW_B, blood glucose concentration and the number of piglets born alive per litter (NBA) were correlated with average daily gain at 7 and 21 days of age ($P < 0.05$). Moreover, piglets with colostrum consumption less than 400 g and low BW_B had reduced average daily weight gain ($P < 0.001$). Litters with less than 12 NBA, a low BW_B piglet, birth order greater than nine or standing time greater than 5 min had lower colostrum consumption ($P < 0.001$) compared to those with a greater number NBA, higher BW_B and shorter standing time. Dietary *L*-arginine HCl supplementation in sow diet during late gestation increased BW_B, blood oxygen saturation, the proportion of NBA and the colostral concentration of immunoglobulin G at one h after onset of farrowing ($P < 0.05$). Moreover, *L*-arginine supplementation reduced stillborn and tended to increase the proportion of piglets with BW_B above 1.35 kg and tended to reduce the relative backfat loss in sows. In conclusion, preweaning piglet mortality associated with sow parity number, climatic parameters, herd size, newborn traits and colostrum consumption. Dietary *L*-arginine supplementation in late gestating sows improved sow and piglet performances.

Department:	Obstetrics Gynaecology and Reproduction	Student's Signature	....
Field of Study:	Theriogenology	Advisor's Signature	....
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LIST OF ABBREVIATIONS

°C	degree celsius
μl	Microliter
ADG	average daily gain
ADG21	average daily gain at 21 days
ADG7	average daily gain at 7 days
ADV	aujeszky's disease virus
ALA	1.7% *L*-alanine
ANOVA	analysis of variance
ARG-0.5	0.5% *L*-arginine hydrochoride
ARG-1.0	1.0% *L*-arginine hydrochloride
BSA	Bovine serum albumin
BW_B	birth weight
CC	colostrum consumption
cm	Centimeter
CO_2	carbon dioxide
CON	conventional gestation diet
CORR	correlation analysis
CSFV	classical swine fever virus
CV	coefficient of variation
CY	colostrum yield
d	day
D	duration of colostrum suckling
ELISA	Enzyme-linked immunosorbent assay
eNOS	endothelium nitric oxide synthase
EU	european union
FMDV	Foot-and-mouth disease virus
FREQ	Frequency
g	Gram
g/d	gram/day

g/kg	gram/kilogram
GENMOD	logistic regression analyses
GLIMMIX macro	generalised linear mixed model
GLM	general linear model
growth factor-β	growth factor-beta
h	Hour
HR	heart rate
IACUC	institutional animal care and use committee
ID	Identification number
Ig	Immunoglobulin
IGF	insulin-like growth
IUGR	intrauterine growth retardation
kcal/kg	Kilocalorie per kilogram
KJ/kg	Kilojoule per kilogram
Kg	Kilogram
Km	Kilometer
L-arginine HCl	*L*-arginine hydrochloride
LS	litter sizes
LY	landrace and Yorkshire
M	Molar
m^2	millimeter square
MEANS	Mean
Mg	Milligram
mg/dL	milligram per deciliter
mg/kg	milligram per kilogram
Min	Minute
MIXED	general linear mixed models procedure
mL	Milliliter
Mm	Millimeter
MM	number of mummified fetuses per litter

MMA	Mastitis-metritis-agalactia
mTOR	mammalian target of rapamycin
NaCl	sodium choride
NBA	number of piglet born alive per litter
ng/mL	nanogram per milliliter
NOAEL	no observe adverse effect level
NTB	number of total born piglet per litter
PDS	post-partum dysgalactia syndrome
PPV	porcine parvovirus infection
PROC	Procedure
PRRS	porcine reproductive and respiratory syndrome
PUFAs	long-chain polyunsaturated fatty acids
PWM21	piglet preweaning mortality during 0 – 21days
PWM7	piglet preweaning mortality during 0 – 7 days
r	correlation coefficient
r^2	regression coefficient
REML	restricted maximum likelihood
RT24h	rectal temperature at 24 h after birth
SAS	statistical analysis system
$SatO_2$	blood oxygen saturation
SB	number of stillborn piglets per litter
SD	standard deviation
sec	Second
SEM	standard error of mean
THI	temperature-humidity index
TTEST	student's *t* test
UNIVARIARE	univariate analysis
USA	the united states of America
VEGF	vascular endothelial growth factor
WG	piglet weight gain

Chapter I

Introduction

1.1 Importance and rational

The reproductive management on the newly developed genetic line of swine must focus on the survival of piglets during sucking period or " piglet preweaning mortality". Under field conditions, swine production in general commercial herds still required much improvement to achieve this goal. One of the major problem in most swine industry is the postpartum management and piglet care during lactation period.

Piglet preweaning mortality is one of the major reproductive components affecting herd productivity in swine industry. In major pig producing countries, the average piglet preweaning mortality rate in swine commercial herds varied between 10 – 20% (Tuchscherer et al., 2000; Koketsu et al., 2006; Kilbride et al., 2012; Kirkden et al., 2013b). It has been demonstrated that many factors including sow parity number, farrowing duration, birth order, dystocia, health, environmental temperature, nutritional status, sex, maternal behavior, piglet birth weight (BW_B), and number of littermate, are all important factors determining the incidence of piglet preweaning mortality under field conditions (Baxter et al., 2009; Panzardi et al., 2013). In general, the causes of piglet mortality before weaning include crushing (33.8%), low viability (29.7%), scours (12.2%), infection (8.1%), congenital abnormality (5.5%) and miscellaneous (10.7%) (Vaillancourt et al., 1990). It is important for veterinarians to understand the possible causes of piglet mortality before weaning to reduce the risk of piglet preweaning mortality and hence increase number of healthy piglet at weaning.

The factors causing piglet preweaning mortality can be classified into three major groups, *i.e.*, sow factors, piglet factors and environmental factors. Sow factors associated with the piglet preweaning mortality include parity number of sow, farrowing duration and colostrum production. In general, the risk of piglet preweaning mortality is increase as the parity number of sows increased (Koketsu et al., 2006). The reason is due to the fact that, as parity number increase, a raise in the number of piglet born, a decrease of individual piglet BW_B and a raise in the number of small piglets within the litter are observed. Furthermore, the duration of farrowing in sows parity number 1 is shorter than sows parity number ≥ 2 (Tummaruk and Sang-Gassanee, 2013). Piglets born after a prolonged farrowing duration are more likely to experience hypoxia and become low viability at birth (Tuchscherer et al., 2000). Colostrum yield has been shown to be highly variable among sows, even within the same breed and in a similar conditions of housing and management (Devillers et al., 2007; Farmer and Quesnel, 2009). Furthermore, colostrum yield is largely dependent on the capacity of colostrum production of sow (Devillers et al., 2007; Quesnel, 2011). The colostrum consumption of the piglets is positively associated with their survival and body weight gain during the first six weeks of life (Devillers et al., 2011). Colostrum consists of immunoglobulin and it is the main source of energy for piglets. Thus, adequate colostrum comsumption can prevent hypothermia and hypoglycaemia in newborn piglets.

Environmental factors associated with piglet preweaning mortality include season, housing and postpartum care. The seasonal influence on piglet preweaning mortality is equivocal. In general, the newborn piglets are very sensitive to thermal stress due to incomplete thermoregulation at birth. It is well established that thermal stress is the most important stressor in newborn piglet (Baxter et al., 2009; Shankar et al., 2009). Under the environment with low ambient temperature, piglets are at risk to be crushed by the sows (Shankar et al., 2009). Le Dividich and Noblet (1981) found that colostrum consumption decrease during cold exposure, exacerbating the likelihood of starvation. On the other hand, high ambient temperature may decrease feed intake of the lactating sows due to heat stress (Li et al., 2010) This may affect milk production and decrease the piglet body weight gain (McNamara and Pettigrew, 2002). On average, preweaning mortality in large herds was lower than that in small herds (Friendship et al., 1986; Hoshino et al., 2009; Nuntapaitoon and Tummaruk, 2013a). The effect of herd size on piglet preweaning mortality maybe related with postpartum management and quality of stock persons. Hoshino et al. (2009)

demonstrated that high-performing herd in Japan had a lower number of pig born dead than low-performing herd.

Piglet factors associated with piglet preweaning mortality included BW_B, number of littermate pigs, and newborn piglet traits. High number of littermate pig is associated with high piglet mortality before weaning (Hoshino et al., 2009; Loncke et al., 2009). An increase litter size (LS) results in an increase the proportion of small piglets, a reduced uniformity of litter and a decrease average BW_B (Campos et al., 2012). These factors negatively affect the piglet vitality and growth performance. Tuchscherer et al. (2000) found that large LSs are associated with high blood glucose concentration in piglets. It has been demonstrated that the high blood glucose concentration is usually found in weak born piglets and stillborn (Lauterbach et al., 1987). Moreover, large litters are associated with a prolonged duration of farrowing (Zaleski and Hacker, 1993b). Piglet with a high BW_B had a shorter period from birth to first sucking and consume colostrum more than a low BW_B (Tuchscherer et al., 2000). Moreover, the within-litter BW_B variation positively correlated with preweaning mortality (Wolf et al., 2008). The reason is that small piglets cannot compete with the larger littermate pigs. Thus, low BW_B piglets usually have low nutritional status and quality of passive immunity (Quiniou et al., 2002).

After parturition, the piglet needs to adapt to extra uterine life. Recent study indicated that piglet preweaning mortality was influenced by several factors associated with the newborn piglet traits (Panzardi et al., 2013). Some of the newborn piglet traits significantly influenced the piglet preweaning mortality included BW_B, number of piglet at birth, farrowing duration, dystocia, birth order, skin color, blood oxygen saturation ($SatO_2$), heart rate (HR), blood glucose concentration, characteristics of the umbilical cord and standing time (Herpin et al., 1996; Panzardi et al., 2013). Recently, Panzardi et al. (2013) found that the $SatO_2$ in newborn piglet average 76.3% and varied among individual from 10% to 100%. However, the relationship between the $SatO_2$ and the piglets survival could not be demonstrated (Casellas et al., 2004; Panzardi et al., 2013). Nevertheless, asphyxia of the newborn piglets remains one of the most important causes of stillbirth and early piglet preweaning mortality. Moreover, earlier study found that piglets with a low $SatO_2$ (*i.e.,* hypoxia) had a longer intervals from birth to the first suckling than the normal piglets (Tuchscherer et al., 2000). This significantly decrease daily weight gain and increase piglet preweaning mortality (Decaluwé et al., 2014).

Blood glucose concentration of the piglets is related to health status and energy reserve of newborn piglets (Baxter et al., 2008). Glucose is a main nutrient in all cells of both fetus and newborn piglet. Blood glucose concentration is also related with colostrum consumption (Quesnel et al., 2012). Low blood glucose level in newborn piglets is associated with a decreased colostrum consumption (Quesnel et al., 2012). The piglets with high blood glucose concentration are usually observed in those born after a long duration of farrowing, due to temporary hypoxia (Tuchscherer et al., 2000). The uterine contractions in sows with a long duration of farrowing also reduce the oxygenation of prenatal piglets. In addition, stress during parturition particularly in over size piglets leading to dystocia can alter the blood glucose concentration in piglets with a too heavy BW_B (Herpin et al., 1996; Mota-Rojas et al., 2011).

Dietary supplementation in pregnant and lactating sows have been intensively investigated during recent years in order to reduce piglet preweaning mortality and to enhance the piglet growth (Kalbe et al., 2013; Quesnel et al., 2014; Tummaruk et al., 2014). For instance, diets supplemented with *L*-carnitine during pregnancy significantly increase BW_B (Musser et al., 1999; Ramanau et al., 2002; Doberenz et al., 2006). The reasons might be due an increase intrauterine nutrient supply of glucose, glucose transporter-1 and maternal IGF-I (Doberenz et al., 2006). Moreover, dietary supplementation with 1% Glutamine in the lactating sow's feed significantly increased milk production of sows, enhanced gut health of the piglets, increased growth rate and survival rate of the piglets (Jackson, 2004). In addition, *L*-arginine supplementation in the sow's diet significantly increase BW_B of newborn piglets (Raghavan and Dikshit, 2004; Gao et al., 2012; Wu et al., 2013). Arginine is an important part in protein synthesis and is a component of the tissues of animals (Wu et al., 1999). In addition, arginine is an important for nitric oxide synthesis and polyamine synthesis (Wu and Morris, 1998). Nitric oxide and polyamine are importance for angiogenesis and embryogenesis and enhance the growth of the placenta and fetus (Reynolds and Redmer, 2001; Wu et al., 2004a). In fact, arginine catabolizes into its main product known as "nitric oxide", in which plays as an important role in the regulation of mammary gland blood flow, resulting in the supplement of nutrients to the lactating mammary gland (Kim and Wu, 2009). Recently, Quesnel et al. (2014) demonstrated that supplementing gestation diet with *L*-arginine HCl during the last third of pregnancy significantly reduced within-litter variation of BW_B.

In Thailand, factors influencing the piglet preweaning mortality in relation with *L*-arginine supplementation have not been investigated. Furthermore, the relationships among preweaning mortality, newborn traits and colostrum consumption of piglets under field conditions are also limited. These factors are important for improving litter performance and lead to an understanding on proper postpartum management in commercial swine herd in Thailand.

1.2 Keywords

Arginine, birth weight, colostrum, pig, preweaning mortality

1.3 Thesis coherence

Piglet preweaning mortality is a one of major problem in swine commercial herd worldwide. Actually, factor influencing piglet mortality includes piglet, sow and environmental factors. Many studies reported factors influencing on piglet preweaning mortality in cool climate. Nonetheless, in tropical climate, no comprehensive study on piglet preweaning mortality had been elucidated. In this study, factors influencing piglet preweaning mortality were investigated from retrospective study and cohort study for determining relationship among those factors on piglet preweaning mortality.

The present research included three parts; the first part (Chapter III, IV and V) investigated piglet preweaning mortality in swine commercial herd in Thailand in relation to piglet BW_B, the number of littermate pigs, sow parity number, season, climatic parameters and herd size. The second part (Chapter VI and VII) determined colostrum consumption of newborn piglets and studied the impact of colostrum consumption on piglet mortality and growth performance until weaning in tropical sows. Additionally, effect of some variables measured right after birth (*i.e.,* $SatO_2$, blood glucose concentration, birth order, BW_B, obstetric intervention, sex, skin color, integrity of the umbilical cord, time elapsed from birth until first attempts to stand and birth interval) on piglet mortality and average daily gain at d 7 (ADG7) and 21 (ADG21) of life were investigated. The third part (Chapter VIII) investigated the effect of *L*-arginine supplementation in the sow's diet during the last trimester of pregnancy (*i.e.,* 13 – 16 weeks of gestation) on piglet BW_B, within-litter BW_B variation, colostrum consumption, concentration of immunoglobulin G (IgG) in colostrum, piglet preweaning mortality and average daily gain (ADG).

In European country (EU), they have international organization for collecting data from all herd in Europe. Nonetheless, data in Thailand still recorded in herd levels. Therefore, the data of farm were completely recorded in the computerized recording system of the herd which should be analyzed for represented data in tropic for basic knowledge on piglet preweaning mortality in tropical climate. The relationships between piglet BW_B, the number of littermate pigs, sow parity number, season and climatic parameters in a commercial swine farm were presented in Chapter III and IV. Moreover, the relationships between piglet, sow and environmental factors (farrowing month and herd size) were presented in Chapter V.

Newborn piglet traits predicted piglet mortality (Panzardi et al., 2013). Differentiation of climate in each country related management strategies in farrowing pen. Piglet born in cool climate needs warm area immediately after birth. Effect of newborn traits on piglet preweaning mortality had been elucidated in tropical climate. Thus, association between newborn traits on piglet preweaning mortality and growth performance were analyzed in Chapter VI and VII.

Piglet BW_B and sow colostrum are piglet and sow factors influencing piglet preweaning mortality (Baxter et al., 2008; Fix et al., 2010; Rootwelt et al., 2013; Decaluwé et al., 2014). Therefore, management strategies for increasing piglet BW_B and colostrum production and quality were investigated in many studies (Mateo et al., 2008; Quesnel, 2011; Che et al., 2013). Arginine supplementation in the early gestating sow until farrowing increasing BW_B (Che et al., 2013). However, fetal development and colostrum production most occur in late gestation period (Bazer and Johnson, 2014). We hypothesized that arginine supplementation in the late gestating sow may increase

BW_B and sow colostrum production (Chapter VII). The knowledge of factor influencing piglet preweaning mortality improved management strategies in gestating sows may advantage for reducing piglet loss and increasing profit in commercial swine herd.

1.4 Research objectives

1) To investigate the occurrence of piglet mortality before weaning in swine commercial herds in Thailand
2) To investigate the relationships between piglet preweaning mortality and BW_B, the number of littermate pigs, sow parity number, season, climatic parameters and herd size
3) To evaluate the effects of some variables measured right after birth on piglet mortality and growth performance at 7 and 21 days of life
4) To determine the colostrum consumption from birth to 24 h after the onset of parturition and to study the impact of colostrum consumption on piglet mortality and growth performance until weaning
5) To investigate the effect of *L*-arginine supplementation in sow diet during the last third of pregnancy on within-litter BW_B variation, colostrum consumption and piglet preweaning mortality

1.5 Research outline

This recent thesis was operated in the Department of Obstetrics, Gynaecology and Reproduction, Faculty of Veterinary Science, Chulalongkorn University from May 2012 to 2016. The study was concentrated in factors influencing piglet preweaning mortality in commercial swine herds in Thailand. This dissertation contains nine chapters (Chapter I – IX).

Chapter I consisted of the introduction of this thesis, importance and rational, keywords, research coherence, research objectives, research outline and research benefits.

Chapter II was the literature review for this thesis.

Chapter III was the retrospective study from a commercial swine farm in Thailand. Data were collected from database of the computerized recording system of the herd. The breed of the sows is Landrace x Yorkshire (LY) F1 crossbred females. Piglet preweaning mortality in a swine commercial herd in Thailand in relation to BW_B, the number of littermate pigs, sow parity number were determined in this chapter.

Chapter IV was the retrospective study from a commercial swine farm in Thailand. The data were calculated the similar data in Chapter III. Climatic parameters effect on piglet preweaning mortality was investigated in this chapter.

Chapter V was the retrospective study of the piglet preweaning mortality in 47 swine commercial farm in Thailand. Piglet preweaning mortality associated with sow, piglet and environment factors were evaluated in this chapter.

Chapter VI was the cohort study of newborn piglet's traits at birth from 805 piglets and 57 multiparous sows in a commercial swine farm. Influenced piglet mortality and growth during suckling period were presented in this chapter. In addition, the blood glucose concentration, $SatO_2$ and HR of newborn piglet were also examined.

Chapter VII was the study of the relationship between newborn piglet's traits and colostrum consumption. The data were used from 1,660 piglets and 85 litters in a commercial swine farm. In addition, the amount of colostrum consumption influencing piglet preweaning mortality and growth were also investigated.

Chapter VIII was the study of the influencing of dietary arginine supplementation in late gestating sow on number of piglet born alive per litter (NBA) and BW_B. Data were collected from 166 sows and 2,292 piglets. In addition, the effects of arginine supplementation on colostrum consumption, piglet mortality and ADG in lactating period were also evaluated.

Chapter IX was the general discussion and conclusions of this thesis. In addition, research limitations and suggestion for further investigations were included in this chapter.

1.6 Research benefits

High mortality of the piglet occurs in preweaning period. Moreover, high economic loss in commercial swine farm was raise in this period. This problem still occurs in the commercial swine farm. Piglet, sow and environment are related with piglet preweaning mortality. This dissertation investigated the factor of piglet preweaning mortality in swine commercial herd in Thailand, including piglet, sow and environmental factors. The report of this dissertation might lead to understand about managing to reduce piglet loss, increase piglet performance and high weaned piglets thought increase profit of commercial swine herd in tropical climate.

Chapter II

Literature review

(Published in Livestock Science (2016) 184: 46 – 57)

2.1 Abstract

Piglet preweaning mortality is one of the major reproductive components that affects herd productivity in the swine industry. Knowledge of factors that influence piglet preweaning mortality are important to improve animal welfare, to reduce production loss and to raise profits in commercial herds. The main objective of the present work was to review the most important non-infectious causes of piglet preweaning mortality and to present the main factors influencing them under commercial conditions. Piglet preweaning mortality is a multifactorial process, the small size of piglets at birth, together with their low body energy storage and their immature immune system, make them prone to chilling, starving, or being crushed by the sow. In general, factors causing piglet preweaning mortality are usually classified into three major groups: piglet (*i.e.,* BW_B, vitality, gender), sow (*i.e.,* colostrum, parity, maternal stress, sow nutrition), and environmental factors (*i.e.,* season and temperature, housing, management). Birth weight is the most determinant factor for piglet survival with direct impact on thermoregulatory capacity and growth; piglet vitality is also correlated with survival and growth and is strongly influenced by the degree of intra-partum hypoxia suffered by the piglet; additionally, piglet preweaning mortality appears to be sex-biased, with males being at greater susceptibility to causal mortality factors. Newborn piglets are highly dependent on colostrum to use it as energy substrate for thermoregulation and growth, and also to acquire passive immunity crucial for their future survival; however, sow's parity is a factor with contradictory effect on piglet preweaning mortality which requires further research; a proper sow's comfort is also important for maternal stress around farrowing might have a negative impact on offspring's development and also increases the risk of crushing;

sow's nutrition will influence foetal development and piglet BW_B, and is determinant to ensure a proper colostrum/milk production. Finally, ambient temperature has an important impact on piglet survival because piglets are very sensitive to cold stress. The housing system used in the farrowing room seem to influence the incidence of crushing. Promising results have been obtained using recent designs that combine initial confinement of the sow with the subsequent ability to move within the same pen. Different management strategies to deal with piglet preweaning mortality are usually performed by producers around farrowing. However, there is a lack of scientific evidence on techniques, such as oral supplementation of piglets or cross-fostering, and further research should be of interest.

2.2 Introduction

The production target in modern commercial swine herds nowadays is close to 30 pigs weaned per sow per year (Knox, 2005). This target has been achieved in two ways: by improving NBA and reducing the farrowing interval (Figure 1). Litter size in sows has been dramatically improved in recent decades by genetic selection for highly prolific sows (Marantidis et al., 2013).

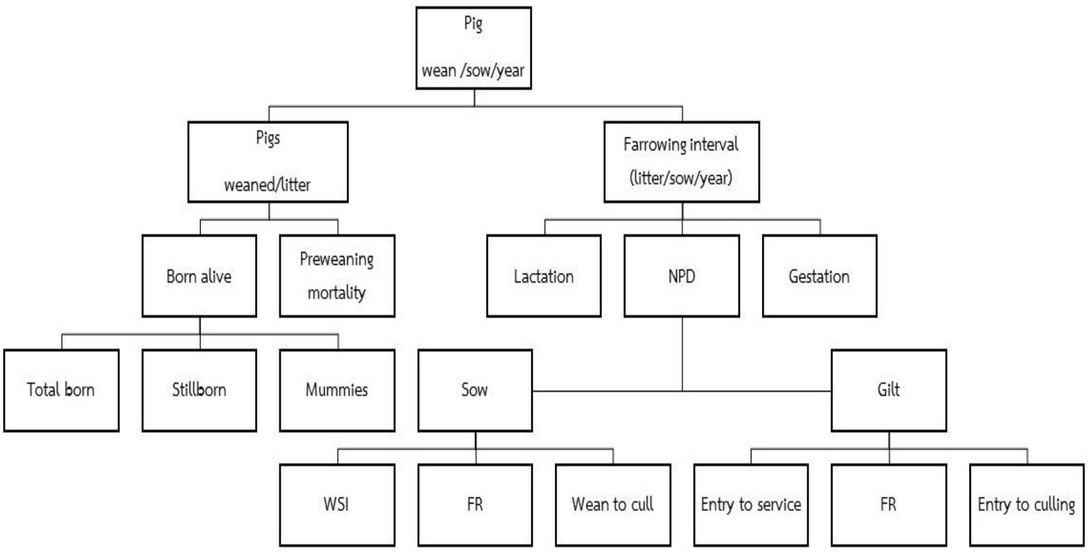

Figure 1 Pig production diagram (NPD: non-productive days; WSI: weaned-to-service interval; FR: farrowing rate) (modified after Dial et al. (1992)).

Despite the improvements in LS acquired through genetic selection, the mean piglet preweaning mortality rate in commercial swine herds ranges between 10 – 20% in major pig-producing countries (Tuchscherer et al., 2000; Koketsu et al., 2006; Kilbride et al., 2012; Kirkden et al., 2013b). Indeed, recent reports showed a mean piglet preweaning mortality rate of 12.9% in the EU, 9.4% in the Philippines, and 12.2% in Thailand (Interpigs, 2014) (Bareau of Agricultural Statistical of Philippine, 2012; Nuntapaitoon and Tummaruk, 2013a; Nuntapaitoon and Tummaruk, 2015). On the other hand, the mortality rate in the nursery and finishing phases usually reaches 2.6% and 2.5%, respectively (EU averages, Interpigs (2014)). Considering these mortality values, reducing the piglet preweaning mortality from 11.5 to 9.0% in a farm with a mean of 13 live-born piglets per sow, would result in an increase of 65 kg of live body weight at slaughter per sow per year (assuming 2.30 farrowings per year). Therefore, mortality in the suckling period remains a major welfare and economic problem in swine industries, which still needs to be properly addressed.

To address piglet preweaning mortality, it is essential to differentiate between prenatal and postnatal piglet mortality. A proper distinction between stillbirths and live-born piglets that died immediately after birth is needed to properly address piglet preweaning mortality in farm conditions. A stillborn piglet did not breathe (lung tissue will not float in water) and has also the periople on the claws (Baxter et al., 2009). In the present review, only piglet preweaning mortality calculated from live-born piglets will be considered. The etiology of piglet piglet preweaning mortality includes non-infectious and infectious causes. Infectious causes are mainly respiratory and diarrhea problems (Chrisensen and Svensmark, 1997). However, the present review will focus on the non-infectious causes of piglet preweaning mortality.

On average, 50 – 80% of piglet deaths occur during the first week after birth, with the most critical period being the first 72 h of life (Koketsu et al., 2006; Shankar et al., 2009). Many factors determine the incidence of piglet preweaning mortality under field conditions, including BW_B, LS, birth order, gender, parity, farrowing duration, maternal behaviour, sow nutritional status, and environmental temperature (Baxter et al., 2009; Muns et al., 2013; Panzardi et al., 2013). It is important for veterinarians to understand the possible causes underlying piglet preweaning mortality and to perform a multifactorial approach of piglet preweaning mortality in farm situations, to increase the number of healthy piglets at weaning. Therefore, the aim of the present work was to review current knowledge concerning important non-infectious causes of piglet preweaning mortality focusing on the main factors found under commercial conditions. Furthermore, the review aims to highlight the most common management interventions performed around farrowing and their impact on piglet preweaning mortality.

2.3 Causes of preweaning mortality in piglets

There is a general agreement that crushing is the principal cause of piglet preweaning death, with chilling and starvation as underlying causes (Edwards, 2002; Herpin et al., 2002; Alonso-Spilsbury et al., 2007). Vaillancourt et al. (1990) found that the causes of death for pigs before weaning were crushing (33.8%), low viability (29.7%), scours (12.2%), infection (8.1%), deformity (5.5%), and others (10.7%) in the USA. Similarly, Koketsu et al. (2006) reported that crushing and a low viability of piglets at birth were the main causes of piglet preweaning mortality in Japanese herds. In England, the cause of mortality of live-born piglets in 458 commercial herds was recorded and the results suggested that crushing is by far the major cause of death (Easicare, 1995). Other minor non-infectious causes of death, such as congenital problems or savaging by the sow also exist.

At farrowing, piglets have to recover from the stress of birth, to cope with a decrease in ambient temperature, and to compete with their siblings. However, piglets are born physiologically and immunologically immature. Due to the epitheliochorial nature of the swine placenta, piglets need to receive a passive immunity supply, mainly from IgG in the colostrum (Herpin et al., 1996; Tuchscherer et al., 2000; Herpin et al., 2002). Piglets are also born with no brown adipose tissue, which is used for thermoregulation (Berthon et al., 1993) and are born wet with placental fluids and with a high surface/volume ratio, due to their small size. As a consequence, newborn piglets are prone to chilling and starvation. Hypothermia and deficits in energy intake are factors that further weaken the piglet and thus increase the risk of crushing by sows.

As a result, piglet preweaning mortality, especially at early stages, is considered to be the outcome of complex interactions among the piglet, the sow and its environment, with crushing being the final act in a complex chain of events (Edwards, 2002; Alonso-Spilsbury et al., 2007). The above-mentioned interactions make it difficult to establish single causes for piglet mortality, but inadequate colostrum consumption might be the main factor that triggers early death in piglets due to undersupply of piglets with nutrients and immunoglobulins (Edwards, 2002; Casellas et al., 2004; Le Dividich et al., 2005; Quesnel et al., 2012). In farm conditions, the assessment of preweaning deaths strongly depends on the farmer's skills and observations. However, the practicalities of production and the multifactorial nature of piglet preweaning mortality limit the accuracy of identifying the underlying cause of death.

2.4 Factors influencing preweaning mortality in piglets

As previously suggested, the cause of death can be influenced by many factors. In general, factors that cause piglet preweaning mortality are usually classified into three major groups, involving the piglet, the sow, and environmental factors (Figure 2).

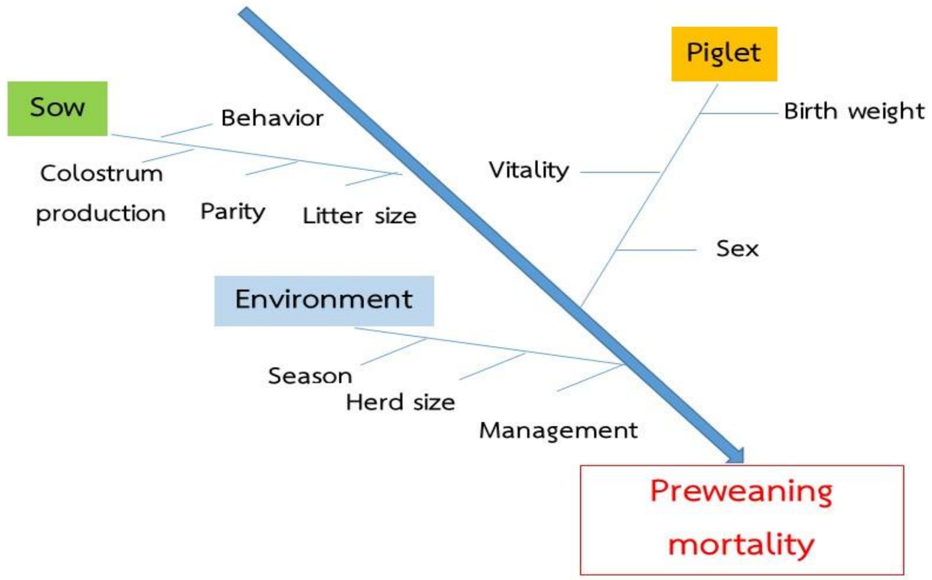

Figure 2 Risk factors associated with preweaning mortality in piglets

2.4.1 Piglet factors

2.4.1.1 Birth weight

Many studies have reported that BW_B is the most important factor for survival and performance (Baxter et al., 2008; Fix et al., 2010; Muns et al., 2013; Rootwelt et al., 2013). Smaller piglets also have a reduced ability to maintain body temperature (Theil et al., 2012). It has been shown that piglets with an individual BW_B of > 1.8 kg had a survival rate of over 90%, whereas piglets with a BW_B of 700 g had a survival rate of only 33% (Chris et al., 2012). Roehe and Kalm (2000) found that decreasing BW_B were associated with a rapid increase in odds ratios of piglet preweaning mortality, and Fix et al. (2010) associated low BW_B piglets with lower survival during the complete production chain. Body weight is also positively correlated with colostrum consumption (Amdi et al., 2013; Ferrari et al., 2014; Nuntapaitoon and Tummaruk, 2014b).

A reduced energy reserve in low BW_B piglets is one factor that explains the higher risk of death. Piglets with a low BW_B have a low body-mass index. Body-mass index is positively correlated with body muscle, glycogen storage and survival rate (Amdi et al., 2013). Body weight strongly influences an important piglet survival indicator-thermoregulation ability. Within the first h after birth, thermoregulation is compromised in piglets because of evaporation of the placental fluids and consequent cooling. Susceptible piglets fail to recover from this initial temperature drop, and hypothermia affects the latency to suckle, leading to starvation, lethargy and, ultimately, to crushing by the sow (Weary et al., 1996). Several studies indicated that rectal temperature measured within 24 h after birth was associated with piglet preweaning mortality (Tuchscherer et al., 2000; Baxter et al., 2008; Baxter et al., 2009; Muns et al., 2013; Panzardi et al., 2013) and suggested that piglets with a low rectal temperature might have a lower thermoregulation ability. Smaller piglets have a higher surface area-to-volume ratio, resulting in a greater susceptibility to heat loss and hypothermia (Herpin et al., 2002). Moreover, low BW_B piglets require longer to reach the teat and suckle, and are less competitive for a teat than heavier littermates (Rooke and Bland, 2002; Le Dividich et al., 2005), thus reducing their colostrum consumption

(Tuchscherer et al., 2000). Vallet and Miles (2012) suggested that small piglets might move slowly due to brain myelination impairment, which affects the speed of nerve impulse transmission, thus compromising suckling and increasing the odds of crushing.

In addition, the within-litter BW_B variation is positively correlated with piglet preweaning mortality (Milligan et al., 2002; Wolf et al., 2008), because small piglets cannot compete with their larger littermate pigs, resulting in low BW_B piglets with a low nutritional status and poor passive immunity (Quiniou et al., 2002). Genetic selection for sows with increased LS has resulted in a reduction in piglet BW_B, mainly due to a decreased uterine space for foetus development and decreased amount of nutrients available per foetus (Campos et al., 2012). Quiniou et al. (2002) observed that between sows with nine and 17 NTB (an 88% increase in LS), there was only a 55% increase in total BW_B. Moreover, with genetic selection for LS it has also been observed an increase in within-litter variation in piglet BW_B (Lund et al., 2002; Quesnel et al., 2008). Due to placenta size, foetal growth can vary with differences in placenta vascularisation and efficiency. Roehe and Kalm (2000) reported that a small placenta results in a low glucose and fructose supply to the foetus, resulting in a decreased growth rate and BW_B of piglets. Placental insufficiency is a major cause of intra-uterine growth restriction that influences BW_B (Baxter et al., 2008; Rootwelt et al., 2013) and the thermoregulatory capabilities of newborn piglets (Mellor and Stafford, 2004).

2.4.1.2 Vitality

Piglet vitality determines the capacity of a piglet to compete for a teat and to suckle (Trujillo-Ortega et al., 2007). A high vitality piglet has been associated with an improved survival rate at seven days and at 10 days of life (Baxter et al., 2008; Vasdal et al., 2011), and has also been positively correlated with piglet growth and survival at weaning (Muns et al., 2013). There is some confusion in the literature concerning the terminology used to evaluate piglet vitality, the terms 'viability' and 'vitality' are used interchangeably in different studies to designate the vigour or physical strength of piglets. To avoid confusion, vitality is defined in the present review as vigour or physical strength.

Physiological variables of piglets have been measured at the moment of birth to assess piglet vitality. A vitality score obtained after recording piglet HR, muscle tone, onset of respiration and attempts to stand at birth have been positively related to survival and rectal temperature one h after birth (Randall, 1971; Zaleski and Hacker, 1993a; Casellas et al., 2004; Baxter et al., 2009). Likewise, the ability to first suckle after birth and thermoregulation ability during the first 24 h of life have been used to reflect piglet vitality and positively correlated with colostrum consumption (Herpin et al., 1996; Tuchscherer et al., 2000). Piglet's vitality has also been evaluated as the capacity to perform rooting behaviour (using a neurobehavioural test or rooting response test) with surviving piglets showing higher rooting capacity (Baxter et al., 2009). More recently, the behavioural traits of piglets after farrowing (*e.g.*, the presence of an udder stimulation reflex, the capacity to move within a circular enclosure) have also been recorded to represent piglet vitality showing a positive correlation with piglet survival and growth (Muns et al., 2013). Most of the already mentioned physiological and behavioural vitality assessments are performed at very instant of birth and some of them require the use of electronic devices, only the vitality score performed by Muns et al. (2013) is performed at the end of farrowing only by visual assessment, thus easy to perform to all the piglets born in the litter on farm conditions.

Neonatal vitality is directly related to intra-partum hypoxia (or asphyxia during delivery) suffered by piglets at birth (Zaleski and Hacker, 1993a; Trujillo-Ortega et al., 2007), which is one of the most important causes of stillbirth and early piglet preweaning mortality in piglets. The integrity of the umbilical cord is also related to piglet vitality. Alteration or rupture of the umbilical cord reduces blood perfusion to piglets, with the associated risk of causing anemia and/or hypoxia, reducing vitality and increasing the risk of early mortality (Rootwelt et al., 2012; 2013). Clearly, any congenital malformation and physical abnormality (*e.g.*, splay-leg) that will impede piglet movements, or any damage to the foetal central nervous system, triggered either by intra-partum hypoxia, congenital causes or maternal stress (Herpin et al., 1996), will reduce piglet vitality and increase the odds of crushing. Finally, neonatal vitality has also been related to blood glucose levels at birth, but controversial results are found in the literature. High blood levels of glucose (45 – 162 mg/dL) at birth are considered to be a consequence of suffering during parturition, and low concentrations (24 – 30 mg/dL) are a sign of low glycogenic body reserves; both circumstances that might negatively influence piglet vitality and survival (Herpin et al., 1996; Trujillo-Ortega et al., 2007; Mota-Rojas et al., 2011; Panzardi et al., 2013; Nuntapaitoon and Tummaruk, 2014c). However, other studies failed to correlate blood glucose concentration at birth with piglet survival (Tuchscherer et al., 2000; Rootwelt et al., 2013).

Intra-partum hypoxia is the main factor that influences piglet vitality by damaging the foetal central nervous system and lowering the capacity to compete for a teat and increasing the time interval between birth and first suckling, which can lead to hypothermia and starvation (Randall, 1972; Zaleski and Hacker, 1993a; Trujillo-Ortega et al., 2007). Low piglet vitality score at birth has been associated to increased blood lactate level, blood partial pressure of CO_2, and reduced blood pH (Herpin et al., 1996). Birth order and posterior body presentation at birth are both factors that have been positively associated with intra-partum hypoxia and shown to be influencing piglet's vitality (Herpin et al., 1996; van Dijk et al., 2005). Uterine contractions in sows with a long farrowing duration also reduce the oxygenation of prenatal piglets, compromising their vitality (Zaleski and Hacker, 1993b; Alonso-Spilsbury et al., 2005; Rootwelt et al., 2013), with a higher risk for piglets born later during farrowing (van Rens and van der Lende, 2004; Motsi et al., 2006). Indeed, Nuntapaitoon and Tummaruk (2014a) observed that birth intervals of > 30 min significantly increased the proportion of piglets suffering from hypoxia. The overuse of oxytocin (*i.e.,* the routine administration of oxytocin immediately after the birth of the first piglet or overdosing) can also compromise piglet vitality by increasing the frequency, intensity and duration of uterine contractions (Mota-Rojas et al., 2005; 2007).

2.4.1.3 Gender

Piglet preweaning mortality is suggested to be sex-biased, with male piglets being at greater risk of death, despite being born with a higher BW_B (Herpin et al., 2002; Baxter et al., 2012a). Baxter et al. (2012a) suggested that females invest energy resources in specific physiological systems (*e.g.*, thermoregulation and immunocompetence), whereas males invest energy resources in body size and body composition (processes linked with reproductive fitness in adulthood), consequently predisposing male piglets to causal mortality factors that are mainly associated with energetic demands (chilling, starvation, crushing or even disease). Similarly, Panzardi et al. (2013) found that female pigs had a higher early postnatal vitality than males; however, Li et al. (2012) found no gender effect on piglet mortality.

2.4.2 Sow factors

2.4.2.1 Colostrum

Colostrum is the first milk secreted by the mammary gland, which sows continuously secrete from around farrowing up to 12 – 24 h (Quesnel et al., 2012), before its secretion becomes cyclic and nursery bouts start (Auldist et al., 2000). Colostrum is a rich source of digestible nutrients and various bioactive compounds such as immunoglobulins, hydrolytic enzymes, hormones, and growth factors (Rooke and Bland, 2002; Wu et al., 2010), thus, it plays a key role in piglet thermoregulation, the acquisition of passive immunity and intestinal development (Devillers et al., 2007).

Colostrum provides the newborn pig with highly metabolisable energy (Le Dividich et al., 1994) and its high content of fat and lactose is efficiently used by the newborn pig to cope with cold stress by increasing its metabolic rate and maintaining its homeothermic balance during the first day after birth (Le Dividich et al., 1994; Herpin et al., 2005). Accordingly, rectal piglet temperature at 24 h (RT24h) of age is positively correlated with colostrum consumption (Devillers et al., 2011) and is negatively correlated with the time interval between birth and first suckling (Tuchscherer et al., 2000). The primary protein component of colostrum consists of immunoglobulins, including IgG, IgM, and IgA isotypes. Immunoglobulin G is the most common bioactive compound in colostrum and is at its highest concentration in the first few h postpartum and decreases rapidly within 24 h (Herpin et al., 2005; Markowska-Daniel and Pomorska-Mol, 2010; Vallet et al., 2013). As has been previously mentioned, piglets need to receive passive immunity from IgGs in colostrum to reduce susceptibility to infection in the immediate postnatal period and also after weaning (Rooke and Bland, 2002).

The absorption of IgG by newborn piglets occurs before gut closure (Bland et al., 2003; Quesnel et al., 2012) which occurs at approximately 24 h of age (Rooke and Bland, 2002). The IgG plasma concentration in piglets at 24 h of age is positively correlated with colostrum consumption (Devillers et al., 2011). Accordingly, Muns et al. (2014b) observed that administering 15 mL of sow colostrum after farrowing to small piglets increased their IgG plasma concentration at four days of age. Porcine colostrum also contains different types of milk-borne growth factors (*e.g.*, the insulin-like growth factors IGF-I and IGF-II, epidermal growth factor, insulin and transforming growth factor-β). According to Xu et al. (2000), milk-borne growth factors via colostrum feeding play a regulatory role in the stimulation of gastrointestinal tissue growth, and the maturation of its function. Colostrum feeding also enhances intestinal macromolecule absorption, the onset of gut closure, and enhances the repair of damaged mucosa (Xu et al., 2000; Rooke and Bland, 2002). All these process are required for the adaptive changes of the gastrointestinal tract during the postnatal period.

Quesnel et al. (2012) estimated that 250 g/kg colostrum consumption per piglet should ensure an optimal growth and passive immunity to the animals. Pierzynowski et al. (2014) also reported that colostrum consumption stimulates the development of the hippocampus structure by the stimulation of brain protein synthesis and brain development during the early postnatal period. Colostrum consumption also increases the piglet body weight gain at weaning (Devillers et al., 2004; Le Dividich et al., 2005; Decaluwé et al., 2014) and up to six weeks of age, suggesting that it has a long-term effect on piglet growth (Devillers et al., 2011). Indeed, colostrum consumption has been positively associated with piglet survival at weaning (Devillers et al., 2011; Decaluwé et al., 2014). Any circumstance that impairs piglet colostrum consumption capacity will increase the risk of mortality or diminish its growth capacity. Factors that influence colostrum consumption include piglet vitality at birth, birth order, NBA, and sow nutrition (Quesnel et al., 2012; Nuntapaitoon et al., 2014a; 2014b; Theil et al., 2014a). The ability of piglets to reach the udder and to suckle causes an increase in colostrum consumption (Amdi et al., 2013). As has already been presented, reduced piglet vitality at birth or any other factor that affects the interval from piglet birth to first suckle and the ability of a piglet to stimulate a teat will negatively influence piglet colostrum consumption. Competition between littermates has a negative effect especially on the piglets of the litter born with lower BW_B, because a high LS increases the number of fights at suckling (Milligan et al., 2001) and increases the risk of starvation and crushing of the small piglets. However, colostrum yield is highly variable among sows, even within the same breed and in the same conditions of housing and management (Devillers et al., 2007; Farmer and Quesnel, 2009). Fraser (1984) suggested that the appropriate stimulation of the udder by piglets might be important to elicit a maximum colostrum yield by the sow. The total sow colostrum yield varies between 2.5 and 5.0 kg in a litter of 8 to 12 piglets (Farmer et al., 2006b). Colostrum yield is independent of LS, and is slightly influenced by litter weight and piglet BW variability (Devillers et al., 2007; Foisnet et al., 2010; Quesnel, 2011; Decaluwé et al., 2013). A reduction or failure to produce colostrum or milk by the sow would have a negative impact on piglet survival and growth. It is suggested that insufficient milk production or lactation failure in sows might account for six to 17% of piglet preweaning mortality (Alonso-Spilsbury et al., 2007). Colostrum yield depends on the breed, feed and water intake, energy status, sanitary status, and parity of the sow, and on other factors such as farrowing induction; environment and hormone status can also influence colostrum production by the sow (Devillers et al., 2007; Quesnel, 2011; Decaluwé et al., 2013; Ferrari et al., 2014). Besides, post-partum dysgalactia syndrome (PDS) or mastitis-metritis-agalactia (MMA) is a multifactorial process with a considerable prevalence among herds, causing lactation failure usually during the first three days after farrowing. Late transferring of sows to farrowing facilities, *ad libitum* feeding during the first days of lactation, dystocia (Papadopoulos et al., 2010), constipation, poor floor hygiene, and high ambient temperature (Kirkden et al., 2013a) are factors that have been observed to increase the odds for PDS.

2.4.2.2 Parity

The effect of parity on piglet preweaning mortality can be contradictory: on one hand, Knol et al. (2002) and Carney-Hinkle et al. (2013) found no influence of parity on the survival rate of piglets, but Muns et al. (2015) observed a lower piglet

piglet preweaning mortality in primiparous sows than in multiparous sows. Moreover, different studies reported a negative correlation between parity and piglet preweaning mortality (Koketsu et al., 2006; Li et al., 2010; Li et al., 2012; Nuntapaitoon and Tummaruk, 2012; 2013a; 2013b; 2015). It is known that second and third parity sows tend to have a higher colostrum yield than other parities (Devillers et al., 2007), and that sows from parity 4 – 6 have higher colostrum yield than primiparous sows (Ferrari et al., 2014). The apparent lower colostrum yield in primiparous sows might explain the negative correlation between parity and piglet preweaning mortality observed by some authors. Accordingly, piglets from primiparous sows consumed less colostrum than piglets from sows with parity 4 – 6 in the experiment of Ferrari et al. (2014). Therefore, immune protection in the progeny of multiparous sows might be greater than in primiparous sows, resulting in a lower piglet mortality and increased daily gain before weaning (Ferrari et al., 2014). Moreover, piglets born from primiparous sows have a lower BW_B and lower serum concentration of IgA and IgG than piglets born from multiparous sows (Carney-Hinkle et al., 2013). Marchant et al. (2000) suggested that lower experience in primiparous sows at farrowing negatively affects piglet survival rate. Ruediger and Schulze (2012) reported that primiparous sows suffered greater post-farrowing stress, which declined in multiparous sows. Furthermore, primiparous sows show poorer reproductive performance and are more sensitive to environmental factors compared to multiparous sows (Tummaruk et al., 2010).

On the other hand, the absence of a relationship between parity and piglet preweaning mortality or the lower piglet preweaning mortality observed in primiparous sows in the experiments of Knol et al. (2002), Carney-Hinkle et al. (2013), and Muns et al. (2015), might be explained because LS increases together with increases in parity (Roehe and Kalm, 2000). The number of BW_B piglets increases together with an increase in LS, although the mean piglet BW_B also increases. Therefore, the BW_B variability within a litter also increases with an increase in LS. This situation is evident with older sows (> 6^{th} parity), as observed by Wientjes et al. (2012), who observed that 0 to 7-day-old piglets were particularly at risk of death when they were reared with old sows. The duration of farrowing in first parity sows is shorter than in sows with a parity > two (Tummaruk and Sang-Gassanee, 2013). In addition, older sows have a longer farrowing duration, due to the presence of excessive fat and reduced uterine muscle tone, which increases the probability of intra-partum hypoxia (Zaleski and Hacker, 1993b). Finally, older sows usually have a reduced and more variable function and accessibility of teats. A 41% reduction in the number of functional teats was found in high-parity sows (Vasdal and Andersen, 2012). Further studies on the effect of parity on piglet preweaning mortality should be carried out.

2.4.2.3 Maternal stress

The peri-partum period (from four days before and up to three days after farrowing) is a sensitive period in piglet production. The parturition process starts a few days before farrowing. During this period, sows might be stressed due to the new environment in the farrowing pen and due to the parturition process (Baxter et al., 2011; Muns et al., 2014a; Yun et al., 2015). Stress during the farrowing period increases the duration of farrowing and decreases colostrum production, thus reducing the energy and IgG supply to piglets (Edwards, 2002; Oliviero et al., 2008). The stress of farrowing can also affect the behaviour of the sow and lead to restlessness and even to aggressiveness (Kalantaridou et al., 2004), which increases the risk of crushing piglets and prevents suckling (Baxter et al., 2011). Muns et al. (2014a) found that sows that were stressed during farrowing showed an increase in activity one day before farrowing. Maternal pre-natal stress can affect behavioural and physiological aspects of the offspring by altering their hypothalamic activity (Kaiser and Sachser, 2001; Kranendonk et al., 2007; Muns et al., 2014a). For example, Muns et al. (2014a) observed that piglets born from stressed sows had a higher mortality and reduced daily gain at weaning, probably due to a reduction in their thermoregulation ability caused by an inhibition of thyroid function due to maternal pre-natal stress (Berthon et al., 1993).

2.4.2.4. Sow nutrition

Maternal nutrient provision might play an important role in piglet preweaning mortality due to its influence in foetuses development during pregnancy, with direct impact on piglet BW_B and vitality (see reviews of Campos et al. (2012); De Vos et al.

(2014); Yuan et al. (2015)). Therefore, dietary supplementation in pregnant and lactating sows to reduce piglet preweaning mortality and enhance piglet growth have been intensively investigated during recent years (Kalbe et al., 2013; Quesnel et al., 2014; Tummaruk et al., 2014). One hand, BW_B of piglets is positively related to energy intake of sows throughout gestation (Campos et al., 2012). Besides, early embryonic loss seems not to be influenced by overfeeding in the modern hyperprolific sow (De Vos et al., 2014). Nonetheless, protein availability for foetal growth is more important during gestation (De Vos et al., 2014). Gestation diets with protein restriction or unbalanced amino acid profile might increase the incidence of piglets born with a low BW_B (Wu et al., 2006; Kim et al., 2009). Foetal growth is controlled by the amino acids in the arginine family (Wu et al., 2007b). Indeed, supplementation of diets with *L*-arginine or *L*-glutamine significantly increased BW_B of piglets (Raghavan and Dikshit, 2004; Gao et al., 2012; Wu et al., 2013). In addition, diets supplemented with *L*-carnitine during pregnancy significantly increased BW_B of piglets (Doberenz et al., 2006). The reasons might be due to an increase in intrauterine nutrient supply of glucose, glucose transporter-1 and maternal IGF-I (Doberenz et al., 2006) and to an increased muscle fiber development (Musser et al., 1999). On the other hand, piglet vitality is also indirectly influenced by sow nutrition. Piglets born from sows supplemented with *L*-carnitine improved their suckling behaviour (Birkenfeld et al., 2006). Supplementing sows with tuna or salmon oil increased suckling behaviour of their piglets and reduced the crushing incidence despite also reducing their BW_B (Rooke et al., 2001a; 2001b). It is known that long-chain polyunsaturated fatty acids (PUFAs) are important in the development of the brain and other physiological functions (De Vos et al., 2014).

The nutrition of sows during late gestation can also influence colostrum yield or colostrum composition (see review of Theil et al. (2014b)). During late gestation, sows have a high energy demand for mammary development and nutrition might affect colostrum production both via mammary gland development and via mechanisms that control colostrum secretion during late gestation (Farmer and Quesnel, 2009). Overfeeding sows during gestation has a negative impact on mammogenesis, due to excessive fat deposition (Farmer and Sørensen, 2001). Fat sows have a high insulin resistance that disrupts glucose transport to the mammary gland for lactose synthesis (Shennan and Peaker, 2000; Père and Etienne, 2007). On the other hand, feed restriction at the end of gestation might only have a small detrimental effect on colostrum yield, because sows already have a large body energy reserve (Dourmad et al., 1999). However, the results of Decaluwé et al. (2013) and Loisel et al. (2014) suggest that an excessive catabolism before farrowing might be detrimental for colostrum yield. Furthermore, dietary-fat supplementation during gestation and dietary supplementation with glutamine during lactation increased milk production of sows, enhanced piglet's gut health and increased growth rate and survival rate of piglets (Rooke et al., 2001b; Jackson, 2004; Laws et al., 2009). In addition, it has been observed that feeding sows with a high amount of dietary fiber during gestation had a beneficial effect on the colostrum consumption of piglets (Theil et al., 2014a).

2.4.3 Environmental factors

2.4.3.1 Season and temperature

The seasonal effect on piglet preweaning mortality is controversial. Koketsu et al. (2006) found that piglet preweaning mortality during the summer period (11.6%, July to September) was higher than in spring (9.4%, April to June). On the other hand, some reports observed that piglet preweaning mortality was highest in the cold season because of a low ambient temperature and cold stress (Dial et al., 1992; Maderbacher et al., 1993). Piglets have a lower limit of the thermoneutral zone at two h of life close to 34°C (Herpin et al., 2002). In general, newborn piglets are very sensitive to cold stress, due to incomplete thermoregulation at birth, few subcutaneous fat reserves and because they are poorly insulated. Piglets require a warm and dry environment for survival, especially during the first days after birth. It is well established that cold stress is the most important stressor in newborn piglets (Baxter et al., 2009; Shankar et al., 2009). Under low ambient temperature environments, piglets are at more risk of being crushed by the sow (Shankar et al., 2009), because the piglet stays close to the udder in search of a heat source. In addition, Pedersen et al. (2013) found that colostrum consumption decreases during cold exposure, exacerbating the likelihood of starvation and reducing Ig concentrations in neonatal piglets. On the other hand, sows have a thermoneutral zone ranging from 18 °C to 20 °C (Silva et al., 2009). High ambient temperature can decrease the feed intake of lactating sows due to heat stress (Li et al., 2010; Malmkvist et al., 2012). Therefore, heat stress compromises colostrum and milk production in sows and growth performance in piglets (Farmer and Quesnel, 2009; Farmer et al., 2010). Moreover, heat stress can also cause alterations in sows, reduce the frequency and duration of nursing periods, increase the time spent urinating or defecating and finally, increase piglet mortality due to crushing (Silva et al., 2006). It has been observed that floor heating in farrowing pens can act as a stressor during the peri-parturient period in sows with limited ability to perform thermoregulatory behaviour (Damgaard et al., 2009; Malmkvist et al., 2009; 2012). In farrowing pens, it has also been observed that maintaining the heat lamp in the side creep area instead of in the front creep area during the first days after farrowing, can reduce sow feed intake (Hrupka et al., 1998).

2.4.3.2 Housing

The size of the herd can play a significant role in minimizing neonatal losses (Oliviero et al., 2010). On average, piglet preweaning mortality in large herds was lower than that in small herds (Friendship et al., 1986; Hoshino et al., 2009). The effect of herd size on piglet preweaning mortality is related to post-partum management and the quality of stockpeople, which is usually better in large herds. (Hoshino et al., 2009) found that high-performing herds in Japan had a lower number of stillbirths due to better farrowing management (farrowing supervision and assistance) than low-performing herds. The housing system and its design has a strong impact on different aspects of sow and piglet welfare and performance; however, it is out of the scope of the present paper to review the different existing farrowing systems or their designs and their welfare implications, but to highlight their main characteristics in relation to piglet preweaning mortality. Conventional farrowing crates were designed to prevent crushing by restricting sow movements and to provide a zone of retreat for the piglets. On average, sows are restricted within a crate with 1.26 m^2 of available floor space, placed within a pen area of 3.54 m^2 (Vosough Ahmadi et al., 2011). It has been demonstrated that sows kept in conventional farrowing crates show signs of an impaired welfare state (*e.g.*, HR and stress-hormone responses, negative or abnormal behaviours) (see review of Baxter et al. (2011)); for this reason, different designs of group- and individual loose-housing systems have been developed as alternatives to the conventional farrowing crate (Wechsler and Weber, 2007; Baxter et al., 2012b). Nonetheless, no commercially viable/feasible option has emerged, and therefore, their commercial use is limited (Vosough Ahmadi et al., 2011; Van Nieuwamerongen et al., 2014). Two main different group-housing systems can be identified for sows during lactation or part of lactation (see review of Van Nieuwamerongen et al. (2014)). Sows can be grouped with their litters (multi-suckling system), or offered a communal area that is only accessible to sows for the whole lactation period (get-away systems). Indoor alternatives can be classified into pens and designed pens (see review of Vosough Ahmadi et al. (2011). On average, pens consist of a uniform floor space of 10.48 m^2 with no distinction between excretory and lying areas. Piglets are provided with a separate creep area with supplementary heat via a lamp or mat. Designed pens contain different types of pens, but typically occupy a whole area or 7.06 m^2 of floor space, with a designated area for nesting/lying of approximately 2.90 m^2 of this space. Piglets are also provided with a separate creep area with supplementary heat via a lamp or mat. In outdoor systems, sows and piglets are usually kept individually in arks or huts (mean floor space of 377 m^2), with access to individual or group paddocks.

Although group housing systems provide more environmental complexity and freedom of movement for the sows and the possibility for extended lactation periods, they have an increased risk of crushing and early cessation or disruption of nursing (Van Nieuwamerongen et al., 2014). Indeed, Wechsler and Weber (2007) concluded that sows should not be group-housed at farrowing, but individually, in large pens with separate nesting/lying and activity areas. Vosough Ahmadi et al. (2011) observed similar total piglet mortality rates (including stillborn piglets) among 145 studies that included conventional crates (18.2%), pens (18.4%) and designed pens (16.5%). Accordingly, Baxter et al. (2012b) described a total piglet mortality rate (corrected for a standardised LS of 11 piglets) of 18.1, 19.3, 15.0, and 17.1% for conventional crates, pens, designed pens, and outdoor systems respectively. In their review, Baxter et al. (2012b) also observed a similar piglet preweaning mortality (corrected for a standardised LS of 11 piglets) among conventional crates (11.3%), pens (12.8%), designed pens (10.2%), and outdoor systems (14.3%). As presented, the piglet preweaning mortality rate is similar among the different individual farrowing housing systems, except for outdoor systems. Crates were especially designed for preventing posterior crushing (beneath the sow's hind quarters), although they are not as effective in preventing ventral crushing when lying down from a sitting position (beneath the udder and rib cage) (Andersen et al., 2005; Wischner et al., 2010; Pedersen et al., 2011). More specifically, in a cohort study of piglet preweaning mortality performed on 112 breeding farms in England by (Kilbride et al., 2012), conventional farrowing crates were compared with three different loose-housing systems (including indoor and outdoor systems). These authors concluded that the risk of piglet preweaning mortality due to crushing was lower in conventional farrowing crates. Nonetheless, the risk of death from other causes was higher in conventional farrowing crates, resulting in a similar level of piglet preweaning mortality among the different farrowing systems. Sows in conventional farrowing crates also present higher number of teats with sever lesions in comparison to loose-housing systems (Verhovsek et al., 2007), which might be detrimental for piglets' colostrum consumption. Similar to in conventional farrowing crates, Baxter et al. (2009) observed that piglet BW_B and rectal temperature one h after birth were the most significant postnatal survival indicators in outdoor systems. However, latency to reach the udder, a teat and to suckle, were not useful as survival indicators in outdoor systems, whereas they are important indicators in indoor conventional systems. Recent studies found that a pen design that allows for confinement of the sows from day 114 of gestation until four days after farrowing reduced piglet preweaning mortality compared to gestation and lactation loose-housing systems (Moustsen et al., 2013; Hales et al., 2015). In the same studies, no alteration of the farrowing progress was observed.

More particularly, floor characteristics of the farrowing pen or the creep area might influence piglet preweaning mortality. Floors with rigid physical features (*i.e.,* slatted iron floor, partial concrete and partial round – weld mesh floor) increase the incidence of foreleg skin lesions in lactating piglets (Mouttotou et al., 1999; Gu et al., 2010) with negative effect on piglet's preweaning growth (Johansen et al., 2004).

Besides, the use of neoprene mats placed on the slatted iron floor of the piglet suckling area reduced the risk of crushing and the risk of piglet's hypothermia by reducing the temperature gradient between the piglet abdomen and the contact floor surface (Gu et al., 2010). Similarly, the use of enriching substrates in the farrowing crates might also help to reduce the incidence of teat lesion (Lewis et al., 2006).

2.4.3.3. Management

In order to minimize the negative impact of the most important factors influencing piglet preweaning mortality presented above, there are some management priorities and procedures, concerning sows and piglets, commonly established in commercial swine herds. Producers usually try to concentrate their efforts on the farrowing day and during the first two days after farrowing.

Farrowing supervision together with manual birth assistance are management practices mainly oriented to reduce the number of stillbirths in swine herds (see review of Vanderhaeghe et al. (2013). Nonetheless, good farrowing supervision and management protocols at birth also contribute to reduce piglet preweaning mortality (Holyoake et al., 1995; Vanderhaeghe et al., 2013). Reduction in number of stillbirth, improvements on survival during the first day, and increased weaning weight have been obtained with elaborated farrowing supervision protocols that included drying the newborn piglets, oral administration of 12 mL of bovine colostrum and oxygen administration through an oral mask (White et al., 1996). But such farrowing supervision protocols are hard to implement at commercial settings due to their complexity. Nonetheless, more simplified protocols have also been studied. Drying piglets at birth have been proved to be useful in commercial herds. Christison et al. (1997) observed that survival was improved when piglets were dried or placed under the heating lamp immediately after birth. Andersen et al. (2009) and Vasdal et al. (2011), after comparing different protocols around farrowing, also found that drying newborn piglets and placing them at the udder was the management combination with higher reduction in piglet mortality in loose-housed sows. Accordingly, Andersen et al. (2007), after comparing the records of an entire year from 39 Norwegian farms, observed that placing the piglets at the udder immediately after birth and assisting them to find a teat reduced mortality, whereas shunting the piglets inside the creep area while feeding the sow did not have any influence on survival.

The most important management strategies performed after farrowing are oriented to increase the energy status and colostrum consumption by the piglet, and to reduce piglet BW_B variability within litter. On one hand, removing larger piglets in a litter from the dam for a set period of time to allow the smaller piglets adequately access to udder (split nursing) is a practice often practiced in commercial herds during the farrowing day. However, that does not seem to have a real impact on litter performance. Donovan and Dritz (2000) only observed a decrease in variation for piglet's ADG in large litters (> nine piglets born alive) with no effect on IgG plasma concentration or mortality rate when performing split nursing of the heaviest 50% of the piglets in the litter for two h. Additionally, Thorup et al. (2006) and Muns et al. (2015) did not reduce low BW_B piglets' mortality through split nursing. On the other hand, oral supplementation of piglets with colostrum or commercial energy boosters is commonly performed to increase low BW_B piglet colostrum consumption and ensure a proper IgG level in commercial herds. However, limited studies performed under commercial conditions can be found in the literature. Gomez et al. (1998) observed that porcine Igs and bovine colostrum could be used as Ig sources in artificial rearing of colostrum-deprived newborn piglets. Emulsified medium-chain triglycerides have also been administrated as energy substrate to 22 – 35 h old piglets with no clear effect on their growth and survival (Wieland et al., 1993a; Wieland et al., 1993b). Besides, administration of emulsified medium-chain triglycerides in excess could lead piglets to coma by increasing the concentration of circulating fatty acids to toxic levels (Wieland et al., 1993b). Nevertheless, a few authors have observed increased survival and growth rates in small piglets supplemented with colostrum under commercial conditions (Pinsumrit et al., 2004; Muns et al., 2014b; 2015). Indeed, Muns et al. (2014b) observed that supplementation of small piglets with extra 15 mL of colostrum early after birth ensured a proper level of serum IgG concentration at day four of life. In addition to split nursing and oral supplementation, cross-fostering is a management practice usually adopted in commercial farms when LS out numbers functional teats and/or to deal with BW_B variability within litters, situations that might limit colostrum consumption by the piglet and lead to increased piglet preweaning mortality. Although cross-fostering has a strong impact on piglet survival and performance (Muns et al., 2014b), there is some controversy in the literature concerning the best cross-fostering strategy. Heim et al. (2012) found no negative effects of fostering in adopted piglets after cross-fostering. However, Kilbride et al. (2014) showed that fostering piglets over 24 h after birth increases the risk of mortality, and Deen and Bilkei (2004) found increased mortality of low BW_B piglets when cross-fostered with high BW_B piglets. Besides, Muns et al. (2014b) and Milligan et al. (2001) observed that litters cross-fostered to uniform litters doubled their BW_B coefficient of variation at the end of lactation. Nonetheless, Deen and Bilkei (2004) pointed out that low BW_B piglet survival is more related to LS after cross-fostering than to the BW_B of their littermates. Finally, Muns et al. (2014b) suggested that farm's sanitary conditions/health status could strongly influence the impact of the cross-fostering strategy performed on farm.

2.5 Dietary supplementation in gestating sows

Dietary supplementation in pregnant and lactating sows have been intensively investigated during recent years in order to reduce piglet preweaning mortality and enhance the piglet growth (Kalbe et al., 2013; Quesnel et al., 2014; Tummaruk et al., 2014). Arginine supplementation in gestation sow improves reproductive performance. Moreover, arginine supplementation in the sow's diet significantly increases BW_B of newborn piglets (Raghavan and Dikshit, 2004; Gao et al., 2012; Wu et al., 2013). Recently, Quesnel et al. (2014) demonstrated that supplementing gestation diet with *L*-arginine during the last third of pregnancy significantly reduced within-litter variation of BW_B. Additional research are still requried to fullfill knowledge concerning arginine supplementation in different parities of sows and in sows raised under tropical climates.

The chemical formula of arginine is $C_6H_{14}N_4O_2$. This amino acid can be changed between amino acids in the Arginine family of amino acid. This family consist of eight types amino acids, including glutamine, glutamate, proline, aspartate, asparagine, ornithine, citrulline and arginine. Arginine is an important part in protein synthesis and is a component of the tissues of animals (Wu et al., 1999). In addition, arginine is an importance for nitric oxide synthesis and polyamine synthesis (Wu and Morris, 1998). Nitric oxide and polyamine are importance for angiogenesis and embryogenesis and enhance the growth of the placenta and fetus (Reynolds and Redmer, 2001; Wu et al., 2004b). Arginine are found in corn, soybean meal, fish meal and blood meal (Wu and Morris, 1998). Therefore, this amino acid group is necessary to supplement animal feed in all stage. Arginine degradation, arginine is convert to other amino acid family is illustrated in Figure 3 as interconversion of the arginine family of amino acids in mammal. Aspartate is required for the synthesis of arginine from citrulline and the recycling of citrulline into arginine. Citrulline products from glutamine and glutamate. Ornithine is converted into citrulline at mitochondria. Arginine can convert ornithine that ornithine produce glutamate/glutamine in cycle of arginine degradation. Arginine requirement in pigs is different depending on the stages of gestation. The estimated arginine requirement in 0 – 90 days gestating sows, > 90 days gestating sows, lactating sows, weaned piglets and fattening pigs are 1.1%, 0.15%, 0.19%, 0.2% and 0.23%, respectively (Wu et al., 2013). Moreover, Wu et al. (2007a) reported that pregnant tolerated large amounts of chronic supplemental arginine at 2.0 g/kg body weight/day oral administered without adverse effect. Similarly, Shao and Hathcock (2008) found that no observe adverse effect level (NOAEL) in animal was 3.6 g/kg of *L*-arginine supplementation and estimate arginine intake from dietary source was 3 – 6 g/day.

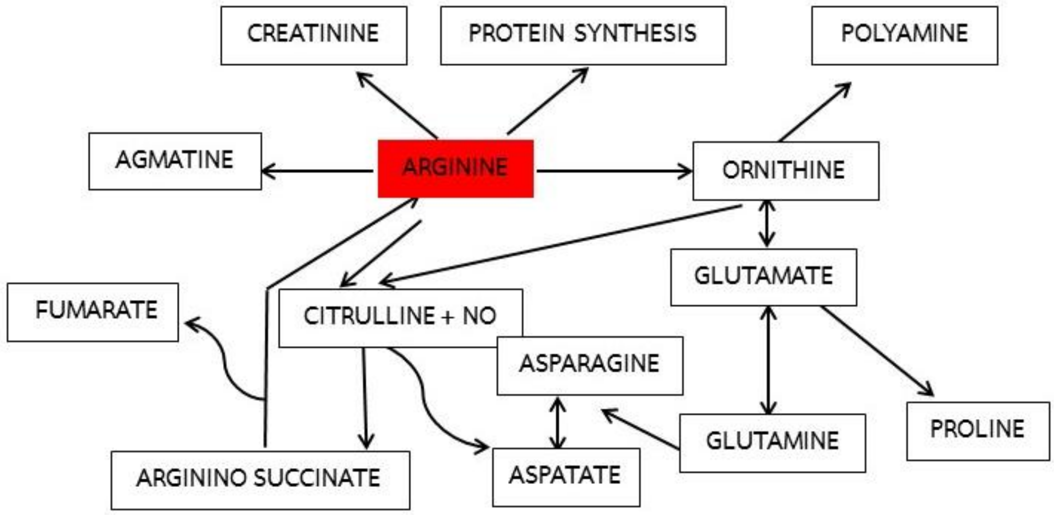

Figure 3 Arginine degradation (modified after (Wu et al., 2007b))

Intrauterine growth retardation (IUGR) lead to inadequate blood supply in the placenta. Moreover, low BW_B piglet had a smaller size of the organs than the piglets with normal BW_B normal and had digestive disorders (Simmons et al., 2005; Wang et al., 2005; Lipsett et al., 2006). The incidence of IUGR is 5 – 10% worldwide. Feed restriction in pregnant sows also affects the development of the placenta and fetus. The importance of arginine in sow during gestation are that arginine is an important part in protein synthesis and is a component of the nitrogen of the protein in the tissues of animals (Wu et al., 1999). In addition, arginine is an important substrate for hormone synthesis, nitric oxide synthesis and polyamine synthesis (Wu and Morris, 1998). Most of the beneficial effects of exogenous provision of arginine is assumed to increased plasma and intracellular concentrations of arginine for the synthesis of nitric oxide, proline, polyamines, and protein (Flynn et al., 2002). Hormone synthesis as insulin, glucagon, growth hormone, prolactin and placental lactogen is an important for metabolism of protein, glucose, amino acid and fatty acid. This is essential for fetal development and mammary gland proliferation (Kim and Wu, 2009). Nitric oxide and polyamine are key factors for angiogenesis and embryogenesis as well as the growth of the placenta and fetus (Reynolds and Redmer, 2001; Wu et al., 2004b). Nitric oxide induces proliferation in fetal endothelial cells. The major mediators of angiogenesis as vascular endothelial growth factor (VEGF) induces eNOS that depend on nitric oxide synthesis to induce new vessel formation (Krause et al., 2011). Moreover, nitric oxide stimulates vascular and alveolar tissue growth for supply nutrient to mammary gland (Kim and Wu, 2009). However, the period from 20 – 70 days of gestation is for placenta development. This is preparation for rapid fetal growth between 70 – 114 days of gestation (Bazer and Johnson, 2014). Quesnel et al. (2014) reported that supplementing gestation diet with *L*-arginine during the last third of pregnancy reduced within-litter variation of BW_B. Thus, *L*-arginine supplementation in late gestating sow increase fetal development, decrease within-litter variation of BW_B and colostrum consumption more than increase placenta development and angiogenesis.

2.6 Conclusions

Piglet preweaning mortality is a serious and important welfare and economic problem of great concern in swine production. Although it is well established that piglet BW_B is the main factor that influences piglet survival and growth, piglet preweaning mortality has a multifactorial aetiology and is influenced by different factors. Through understanding and knowledge of the different causes and factors that influence piglet preweaning mortality, we can therefore reduce piglet preweaning mortality by nutritional intervention (see review of De Vos et al. (2014)) or management strategies (see reviews of Kirkden et al. (2013a); Kirkden et al. (2013b); Rutherford et al. (2013)) of farm conditions. As observed, it is important for veterinarians and producers to understand and properly diagnose the factors that influence piglet preweaning mortality on their farms, in order to develop an efficient intervention protocol. However, despite the importance of piglet vitality there is a lack of vitality assessment protocols or strategies that can be performed by producers to a large number of piglets in sow commercial herds. Moreover, given the importance of colostrum as only energy source available and its role in providing passive immunity to piglets, producers should focus on ensuring a proper colostrum intake by the piglets after birth, as well as on providing a comfortable environment and proper nutrition to sows around farrowing. Besides, confusing factors such as the impact of sow parity need to be further studied. Furthermore, most of the studies on the factors that influence piglet survival are performed in temperate or cold climates and further research in hot or tropical climates is necessary to assess the final impact of factors that influence piglet preweaning mortality , which might be different and require different management approaches to piglet preweaning mortality . In addition, from the literature, we can conclude that individual loose-farrowing systems show similar piglet preweaning mortality levels to those of conventional farrowing crates, with designed pens offering promising perspectives for future implementation at a commercial scale. Notably, recent studies suggested that an individual farrowing pen design, which combines the initial confinement of the sow with the subsequent ability to move within the pen, offers the potential to become a more suitable farrowing environment to meet biological needs and production goals; nonetheless, further studies are required. Finally, more feasible farrowing protocols should be of great interest for producers, and more studies on oral supplementation to low birth piglets are of great interest (*e.g.*, colostrum supplementation or oral supplementation using commercial boosters). Besides, the impact cross-fostering on piglet preweaning mortality also needs further reasearch to better understand its proper implementation in different situations (*e.g.*, in farms with poor health status).

Chapter III

Piglet preweaning mortality in a commercial swine herd in Thailand

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3.1 Abstract

In the modern swine industry, NBA is dramatically increasing due to genetic improvement of litter traits. However, knowledge on post-partum management is inadequate to reduce piglet preweaning mortality. The present study aimed to investigate piglet preweaning mortality in a commercial swine herd in Thailand in relation to the number of littermate pigs and piglet BW_B. Data included 11,154 litters from 3,574 sows farrowed from January 2009 to December 2012. Littermate pig was defined as the number piglets after cross-fostering. Number of littermate pigs was classified as 1 – 7, 8 – 10, 11 – 12 and 13 – 15 piglets/litter. Mean BW_B of the piglets was classified as low (< 1.30 kg), medium (1.30 – 1.79 kg) and high (≥ 1.80 kg). Piglet preweaning mortality was calculated, logged transformed and analyzed by general linear mixed models. On average, piglet preweaning mortality was 14.5% (median = 10.0%). Piglet preweaning mortality in the litter with 13 – 15 littermate pigs (24.1%) was significantly higher than the litter with 1 – 7 (11.9%, $P < 0.001$), 8 – 10 (11.8%, $P < 0.001$) and 11 – 12 (14.6%, $P < 0.001$) littermate pigs. The litters with a low piglet BW_B had a higher piglet preweaning mortality rate (18.8%) than the litters with a medium (15.7%, $P < 0.001$) and a high piglet BW_B (12.1%, $P < 0.001$). In conclusion, to reduce piglet preweaning mortality in commercial swine herds, special care needs to be taken in litters with more than 13 littermate pigs and with piglets with BW_B below 1.30 kg.

3.2 Introduction

Piglet preweaning mortality is an important problem in modern commercial swine herds worldwide. Earlier studies demonstrated that the average piglet preweaning mortality in general swine commercial herds worldwide varies from 10%

to 20% (Koketsu et al., 2006; Kilbride et al., 2012; Kirkden et al., 2013a). Piglet preweaning mortality reflects both economic loss and animal welfare issues. On average, 50% to 80% of piglet mortality occurs during the first week after birth with the most critical period being the first three days of life (Koketsu et al., 2006). It has been demonstrated that many factors, including sow parity number, farrowing duration, birth order, health, maternal behaviour and the vitality of the piglets, are important factors determining piglet preweaning mortality under field conditions (Baxter et al., 2008; Panzardi et al., 2013). However, no comprehensive study on factors associated with piglet preweaning mortality in Thailand has been conducted.

In the modern swine industry, the NBA is dramatically increasing due to the genetic improvement of litter traits (Marantidis et al., 2013). However, knowledge concerning post-partum management is still inadequate to reduce piglet preweaning mortality and increase the number of piglets at weaning. A recent study in the United Kingdom revealed that piglet preweaning mortality increased from 8.6% to 23.3% when the number of piglets in the litter after cross-fostering (*i.e.*, littermate pigs) increased from ≤ 10 to ≥ 14 piglets/ litter (Kilbride et al., 2012). The high risk of piglet preweaning mortality is also associated with a high NTB and a low BW_B (Milligan et al., 2002; van Rens et al., 2005). The NBA is also associated with the individual piglet BW_B (Milligan et al., 2002). Therefore, these two factors should be carefully evaluated together. Moreover, large litters are associated with a prolonged farrowing duration. Piglets born after a prolonged farrowing duration are more likely to experience hypoxia and become stillborn or show low viability at birth (Tuchscherer et al., 2000). A proportion of weak born piglets commonly found in large litters may contribute to a high proportion of piglet preweaning mortality. The objective of the present study was to investigate piglet preweaning mortality in a commercial swine herd in Thailand in relation to the number of littermate pigs and piglet BW_B.

3.3 Materials and methods

3.3.1 Data

The present study was conducted in a commercial swine herd located in the eastern region of Thailand. Data were collected from the database of the computerized recording system of the herd (PigLIVE®, Life informatics co., ltd., Nonthaburi, Thailand) during a four-year period from January 2009 to December 2012. The raw data included 12,594 litters from 3,860 sows. The data included sow identity, farrowing date, sow parity number, NBA, number of stillborn piglets per litter (SB), number of mummified fetuses per litter (MM), litter birth weight, average individual BW_B of the piglets, number of cross-fostered piglets (see below), weaning date, average body weight of piglets at weaning and number of piglet at weaning per litter.

3.3.2 Exclusion criteria

All of the raw data of each litter were carefully scrutinized for correctness. Lactation length was defined as the interval from farrowing to weaning. Litters with lactation length < 21 days (n = 1,219, 9.7%) or > 28 days (n = 85, 0.7%) were excluded from the analyses. Incorrect or error data recorded, *i.e.,* number of piglets at weaning per litter ≤ 0 (n = 100, 0.8%) or > 16 (n = 2, 0.01%), piglet weaning weight < 3.0 kg (n = 13, 0.1%) or > 15.0 kg (n = 3, 0.02%), and piglet BW_B < 3.0 kg (n = 18, 0.1%) were excluded from the analyses. Thus, a total of 1,440 litters (11.4%) were excluded from the analyses. Therefore, 11,154 litters from 3,574 sows were included in the analyses.

3.3.3 General management

The number of productive sows in the herd was 1,700 sows. The breed of the sows was LY crossbred females. All of the gilts and sows were kept in a conventional open-housing system facilitated with equipment (*e.g.*, fan and water sprinkler) to reduce the impact of high ambient temperature. The gilts and sows were kept in individual crates during gestation. Pregnant sows were moved to the farrowing pens about one week before the expected farrowing date. They were kept in pens with a space allowance of 4.5 m^2 per sow. Replacement gilts were produced within the herd. In general, the gilts were mated at ≥ 224 days of age with a body weight of ≥ 135 kg at the second or later observed oestrus. Conventional artificial insemination was used for all gilts and sows. The feed was provided twice a day (about 1.5 – 3.5 kg per day) during gestation. The gilts and sows received water *ad libitum* by water nipples. Both the replacement gilts and sows were vaccinated against classical swine fever virus (CSFV), Aujeszky's disease virus (ADV), porcine parvovirus infection (PPV) and foot-and -mouth disease virus (FMDV). The pregnant females were vaccinated against FMDV before farrowing and against CSFV and PPV after farrowing. Vaccination for ADV was performed in all gilts and sows every four months. This herd was seropositive for porcine reproductive and respiratory syndrome (PRRS), but no PRRS vaccination was performed during the studied period. During lactation, the sows were fed twice a day (about 5 – 6 kg of feed per day) with a rice-corn-soybean-chicken ration containing 18.0% crude protein, 3,250 kcal/kg metabolizable energy and 1.10% lysine. In general, the planned removal of sows was performed after parity six.

3.3.4 Meteorological data

Daily meteorological data were obtained from the official provincial meteorological stations near (< 100 km) the herd. The outdoor 24-h temperature and humidity in these area in the hot (15 February to 14 June), rainy (15 June to 14 October) and cool (15 October to 14 February) seasons were 28.0 °C/78.7%, 27.3 °C/84.3% and 26.0 °C/73.9%, respectively. The mean minimum-maximum daily temperatures were 24.1 – 34.6 °C, 24.4 – 32.6 °C and 21.2 – 32.8 °C in the hot, rainy and cool seasons, respectively.

3.3.5 Definition

The "total number of piglets born per litter (NTB)" was defined as the sum of NBA, SB and MM. "Number of littermate pigs" was defined as the NBA after cross-fostering. In general, cross-fostering was performed in some litters within 48 h after birth. The number of cross-fostered piglets was recorded in all litters. If no cross-fostering was performed, the number of cross-fostered piglets was defined as "0". If the piglets were taken away from the biological mother, the number of cross-fostered piglets was recorded as −1, −2, −3, etc. On the other hand, if piglets were added into a litter, the number of cross-fostered piglets was recorded as +1, +2, +3, etc. "Piglets preweaning mortality" was defined as the percentage of live-born piglets after cross-fostering that died from birth to weaning. Piglet preweaning mortality at the individual sow level was calculated: piglet preweaning mortality (%) = (number of littermate pigs − number of piglets at weaning) / number of littermate pigs.

3.3.6 Classification

In the statistical analyses, sows were classified according to parity numbers into three groups, *i.e.*, 1, 2 – 4 and 5 – 9. Litter sizes at birth were classified into four groups, *i.e.*, 1 – 7, 8 – 10, 11 – 12, and 13 – 15 piglets. Average BW_B of the piglets was classified into three groups, *i.e.*, low (< 1.30 kg), medium (1.30 – 1.79 kg) and high (≥ 1.80 kg).

3.3.7 Statistical analysis

Statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA). Descriptive statistics were carried out by using MEANS and FREQ procedures. Pearson's correlation was conducted to analyze the association between piglet preweaning mortality and reproductive parameters including BW_B and number of littermate pigs. Additionally, a general linear mixed model procedure was performed to analyze various factors influencing piglet preweaning mortality. The piglet preweaning mortality rates were regarded as dependent variables. Normality of the variable was determined by using the residual plot under general linear model procedure. Kurtosis, skewness and Kolmogorov-Smirnov statistics were used to determine normality of the dependent variables. Due to a skew distribution of piglet preweaning mortality (Figure 4), the original data were log transformed before being analyzed. The factors and interactions included in the statistical model were tested for significance and omitted from the model in a stepwise fashion, leaving only factors and interactions with a significance level of $P < 0.1$. The statistical models included parity number (1, 2 – 4 and 5 – 9), BW_B classes (low, medium, high), number of littermate pig classes (1 – 7, 8 – 10, 11 – 12 and 13 – 15) and interaction between parity number and BW_B, parity number and number of littermate pigs, and number of littermate pigs and BW_B. Sow ID was added in the statistical model as a random effect. Least-square means were obtained from statistical models and were compared by Tukey-Kramer test. Values with $P < 0.05$ were regarded as statistically significant.

3.4 Results

3.4.1 Descriptive statistics

Descriptive statistics, including number of non-missing values, arithmetic means, standard deviation and ranges of sow reproductive performances are presented in Table 1. On average, piglet preweaning mortality was 14.5% (median = 10.0%).

Table 1 Descriptive statistics (*i.e.*, mean ± standard deviation, median and range) on reproductive data of 11,154 litters from 3,574 sows farrowed from 2009 to 2012 in a commercial herd in Thailand

Variables	Mean ± SD	Median	Range
Parity number	3.6 ± 1.9	3.0	1.0 – 9.0
Total number of piglets born per litter	12.0 ± 2.9	12.0	1.0 – 24.0
Number of piglets born alive per litter	10.7 ± 2.6	11.0	1.0 – 19.0
Mummified fetuses per litter, %	3.8 ± 7.2	0	0.0 – 91.7
Stillborn piglets per litter, %	6.1 ± 8.8	0	0.0 – 87.5
Piglet birth weight, kg	1.62 ± 0.23	1.61	0.7 – 3.2
Lactation length, days	24.9 ± 1.4	25.0	21.0 – 28.0
Piglet preweaning mortality, %	14.5 ± 15.9	10.0	0.0 – 92.9
Number of piglets at weaning	9.2 ± 2.1	10	1.0 – 16.0
Body weight of piglets at weaning, kg	6.72 ± 1.1	6.70	3.1 – 15.0

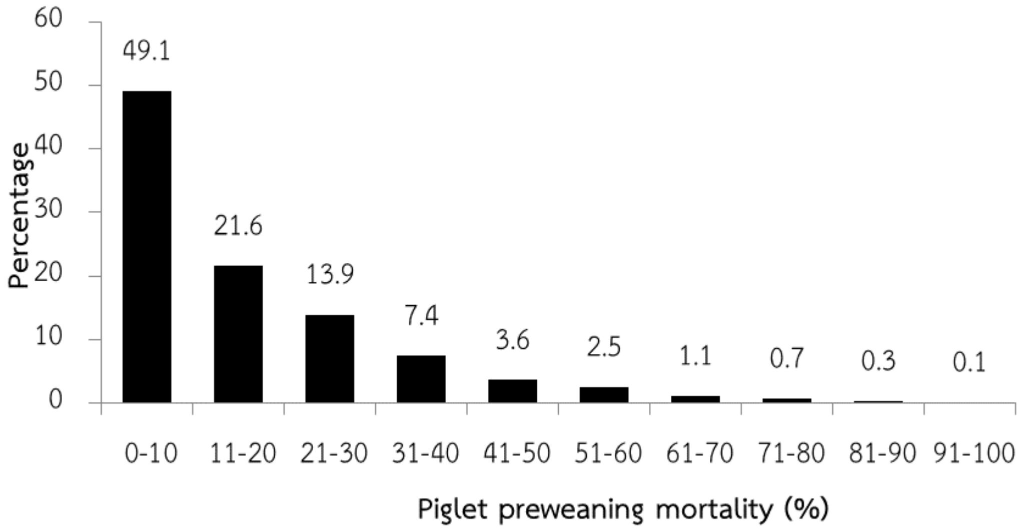

Figure 4 Frequency distribution of the percentage of piglet preweaning mortality in 11,154 litters from 3,574 Landrace × Yorkshire crossbred sows in a commercial swine herd in Thailand during 2009 – 2012

Figure 4 illustrates the frequency distribution of piglet preweaning mortality. As can be seen from the figure, 49.1% of the litters had a piglet preweaning mortality of 0 – 10% and 21.6% of the litters had a piglet preweaning mortality rate of 11 – 20%. On average, the number of littermate pigs was 10.9 ± 2.1 piglets per litters. After cross-fostering, the percentage of litters with 1 – 7, 8 – 10, 11 – 12 and 13 – 15 littermate pigs were 6.0%, 32.7%, 43.4% and 18.0%, respectively. The number of piglets at weaning averaged 9.2 ± 2.1 piglets (median = 10 piglets).

The frequency distribution of number of piglets at weaning is presented in Figure 5. As can be seen from the figure, 17.2% of the sows were able to wean 11 piglets and 10.5% of the sows were able to wean ≥ 12 piglets. Among all the litters, 70.5% of the piglets were reared by their biological mothers.

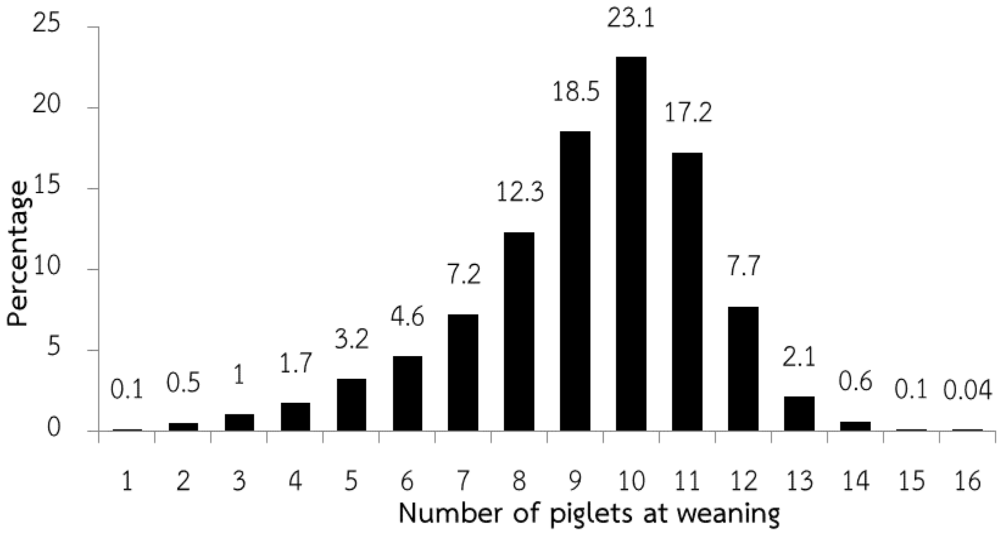

Figure 5 Frequency distribution of number of piglets at weaning in 11,154 litters from 3,574 Landrace × Yorkshire crossbred sows in a commercial swine herd in Thailand during 2009 – 2012

On average, 47.8% of the litters were not cross-fostered and all of the piglets were entirely reared by their biological mother. The NBA reared by an adopted mother varied from 1 to 14 piglets per litter (Figure 6). Frequency distribution and cumulative frequency of the number of cross-fostered piglets are illustrated in Figure 6.

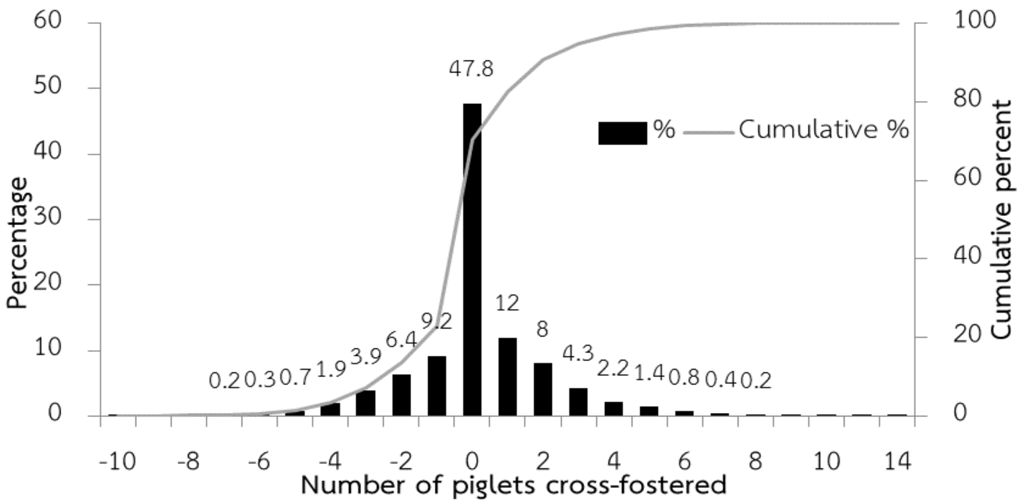

Figure 6 Frequency distribution of number of cross-fostered piglets in 11,154 litters from 3,574 Landrace × Yorkshire cross-bred sows in commercial swine herd in Thailand during 2009 – 2012

3.4.2 Correlation

Piglet preweaning mortality (log transformation) significantly correlated with both the number of littermate pigs and the piglet BW_B (Table 2). As the number of littermate pigs increased, piglet preweaning mortality also increased (r = 0.339, P < 0.001). On the other hand, piglet preweaning mortality decreased when the piglet BW_B increased (r = −0.185, P < 0.001). Additionally, when piglet preweaning mortality increased, the number of piglets at weaning also significantly decreased (r = −0.396, P < 0.001). Interestingly, the number of piglets at weaning per litter was also positively associated with NTB (r = 0.326, P < 0.001), NBA (r = 0.195, P = 0.001) and number of littermate pigs (r = 0.583, P < 0.001).

Table 2 Pearson's correlations between piglet preweaning mortality (log transformation) and reproductive parameters (*i.e.,* number of littermate pigs, piglet birth weight, parity number) in 11,154 litters from 3,574 sows farrowed from 2009 to 2012 in a commercial herd in Thailand

Parameters	Correlation Coefficient (r)	P value
Positive correlation		
Total number of piglets born per litter	0.205	< 0.001
Number of piglet born alive per litter	0.195	< 0.001
Number of littermate pigs per litter	0.339	< 0.001
Number of piglets cross-fostered	0.114	< 0.001
Negative correlation		
Piglet birth weight	− 0.185	< 0.001
Number of piglets at weaning per litter	− 0.396	< 0.001
Piglet body weight at weaning	− 0.135	< 0.001

3.4.3 Effect of number of littermate pigs

The piglet preweaning mortality rates in the litters with different numbers of littermate pigs are presented in Table 3. As can be seen from the table, the piglet preweaning mortality in the litters with 13 – 15 littermate pigs (24.1%) was higher than the litters with 1 – 7 littermate pigs (11.9%, *P* < 0.001), 8 – 10 littermate pigs (11.8%, *P* < 0.001) and 11 – 12 littermate pigs (14.6%, *P* < 0.001). However, piglet preweaning mortality in the litter with 1 – 7 littermate pigs did not differ significantly compared the litters with 8 – 10 littermate pigs (*P* = 0.316).

Table 3 Piglet preweaning mortality (%) in the litters with different number of littermate pigs

Number of littermates pigs	Number of litters	Piglet preweaning mortality (%)
1 – 7	670	11.9 ± 0.8^a
8 – 10	3,642	11.8 ± 0.4^a
11 – 12	4,839	14.6 ± 0.4^b
13 – 15	2,003	24.1 ± 0.6^c

$^{a, b, c}$ Different superscripts within column indicate significant difference (*P* < 0.05)

3.4.4 Effect of piglet birth weight

Piglet preweaning mortality in the litters with low piglet BW_B (18.8%) was higher than the litters with medium piglet BW_B (15.7%, *P* = 0.002) and the litters with high piglet BW_B (12.1%, *P* < 0.001) (Table 4). Furthermore, piglet preweaning mortality in the litter with medium piglet BW_B was significantly higher than the litter with high piglet BW_B (*P* < 0001).

Table 4 Piglet preweaning mortality (%) by piglet birth weight classes

Birth weight (kg)	Number of sows	Preweaning mortality (%)
Low	642	18.8 ± 0.8^a
Medium	8,284	15.7 ± 0.3^b
High	2,228	12.1 ± 0.5^c

$^{a, b, c}$ Different superscripts within column indicate significant difference (*P* < 0.05)

Table 5 Piglet preweaning mortality (%) by individual piglet birth weight and littermate pigs

Number of littermate pigs	Piglet birth weight		
	Low	Medium	High
1 – 7	12.7 ± 2.5^{a,A}	12.1 ± 0.8^{a,A}	8.9 ± 1.0^{a,A}
	(n = 46)	(n = 386)	(n = 238)
8 – 10	14.6 ± 1.3^{a,A}	10.9 ± 0.3^{b,A}	8.7 ± 0.5^{c,A}
	(n = 183)	(n = 2,539)	(n = 920)
11 – 12	16.7 ± 1.1^{a,A}	14.6 ± 0.3^{a,B}	11.3 ± 0.5^{b,B}
	(n = 229)	(n = 3,749)	(n = 861)
13 – 15	29.8 ± 1.3^{a,B}	24.5 ± 0.4^{a,C}	18.0 ± 1.0^{a,C}
	(n = 184)	(n = 1,610)	(n = 209)

$^{a, b, c}$ Different lower-case letters indicate significant difference within row (P < 0.05)

$^{A, B, C}$ Different capital letters indicate significant difference within column (P < 0.05)

Table 5 demonstrated the interaction effects of piglet BW_B and number of littermate pigs. It was found that piglet preweaning mortality increased when the number of littermate pigs increased in all categories of piglet BW_B. In the litters with medium and high piglet BW_B, piglet preweaning mortality significantly increased when the litters contained ≥ 10 piglets per litter (Table 5). However, in the litters with low piglet BW_B, piglet preweaning mortality significantly increased when the litters contained ≥ 13 piglets per litter (Table 5).

3.4.5 Effect of sow parity number

On average, piglet preweaning mortality was 15.9%, 14.5% and 16.3% for sow parity numbers 1, 2 – 4 and 5 – 9, respectively (P = 0.143). However, the interaction between sow parity number and number of littermate pigs was significant (P = 0.032), indicating that the influence of sow parity number on piglet preweaning mortality depends on number of littermate pigs. Table 6 demonstrates piglet preweaning mortality of sow parity numbers 1, 2 – 4 and 5 – 9 in each category of number of littermate pigs. It was found that, with a limited number of littermate pigs, sows in parity group 2 – 4 had a significantly lower piglet preweaning mortality rate than sow parity groups 1 and 5 – 9 (Table 6). However, the difference among parity groups of sows was less pronounced when number of littermate pigs increased. In all parity groups, piglet preweaning mortality significantly increased when number of littermate pigs was ≥ 11 piglets per litter (Table 6).

Table 6 Piglet preweaning mortality (%) in sow parity numbers 1, 2 – 4 and 5 – 9 by number of littermate pigs

Number of littermate pigs	Sow parity number		
	1	2 – 4	5 – 9
1 – 7	$12.3 \pm 1.1^{ab,A}$	$10.2 \pm 1.2^{a,A}$	$13.1 \pm 1.4^{b,A}$
	(n = 223)	(n = 271)	(n = 176)
8 – 10	$12.9 \pm 0.6^{a,A}$	$10.7 \pm 0.6^{a,A}$	$11.8 \pm 0.7^{a,A}$
	(n = 737)	(n = 1,710)	(n = 1,195)
11 – 12	$15.4 \pm 0.7^{a,B}$	$13.4 \pm 0.6^{a,B}$	$15.0 \pm 0.6^{a,B}$
	(n = 635)	(n = 2,511)	(n = 1,693)
13 – 15	$23.0 \pm 0.9^{a,C}$	$23.8 \pm 0.7^{a,C}$	$25.4 \pm 0.9^{a,C}$
	(n = 420)	(n = 952)	(n = 631)

[a, b] Different lower-case letters indicate significant difference within row ($P < 0.05$)

[A, B, C] Different capital letters indicate significant difference within column ($P < 0.05$)

Table 7 shows the influence of sow parity number on piglet preweaning mortality in each category of piglet BW_B. Interestingly, piglet preweaning mortality significantly decreased when the piglet BW_B increased in all categories of sow parity number (Table 7). As can be seen from the table, piglet preweaning mortality was lowest when the high BW_B piglets were reared by sow parity group 2 – 4 (10.6%) and it was highest when the low BW_B piglets were reared by sow parity group 5 – 9 ($P < 0.001$).

Table 7 Piglet preweaning mortality (%) in low, medium and high piglet birth weight by sow parity number

Sow parity number	Piglet birth weight		
	Low	Medium	High
1	$18.4 \pm 4.8^{a,A}$	$16.1 \pm 0.4^{ab,A}$	$13.1 \pm 1.0^{b,A}$
	(n = 395)	(n = 1,392)	(n = 228)
2 – 4	$18.1 \pm 1.4^{a,A}$	$14.8 \pm 0.3^{a,A}$	$10.6 \pm 0.5^{b,A}$
	(n = 145)	(n = 2,539)	(n = 1,286)
5 – 9	$20.0 \pm 1.6^{a,A}$	$16.3 \pm 0.4^{a,A}$	$12.7 \pm 0.6^{b,A}$
	(n = 102)	(n = 2,879)	(n = 714)

$^{a, b}$ Different lower-case letters indicate significant difference within row ($P < 0.05$)

$^{A, B}$ The same capital letters within column did not differ significantly ($P > 0.05$)

3.5 Discussion

The present study demonstrated that a higher number of littermate pigs was associated with greater piglet preweaning mortality. It was found that when the number of littermate piglets was > 10 piglets per litter, piglet preweaning mortality increased by 2.8%. Likewise, when the number of littermate pigs was ≥ 13 piglets per litter, piglet preweaning mortality increased by 12.3% compared to the basal level (*i.e.*, 11.8% when there are ≤ 10 littermate pigs; see Table 3). Therefore, in the modern swine industry, more effort must be expended on the litters with a high number of littermate pigs to minimize piglet preweaning mortality. Earlier studies demonstrated that piglets born in large litters are at risk of showing low viability at birth (Tuchscherer et al., 2000; Panzardi et al., 2013). This is due to the fact that piglets born in large litter may suffer from a long duration of farrowing, especially those born late in the litter (Tuchscherer et al., 2000). Weakness among piglets may be caused by various degrees of asphyxia and this subsequently influences their suckling behaviour.

The present study found that low BW_B lead to high piglet preweaning mortality. This is in agreement with earlier studies (Tuchscherer et al., 2000). Roehe and Kalm (2000) found that piglets with BW_B of 1.8, 1.5, 1.2 and 1.0 kg had higher ratios of piglet preweaning mortality (odd ratio = 1.4, 2.7, 7.0 and 16.1, respectively) than piglets with a BW_B of 2.1 kg. Vallet and Miles (2012) found that there was less myelin basic protein mRNA in the brain stems of small piglets than in the brain stems of large piglets. This protein is known to affect the speed of transmission of nerve impulses. Therefore, the small piglets may have had slower speeds of movement and reflexive actions than the large piglets. Most cases of piglet preweaning mortality are caused by crushing by the dam (Kirkden et al., 2013a). The impairment of myelination in small piglets may also contribute to the risk of crushing (Vallet and Miles, 2012).

Furthermore, it has been demonstrated that low BW_B piglets reach the teat later and consume less colostrum than those with higher BW_B (Tuchscherer et al., 2000). It is known that the survival rate of piglets is largely dependent on colostrum consumption because the piglets receive immunoglobulin mainly through colostrum consumption (Markowska-Daniel and Pomorska-Mol, 2010; Vallet et al., 2013). Body weight is positively correlated with colostrum consumption (Ferrari et al., 2014). Low BW_B piglets require longer time to reach the teat and first suckle, and are less competitive for a teat than heavier littermates (Le Dividich et al., 2005), thus reducing its colostrum consumption (Tuchscherer et al., 2000). Furthermore, piglets with low colostrum consumption are more likely to die by crushing or health problems. Survival rate of piglets is largely dependent on colostrum consumption because piglets receive passive immunity through colostrum (Markowska-Daniel and Pomorska-Mol, 2010; Vallet et al., 2013).

Body weight of the newborn piglets strongly influences the piglet thermoregulation ability. Within the first h after birth, thermoregulation is compromised in piglets because of evaporation of the placental fluids and consequent cooling. Susceptible piglets fail to recover from this initial temperature drop, hypothermia affects latency to suckle leading to starvation, lethargy and, ultimately, leading to crushing by the sow (Weary et al., 1996). Several studies indicated that rectal temperature was associated with piglet preweaning mortality (Tuchscherer et al., 2000; Baxter et al., 2008; Muns et al., 2013; Panzardi et al., 2013), suggesting that piglets with low rectal temperature might have lower thermoregulation ability. Furthermore, small piglets have higher surface area to volume ratio, resulting in greater susceptibility to heat loss and hypothermia (Herpin et al., 2002). Therefore, low BW_B piglets are at high risk of death because of reduced energy reserves.

Interestingly, in the present study, piglet preweaning mortality significantly decreased when the piglet BW_B increased in all categories of sow parity number. Nevertheless, the piglet preweaning mortality was lowest when the high BW_B piglets were reared by sow parity group 2 – 4 (10.6%) and it was highest when the low BW_B piglets were reared by sow parity group 5 – 9. These indicates that parity number of sows influenced the association between BW_B and piglet preweaning mortality. Based on the present result, low BW_B piglets are not recommended to be reared by old sows.

Earlier studies found that piglet preweaning mortality was substantially decreased by intensive farrowing supervision (Kilbride et al., 2012; Panzardi et al., 2013). Effective farrowing supervision as well as post-partum care allows practitioners to provide assistance to sows and take good care of neonatal piglets. Therefore, proper post-partum management for low BW_B piglets may possibly reduce the risk of piglet preweaning mortality (Muns et al., 2013).

3.6 Conclusion

Piglet preweaning mortality average 14.5% with a median of 10.0%. Of all the litters, 49.1% had a piglet preweaning mortality rate of 0 – 10% and 21.6% had a piglet preweaning mortality rate of 11 – 20%. To reduce piglet preweaning mortality and achieve high numbers of piglets at weaning in commercial swine herds, special care needs to be taken in litters with more than 13 littermate pigs and with the piglets with BW_B below 1.3 kg. Low BW_B piglets are not recommended to be reared by old sows.

Chapter IV

Influences of climatic parameters on piglet preweaning mortality in the tropics

(Submitted in Tropical Animal Health and Production)

4.1 Abstract

The objective of the present study was to determine the influences of temperature, humidity and temperature-humidity index (THI) on piglet preweaning mortality in a conventional open-housing system commercial swine herd in Thailand. The analyzed data included 11,157 litters from 3,574 sows. The daily meteorological data (i.e., temperature, humidity and THI) were collected from a meteorological station near the herd. The associations between temperature, humidity and THI for periods before and after farrowings and piglet preweaning mortality were analysed. Piglet preweaning mortality (log transformation) and the proportion of litters with piglet preweaning mortality greater than 20% were analysed by using general linear mixed models and generalized linear mixed models (GLIMMIX), respectively. On average, the piglets preweaning mortality and the proportion of litters with piglet preweaning mortality greater than 20% were 14.5% and 26.4%, respectively. Piglet preweaning mortality was positively correlated with the mean temperature ($r = 0.028$, $P = 0.003$), humidity ($r=0.038$, $P<0.001$) and THI ($r=0.036$, $P<0.001$) during 0-7 days postpartum. In primiparous sows, piglet preweaning mortality was increased from 12.1% to 18.5% (+6.4%, $P<0.001$) when the mean temperature during 0–7 days postpartum increased from <25.0 °C to ≥29 °C. However, the influence of the temperature during 0–7 days postpartum was insignificant in multiparous sows. Likewise, piglet preweaning mortality was increased from 10.7% to 16.7% (+6.0%, $P=0.012$) when humidity during 0–7 days postpartum increased from <60% to ≥80% in primiparous sows but it was insignificant in multiparous sows. Moreover, the proportion of the litters with piglet preweaning

mortality greater than 20% in primiparous sows was increased from 18.3% to 32.4% (+14.1%, P=0.017) when the THI during 0–7 days postpartum increased from <73 to ≥ 81. In conclusion, the influences of temperature, humidity and THI on piglet preweaning mortality were more evidence in primiparous than multiparous sows. These data implied that strategies to reduce temperature for postpartum sows in the open–housing system in Thailand are inadequate and the proper management of postpartum primiparous sows should be emphasized.

4.2 Introduction

Global warming and climatic changes have a high impact on swine industry worldwide (Wegner et al., 2014; De Rensis et al., 2017). In Thailand, sows are commonly housed in a conventional open-housing system. Therefore, the climatic parameters and sow reproductive performances are highly associated. Although, studies on the association between climatic parameters and reproductive performance have been performed (Tummaruk et al., 2004; Suriyasomboon et al., 2006; Tummaruk et al., 2010), data on the association between climatic parameters and piglet preweaning mortality are still lacking. Management in the farrowing house play an important role on the piglet mortality during the sucking period (Muns and Tummaruk, 2016b). Comprehensive study of strategies in lactating management is necessary knowledge in commercial swine farm in tropical countries. The objective of the present study was to determine the influences of temperature, humidity and THI on piglet preweaning mortality in a conventional open-housing system commercial swine herd in Thailand.

4.3 Materials and Methods

4.3.1 Data

The present study was conducted in a commercial swine herd located in the eastern region of Thailand. Data were collected from the database of the computerized recording system of the herd (PigLIVE®, Life informatics co., ltd., Nonthaburi, Thailand) during a four-year period from January 2009 to December 2012.

The raw data included 12,594 litters from 3,860 sows. The data included sow identity, farrowing date, sow parity number, NBA, SB, MM, litter birth weight, average individual BW_B, number of cross-fostered piglets, weaning date, average body weight of piglets at weaning and number of piglet at weaning per litter. The NTB was defined as the sum of NBA, SB, MM. "Number of littermate pigs" was defined as the NBA after cross-fostering (Nuntapaitoon and Tummaruk, 2015). "Piglet preweaning mortality" was defined as the percentage of live-born piglets after cross-fostering that died from birth to weaning. Piglet preweaning mortality at the individual sow level was calculated: Piglet preweaning mortality (%) = (number of littermate pigs – number of piglets at weaning) / number of littermate pigs.

4.3.2 Exclusion criteria

All of the raw data of each litter were carefully scrutinized for correctness. Lactation length was defined as the interval from farrowing to weaning. Litters with lactation length < 21 days (n = 1,319, 10.5%) or > 28 days (n = 76, 0.6%) were excluded from the analyses. Incorrect or error data recorded, *i.e.*, number of piglets at weaning per litter ≤ 0 (n = 3, 0.02%) or > 16 (n = 2, 0.02%), piglet weaning weight < 3.0 kg (n = 7, 0.06%) or > 15.0 kg (n = 3, 0.02%), and piglet BW_B < 0.8 kg (n = 7, 0.06%) or > 2.5 kg (n = 20, 0.16%) were excluded from the analyses. Thus, a total of 1,437 litters (11.41%) were excluded from the analyses. Therefore, 11,157 litters from 3,574 sows were included in the analyses.

4.3.3 General management

The number of productive sows in the herd was 1,700 sows. The breed of the sows was LY crossbred females. All of the gilts and sows were kept in a conventional open-housing system facilitated with equipment (*e.g.*, fan and water sprinkler) to reduce the impact of high ambient temperature. The gilts and sows were kept in individual crates during gestation. Pregnant sows were moved to the farrowing pens about one week before the expected farrowing date. They were kept in pens with a space allowance of 4.5 m^2 per sow. Replacement gilts were produced within the herd.

In general, the gilts were mated at ≥ 224 days of age with a body weight of ≥ 135 kg at the second or later observed oestrus. Conventional artificial insemination was used for all gilts and sows. The feed was provided twice a day (about 1.5 – 3.5 kg per day) during gestation. The gilts and sows received water *ad libitum* by water nipples. Both the replacement gilts and sows were vaccinated against CSFV, APV, PPV and FMDV. The pregnant females were vaccinated against FMDV before farrowing and against CSFV and PPV after farrowing. Vaccination for ADV was performed in all gilts and sows every four months. This herd was seropositive for PRRS. During lactation, the sows were fed twice a day (about 5 – 6 kg of feed per day) with a rice-corn-soybean-chicken ration containing 18.0% crude protein, 3,250 kcal/kg metabolizable energy and 1.10% lysine. In general, the planned removal of sows was performed after parity six.

4.3.4 Meteorological data

The daily meteorological data were collected from a meteorological station near the herd (less than 100 kilometers). The means of all climatic parameters from 2009 to 2012 are presented in Figure 8. The THI on each day was calculated: THI = temperature – [0.55 – (0.55 × humidity)] × (temperature – 58) (Kelly and Bond 1971). Climatic parameters (*i.e.,* temperature, humidity and THI) before (0 – 30 and 0 – 7 days) and after (0 – 7 and 0 – 24 days) farrowings were calculated. The mean temperature was classified into six groups, *i.e.,* < 25.0, 25.0 – 25.9, 26.0 – 26.9, 27.0 – 27.9, 28.0 – 28.9 and ≥ 29.0°C. The mean relative humidity was classified into four groups, *i.e.,* < 60.0, 60.0 – 60.9, 70.0 – 70.9 and ≥ 80.0% and the mean THI was classified into four groups, i.e., < 73.0, 73.0 – 78.9, 79.0 – 80.9 and ≥ 81.0.

4.3.5 Statistical analysis

The statistical analyses were performed using the SAS software (SAS Institute Inc., Cary, NC, USA). Descriptive statistics were carried out by using MEANS and FREQ procedures. Piglet preweaning mortality and the proportion of litters with piglet preweaning mortality greater than 20% were regarded as dependent variables. The piglet preweaning mortality was logged transformed and were analyzed by general linear mixed models procedure (PROC MIXED). The mixed models were formulated by including both fixed and random effects and used restricted maximum likelihood (REML) as an estimation method. The fixed effects included number of littermate pig classes (1 – 7, 8 – 10, 11 – 12, and 13 – 15 piglets), piglet BW_B classes (< 1.30, 1.30 – 1.79 and ≥ 1.80 kg), parity groups (1, 2 – 4 and 5 – 9), farrowing years, farrowing seasons, and interaction between parity and seasons. Sow was added in the statistical models as a random effect. To evaluate the seasonal influence in each parity group, the analyses were also applied by parity groups using the general linear model procedure (PROC GLM). The models included the effect of number of littermate pigs, piglet BW_B, farrowing years, season and interactions between farrowing years and season. The influences of temperature, humidity and THI on piglet preweaning mortality were analyzed by general linear mixed models using the MIXED procedure of SAS. The meteorogical data were merge with the reproductive data. Pearson's correlation was performed to study collinearity among the climatic parameters and piglet preweaning mortality. The effects of temperature, humidity and THI were included in the statistical models one at a time. The influence of temperature, humidity and THI on the proportion of litters with piglet preweaning mortality greater than 20% were analyzed by generalised linear mixed model procedures (GLIMMIX macro) of SAS. Least-square means were obtained from each class of the factors and were compared by a least-significant-difference test. Values with $P < 0.05$ were regarded to be statistically significant.

4.4 Results

Descriptive statistics, including number of non-missing values, arithmetic means, standard deviation and ranges of sow reproductive performances, are presented in Table 8. As can be seen from the table, the NTB, the NBA and piglet BW_B was 12.0 ± 2.9, 10.7 ± 2.6 and 1.62 ± 0.22 kg, respectively. Lactation length was 24.9 ± 1.4 days (range 21 – 28 days).

Table 8 Descriptive statistics (*i.e.,* mean ± standard deviation and range) on reproductive data in a commercial swine herd in Thailand during 2009 – 2012

Variables	Mean ± SD	Range
Number of sows	3,574	–
Number of farrowing	11,157	–
Parity number	3.6 ± 1.9	1.0 – 9.0
Reproductive performance		
Number of total piglets born per litter	12.0 ± 2.9	1.0 – 24.0
Number of piglets born alive per litter	10.7 ± 2.6	1.0 – 19.0
Mummified fetuses per litter, %	3.8 ± 7.3	0.0 – 91.7
Stillborn piglets per litter, %	6.1 ± 8.9	0.0 – 87.5
Piglet birth weight, kg	1.62 ± 0.2	0.7 – 2.9
Lactation length, days	24.9 ± 1.4	21.0 – 28.0
Preweaning mortality, %	14.5 ± 15.9	0.0 – 92.9
Proportion of litters with preweaning mortality greater than 20%, %	26.4 ± 44.1	0 – 100
Number of piglets at weaning per litter	9.2 ± 2.1	1.0 – 16.0
Body weight of piglets at weaning, kg	6.71 ± 1.1	3.1 – 15.0

On average, piglet preweaning mortality and the proportion of litters with piglet preweaning mortality greater than 20% were 14.5% and 26.4%, respectively. Figure 7 illustrates the frequency distribution of preweaning mortality. As can be seen from the figure, 49.5% of the litter had preweaning mortality of 0 – 10% and 21.6% of the litter had preweaning mortality of 10 – 20%. The number of piglets preweaning mortality were 14.3%, 14.5% and 14.8% in hot, rainy and cool seasons, respectively.

The climatic parameters between 2009 and 2012 are presented in Figure 8. Factors influencing piglet preweaning mortality are presented in Table 9. As can be seen from the table, number of littermate pigs, piglet BW_B, parity groups and farrowing years influenced piglet preweaning mortality ($P < 0.05$).

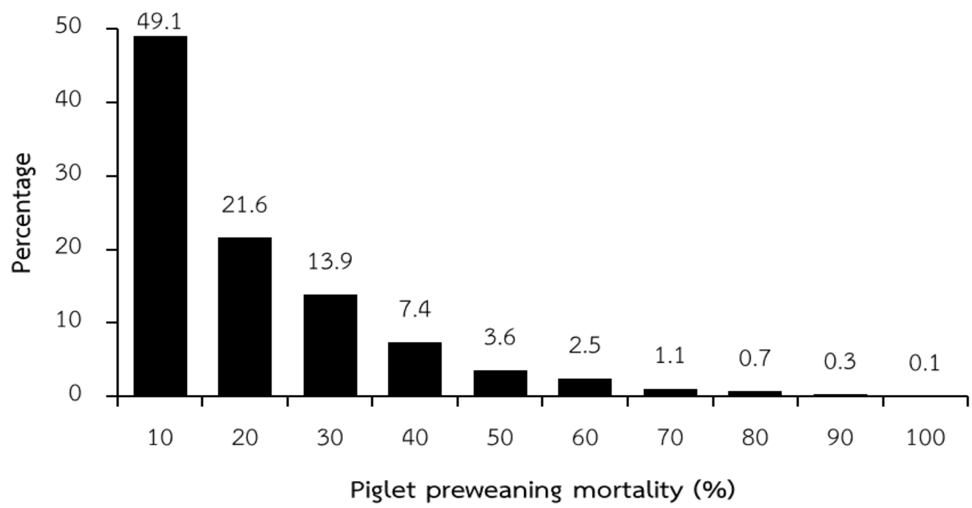

Figure 7 Frequency distribution of the piglet preweaning mortality per litter (n = 11,157)

Table 9 Statistical models for analyzing the factors influening piglet preweaning mortality (log transformation, models I, II, IV and VI) and the proportion of litters with piglet preweaning mortality greater than 20% (models III, V and VII) from 11,157 litters

Factors	Models						
	I	II	III	IV	V	VI	VII
Parity	0.008	0.019	0.012	0.419	0.052	0.281	0.088
Number of littermate pigs	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Birth weight	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Farrowing years	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Farrowing season	0.221	–	–	–	–	–	–
Temperature	–	0.038	0.449	–	–	–	–
Humidity	–	–	–	0.085	0.053	–	–
THI	–	–	–	–	–	0.871	0.397
Parity × Farrowing season	0.220	–	–	–	–	–	–
Parity × Temperature	–	0.056	0.106	–	–	–	–
Parity × Humidity	–	–	–	0.100	0.241	–	–
Parity × THI	–	–	–	–	–	0.220	0.012

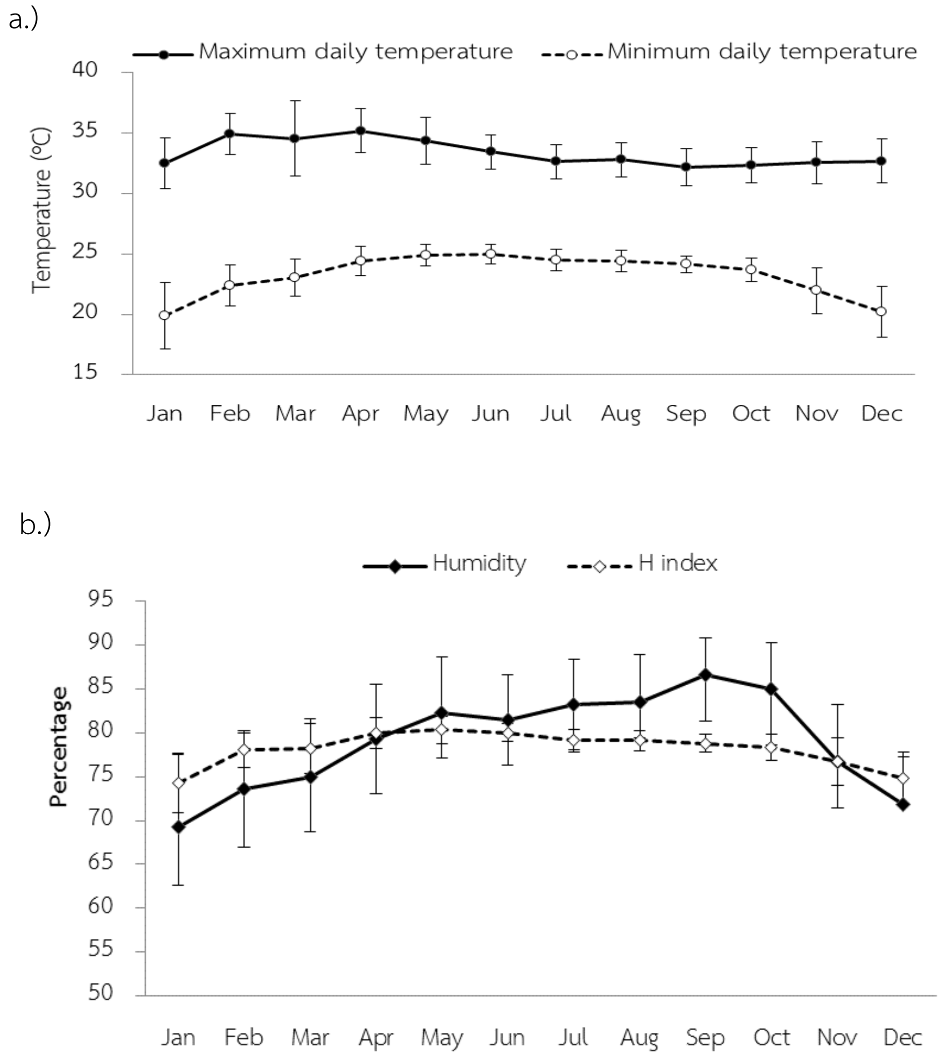

Figure 8 Average of outdoor minimum and maximum temperature (a.) and mean humidity and temperature-humidity index (THI) (b)

The correlations among climatic parameters (temperature, humidity and THI) and piglet preweaning mortality are presented in Table 10. At 0 – 7 days postpartum, piglet preweaning mortality correlated with temperature (r = 0.028, P = 0.003), humidity (r = 0.030, P = 0.002) and THI (r = 0.024, P = 0.010).

Table 10 Pearson's correlation between climatic parameters (*i.e.,* temperature, humidity and temperature-humidity index) on piglet preweaning mortality (log transformation)

Climatic parameters	*r*	*P Value*
Temperature		
0 – 7 days before farrowing	NS	NS
0 – 30 days before farrowing	0.021	0.029
0 – 7 days postpartum	0.028	0.003
0 – 24 days postpartum	0.020	0.032
Humidity		
0 – 7 days before farrowing	0.030	0.002
0 – 30 days before farrowing	0.032	< 0.001
0 – 7 days postpartum	0.038	< 0.001
0 – 24 days postpartum	0.040	< 0.001
Temperature–humidity index		
0 – 7 days before farrowing	0.024	0.010
0 – 30 days before farrowing	0.028	0.004
0 – 7 days postpartum	0.036	< 0.001
0 – 24 days postpartum	0.031	0.001

4.4.1 Temperature

The temperature during 0–7 days postpartum influenced piglet preweaning mortality (*P* = 0.038) (Table 9). On average, the piglet preweaning mortality was increased from 14.2% to 16.2% (+2.0%, *P* = 0.004) when the temperature during 0 – 7 days postpartum increased from < 25 °C to ≥ 29 °C. Interaction between temperature during 0–7 days postpartum and sow parity number influence piglet preweaning mortality (P = 0.056) (Table 9). The effect of temperature during 0 – 7 days after farrowing on piglet preweaning mortality by parity numbers is demonstrated in Figure 9a. As can be seen from the figure, the piglet preweaning mortality was increased from 12.1% to 18.5% (+6.4%, P<0.001) when the average temperature during 0 – 7 days postpartum increased from < 25 °C to ≥ 29°C in primiparous sows. Moreover, the proportion of litters with piglet preweaning mortality greater than 20% in primiparous sows was increased from 19.2% to 37.2% (+18.0%, P = 0.002) when the temperature during 0 – 7 days postpartum increased from <25 °C to ≥ 29 °C (Figure 9b).

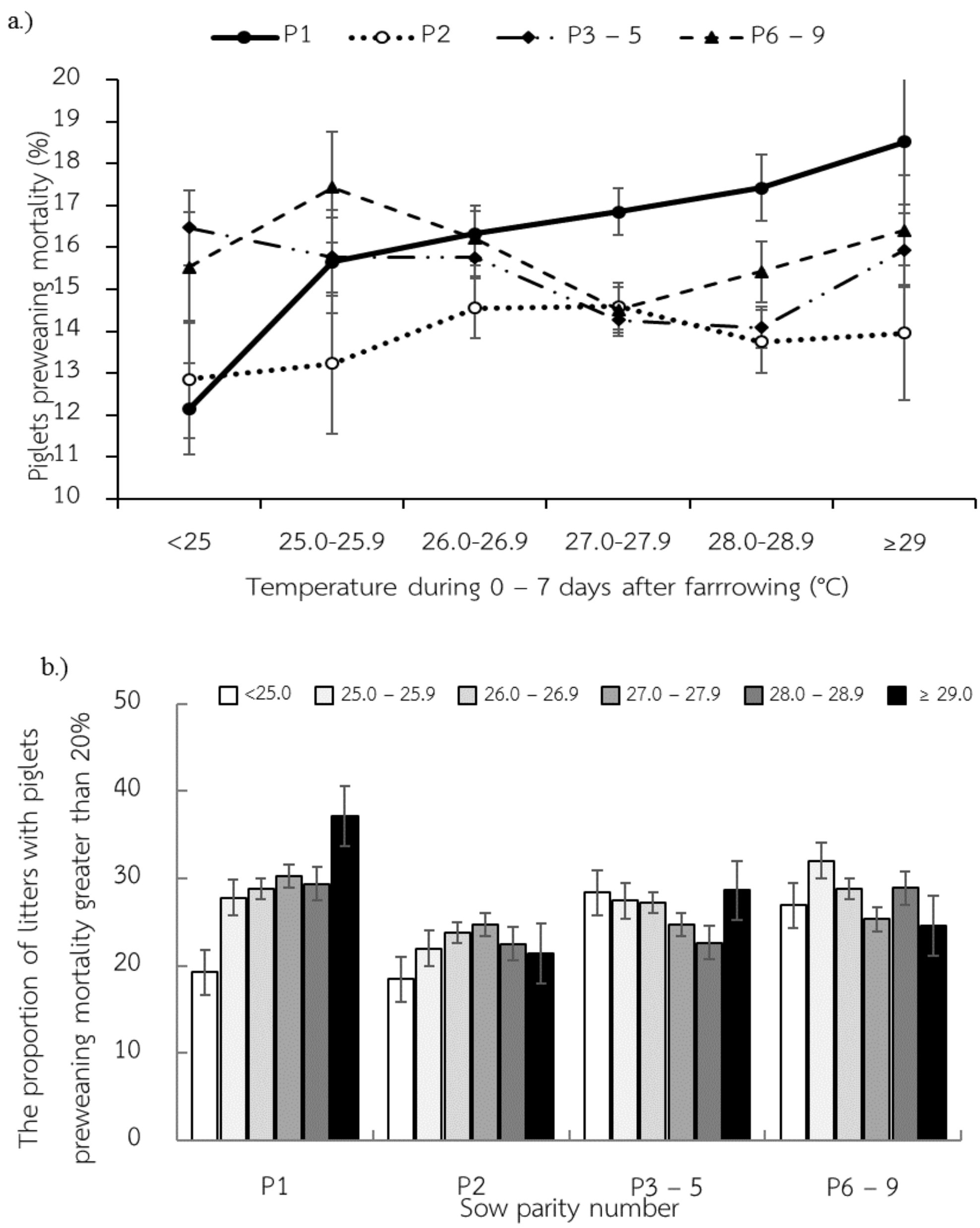

Figure 9 Effect of temperature during 0 – 7 days postpartum on piglet preweaning mortality (a.) and the proportion of litters with piglet preweaning mortality greater than 20% (b.) (least-square mean ± S.E.M.) by parity classes

4.4.2 Humidity

On average, piglet preweaning mortality increase from 14.7% to 15.2% (0.5%, P = 0.134) when the humidity during 0 – 7 days postpartum increased from < 60% to ≥ 80%. The effect of humidity during 0 – 7 days after farrrowing on piglet preweaning mortality by parity groups is demonstreated in Figure 10a. As can be seen from the figure, an increased of piglet preweaning mortality from 10.7% to 16.7% (+6.0%, P = 0.012) was found when humidity during 0 – 7 days after farrowing increased from <60% to ≥80% in primiparous sows. Moreover, the proportion of litters with piglet preweaning mortality greater than 20% in primiparous sows was increased from 19.8% to 30.0% (+10.2%, P = 0.037) when the humidity during 0 – 7 days postpartum increased from < 60.0% to ≥ 80% (Figure 10b). Figure 11 demonstrated the effects of average humidity during 0 – 7 days postpartum on the proportion of litters with piglet preweaning mortality greater than 20% across parities. As can be seen from the figure, the proportion of the litters with piglet preweaning mortality greater than 20% was increased from 19.5% to 26.6% (+7.1%, P = 0.040) when humidity during 0 – 7 postpertum increased from < 60% to 70% (Figure 11).

4.4.3 Temperature–humidity index

The effect of THI during 0 – 7 days postpartum on piglet preweaning mortality by parity groups is demonstreated in Figure 12a. As can be seen from the figure, an increase of piglet preweaning mortality from 12.0% to 17.8% (+5.8%, P = 0.005) was found when the THI during 0 – 7 days postpartum increased from < 73 to ≥ 81 in primiparous sows but it was insignificant in multiparous sows (Figure 12a). Moreover, the proportion of the litters with piglet preweaning mortality greater than 20% in primiparous sows was increased from 18.3% to 32.4% (+14.1%, P = 0.017) when the THI during 0 – 7 days postpartum increased from < 73 to ≥ 81 (Figure 12b).

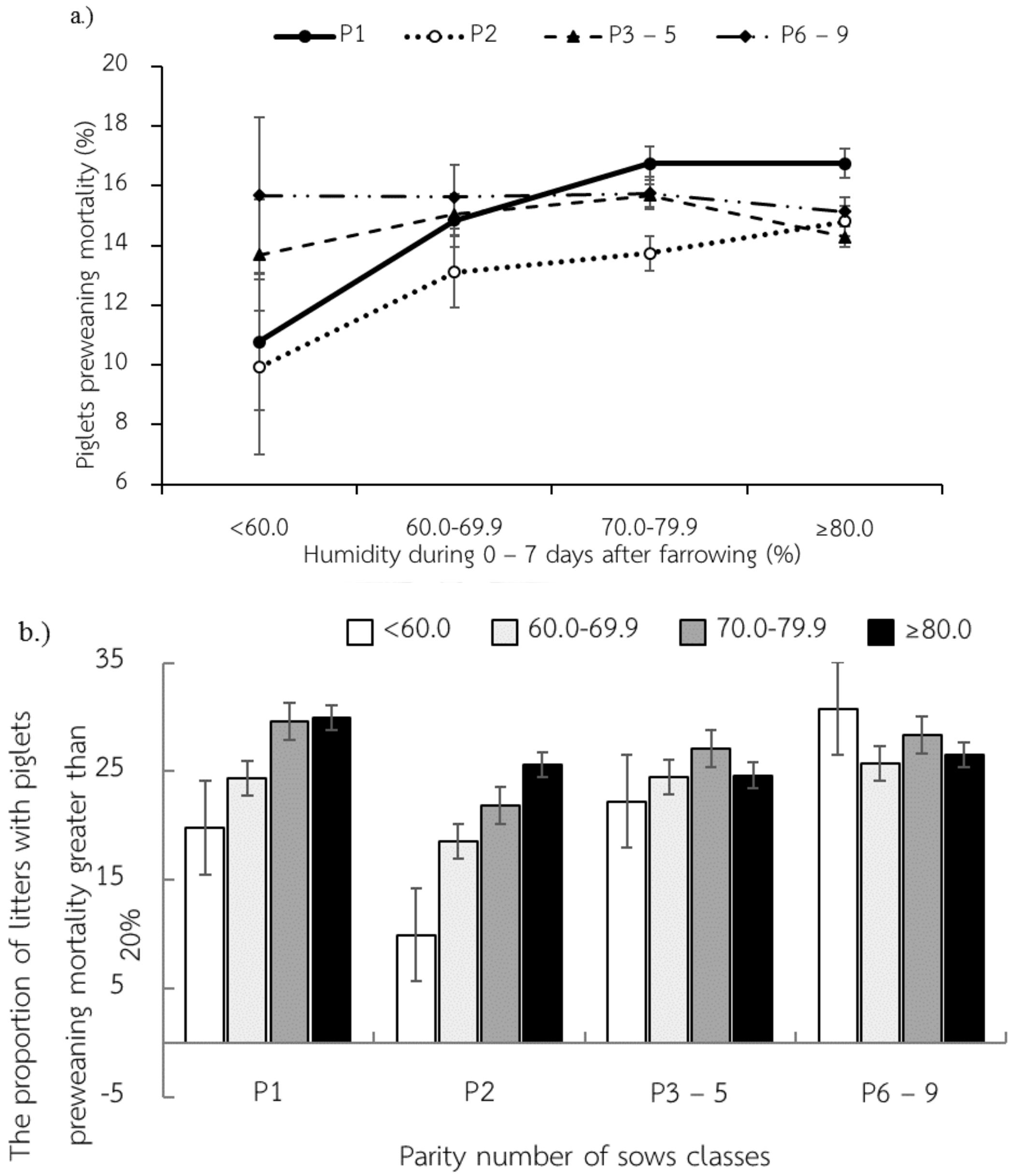

Figure 10 Effect of humidity during 0 – 7 days postpartum on piglet preweaning mortality (a.) and the proportion of litters with piglet preweaning mortality greater than 20% (b.) (least-square mean ± S.E.M.) by parity classes

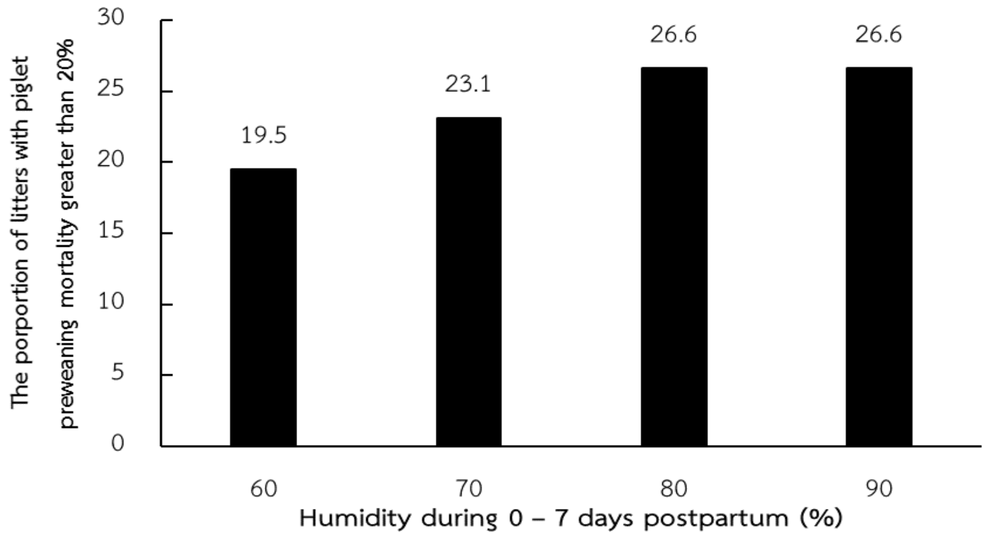

Figure 11 Effect of humidity during 0 – 7 days postpartum on the proportion of litters with piglet preweaning mortality greater than 20% (least-square mean ± S.E.M.)

4.5 Discussion

The present study demonstrates the occurrence of piglet preweaning mortality and the proportion of litters with piglet preweaning mortality greater than 20% in a swine commercial herd in Thailand. The study reveled that, on average, the piglet preweaning moratlity under farm conditions was 14.5%. This number is realtively hight but it is in agreement with a number of earlier reports in both Thailand and other countries (Koketsu et al., 2006; Baxter et al., 2009; Nuntapaitoon and Tummaruk, 2015; Muns and Tummaruk, 2016b). In addition, the poroportion of the litters with piglet preweaning mortality greater than 20% was also analysed. This is a new trait that has never been report before. This parameter indicates the proportion of problematic sows or litters within the herd. In the present study, 26.4% of the litters/sows had piglet preweaning moratlity greater than 20%. Interestingly, this parameter was significantly associated with the climatic paramaters during 0 – 7 days after farrowing. For instance, the proportion of litters with piglet preweaning mortality greater than 20% in primiparous sows was increased from 19.8 to 30.0% (+10.2%) when the humidity during 0 – 7 days postpartum increased from < 60.0% to ≥ 80%.

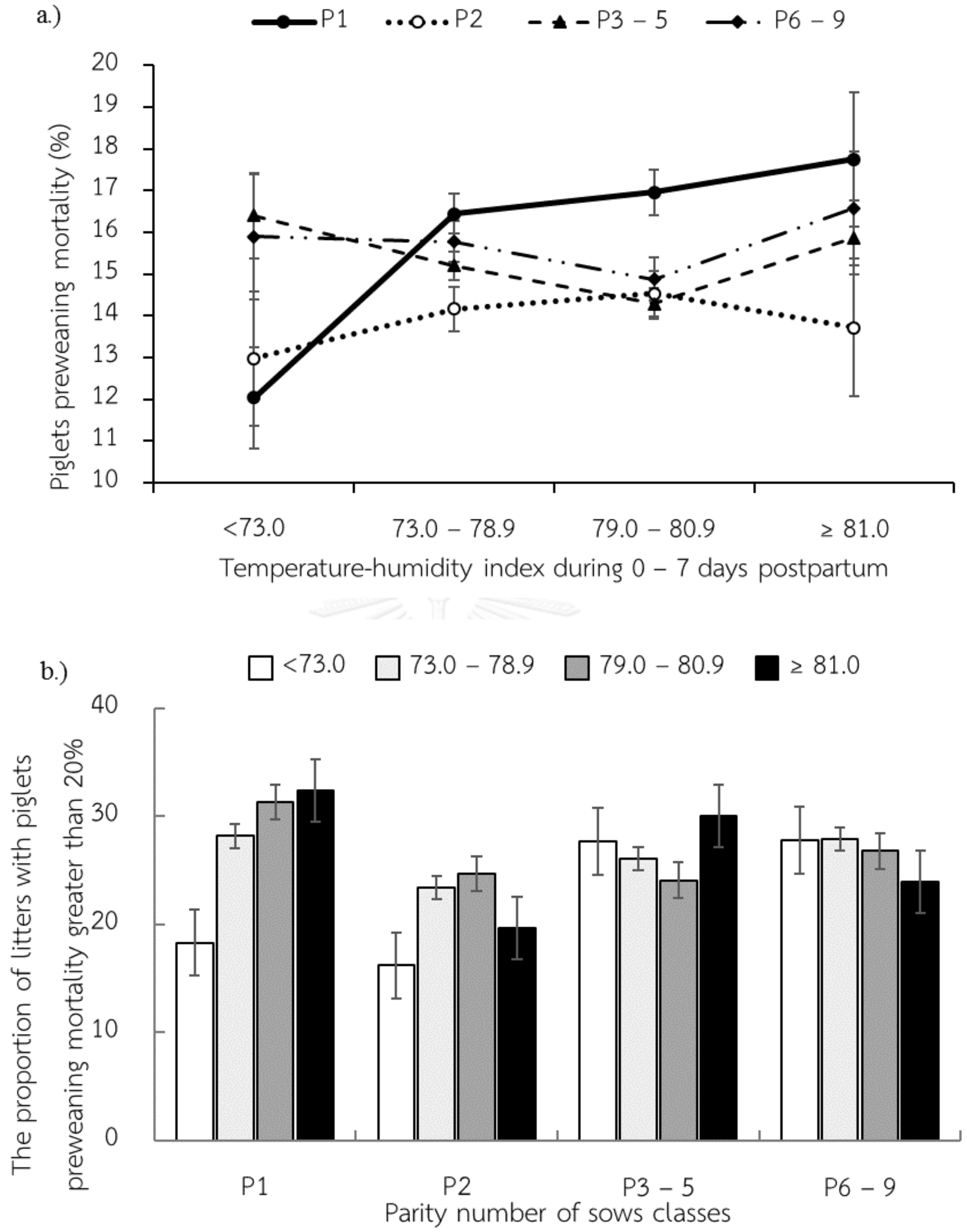

Figure 12 Effect of temperature-humidity index during 0 – 7 days postpartum on piglet preweaning mortality (a.) and the proportion of litters with piglet preweaning mortality greater than 20% (b.) (least-square mean ± S.E.M.) by parity classes

Likewise, an increased in the temperature during 0 – 7 days postpartum from < 25 °C to ≥ 29 °C in primiparous sows resulted in up to 18.0% (from 19.2% to 37.2%) increase in the proportion of litters with piglet preweaning mortality greater than 20% in primiparous sows. These results indicate that the climatic parameters (*i. e.*, temperature, humidity and THI) under tropical climates had a significant impact on both the piglet and the litter/ sow levels. The reason might be due to that when the temperature, humidity or THI rose above their comfort zone, the sow health and the daily feed intake might be compromised. Thus, both the milk yield and the piglet growth may be reduced. The correlation analyses indicate that the climatic parameters during 0 – 7 days postpartum rather than that of other periods influences the piglet preweaning mortality. This indicates that postpartum sows might be more stress and more sensitive to climatic effects compare to prepartum or lactating sows. Thus, the influences of climatic parameters on piglet preweaning mortality are highly evidence during 0 – 7 days postpartum. Therefore, in the present study, climatic parameters during 0 – 7 days postpartum were used in all of the multivariated statistical models.

Koketsu et al. (2006) found that high piglet preweaning mortality was observed during summer in Japan. Likewise, piglet preweaning mortality was highest during autumn in Germany (Wegner et al., 2014). These studies indicate a significant association between season and piglet mortality trait. In Thailand, high ambient temperature, high humidity and also high fluctuations in ambient temperature and humidity are observed throughout the year (Tummaruk et al., 2010; Jaichansukkit et al., 2017). This situation could induce stress in sows, especially in those reared in an open-housing system. Recently, Jaichansukkit et al. (2017) demonstrated that daily fluctuation of ambient temperature and the average daily maximum temperature during late gestation period significantly increased the number of mummified fetuses and stillborn piglet per litter in sows in Thailand. Nevertheless, the carried-over effects of the temperature on the neonatal piglet vitality and piglet preweaning mortality have not been investigated. Moroever, in the previous study, the effects of humidity and THI on the mummified fetus and stillborn piglets could not be demonstrated. In the present study, a significant correlation between temperature, humidity and THI during 0 – 30 and/or 0 – 7 days before farrowing and piglet preweaning mortality were observed. This finding indicate that high ambient temperature, high humidity and/or high THI during late gestation may influence not only the fetal mortality but also it may compromise the fetal growth during late gestation. Therefore, neonatal piglet vitality maybe reduced and piglet preweaning mortality can be increased. Under field conditions, 50 – 80% of piglet preweaning mortality occur during the first week of life and the most critical period is the first 24 h after birth (Shankar et al. 2009; Muns et al. 2016). Inappropriate temperature, humidity and THI during the periods around parturition may compromise the piglet vitality and the sow ability to recover from parturition stress. Therefore, piglet preweaning mortality was relatively high and significantly associated with the climatic parameters during both pre- and postpartum periods.

Indeed, the optimal temperature for sows is 22 °C, whereas the optimal temperature for newborn piglet is ≥ 34 °C (Herpin et al., 2002; Bloemhof et al., 2008). Hot and humid climates in Thailand may negatively influence the sows rather than the piglets. Moreover, the hot and humid environment may induce cortical release due to heat stress and subsequently reduced oxytocin release and prolong the duration of farrowing (Malmkvist et al., 2009). Postpartum sows that suffer from hot and humid climates may have a decreased feed intake, increased weight loss and reduced milk production (Brown-Brandl et al., 2001; Farmer and Prunier, 2002; Silva et al., 2009). Therefore, the proportion of the litters with piglet preweaning mortality greater than 20% was relatively high in Thailand and it was significantly increased when the environmental temperature and humidity during postpartum periods increase.

The present study demonstrated that the association between climatic factors and piglet preweaning mortality was more pronounced in primiparous than multiparous sows. This finding is in accordance with an earlier study (Marchant et al., 2000). The reason might be due to that primiparous sows have a lower colostrum yield than multiparous sows (Devillers et al., 2007). Thus, piglet reared by primiparous sows might have had a lower energy supply and lower serum concentration of immunoglobulins compared to multiparous sows (Carney-Hinkle et al., 2013; Ferrari et al., 2014). Furthermore, primiparous sows are still utilize feed for both their body reserves and milk production (Neil et al., 1996). Thus, the feed comsumtion maynot adequated. Likewise, a previous study also demonstrated that the seasonal influence on litter size in pig was more pronounce in primiparous than multiparous sows (Tummaruk et al., 2010). This indicates that primiparous sows had a higher risk of having high piglet preweaning mortality if the climate was not appropriate.

4.6 Conclusion

Temperature, humidity and THI during 0 – 7 days after farrowing significantly influence both the percentage of piglet preweaning mortality and the the proportion of litters with piglet prewaning mortality greater than 20%. The influence of temperature, humidity and THI was more evidence in primiparous than multiparous sows. When the temperature during 0 – 7 days after farrowing rose from < 25.0 °C to ≥ 29 °C, primiparous sow had an increased in piglet preweaning mortality of 6.4% and an increased in the proportion of litters with piglet preweaning mortality greater than 20% of 18.0%. These data implied that strategies to optimise temperature, humidity and THI in the open-housing system for postpartum sows in Thailand are not adequate and the proper management of postpartum primiparous sows should be emphasized.

Chapter V

Factors influencing piglet preweaning mortality in 47 commercial swine herds in Thailand

(Submitted in Tropical Animal Health and Production)

5.1 Abstract

The present study aims to determine the occurrence of piglet preweaning mortality in commercial swine herds in Thailand in relation to piglet, sow and environmental factors. Data were collected from the database of the computerized recording system from 47 commercial swine herds in Thailand. The raw data were carefully scrutinized for accuracy. Litters with a lactation length < 16 days or > 28 days were excluded. In total, 199,918 litters from 74,088 sows were included in the analyses. Piglet preweaning mortality at the individual sow level was calculated as: piglet preweaning mortality (%) = (number of littermate pigs – number of piglets at weaning) / number of littermate pigs. Litters were classified according to sow parity numbers (1, 2 – 5 and 6 – 9), average BW_B of the piglets (0.80 – 1.29, 1.30 – 1.79, 1.80 – 2.50 kg), number of littermate pigs (5 – 7, 8 – 10, 11 – 12 and 13 – 15 piglets) and size of the herd (small, medium, and large). Pearson correlations were conducted to analyse the associations between piglet preweaning mortality and reproductive parameters. Additionally, a general linear model procedure was performed to analyse the various factors influencing piglet preweaning mortality. On average, piglet preweaning mortality was 11.2% (median = 9.1%) and varied among herds from 4.8% to 19.2%. Among all the litters, 62.1%, 18.1% and 19.8% of the litters had a piglet preweaning mortality rate of 0 – 10%, 11 – 20% and greater than 20%, respectively. As the number of littermate pigs increased, piglet preweaning mortality also increased (r = 0.390, P < 0.001). Litters with 13 – 16 littermate pigs had a higher piglet preweaning mortality than litters with 5 – 7, 8 – 10 and 11 – 12 littermate pigs (20.8%, 7.8%, 7.2% and 11.2%, respectively; P < 0.001). Piglet preweaning mortality in large sized herds was

higher than in small and medium sized herds (13.6%, 10.6% and 11.2%, respectively; $P < 0.001$). Interestingly, in all categories of herd size, piglet preweaning mortality was increased almost two times when the number of littermates increased from 11 – 12 to 13 – 16 piglets. Furthermore, piglets with BW_B of 0.80 – 1.29 kg in large sized herds had a higher risk of mortality than small and medium sized herds (15.3%, 10.9% and 12.2%, respectively, $P < 0.001$). In conclusion, in commercial swine herds in the tropics, piglet preweaning mortality averaged 11.2% and varied among herds from 4.8% to 19.2%. The litters with 13 – 16 littermate pigs had piglet preweaning mortality of up to 20.8%. Piglets with low BW_B (0.80 – 1.29 kg) had a higher risk of preweaning mortality. Management strategies for reducing piglet preweaning mortality in tropical climates should be emphasized in litters with a high number of littermate pigs, low piglet BW_B, and large herd sizes.

5.2 Introduction

The majority of pig mortality occurs during the lactation period, and significantly decreases profitability of commercial swine herds. Recent data in EU indicated that the average piglet preweaning mortality rate was 12.4%, and varied among herds between 11.4% – 13.6% (AHDP, 2016). Piglet preweaning mortality is associated with many factors. An early study demonstrated that sow factors (*e.g.*, parity number, colostrum yield, maternal stress and nutrition), piglet factors (*e.g.*, BW_B, number of littermates, vitality and gender) ,and environmental factors (*e.g.*, season, housing and management) influenced mortality rate of piglets during the suckling period (Muns et al., 2016). Knowledge on factors that influence piglet preweaning mortality is of importance to reduce economic loss in the swine industry. Therefore, a comprehensive study on factors associated with piglet preweaning mortality should be conducted.

Birth weight and number of piglets in the litter influence piglet preweaning mortality (Kilbride et al., 2012; Nuntapaitoon and Tummaruk, 2015). One of the sow factors associated with piglet preweaning mortality is the sow parity number. On average, colostrum yield, immunoglobulin and piglet BW_B are different among parities (Carney-Hinkle et al., 2013; Wegner et al., 2016). There is still a lack of knowledge on the associations between piglet preweaning mortality and sow, piglet and environmental factors in tropical swine farms.

Season of farrowing has a large impact on piglet performance (Wegner et al., 2016). High ambient temperature around farrowing negatively affects sow health (Baxter et al., 2009; Kirkden et al., 2013b). Similarly, high THI after farrowing increases piglet preweaning mortality (Wegner et al., 2016). Indeed, high temperature was shown to increase cortisol hormone concentration in stressed sows (Malmkvist et al., 2012). Severe heat stress in tropical climates has also been observed to cause agalactia (Renaudeau and Noblet, 2001). Friendship et al. (1986) found that large sized herds had a lower piglet preweaning mortality than small sized herds. In Thailand, no comprehensive study on environmental factors associated with piglet preweaning mortality has been conducted. The present study aims to determine the occurrence of piglet preweaning mortality in commercial swine herds in Thailand in relation to piglet, sow and environmental factors.

5.3. Materials and methods

5.3.1 Data

Data were collected from the database of the computerized recording system (PigLIVE®, Live informatics Co., Ltd., Nonthaburi, Thailand) from 47 commercial swine herds in Thailand, during a seven-year period from January 2007 to December 2013. The raw data included 228,308 litters from 77,667 sows. The data included sow identity, farrowing date, sow parity number, NBA, SB, MM, litter birth weight, average individual BW_B of the piglets, number of cross-fostered piglets, weaning date, average body weight of the piglets at weaning and number of piglets at weaning per litter.

5.3.2 Exclusion criteria

The raw data were carefully scrutinized for accuracy. Lactation length was defined as the interval from farrowing to weaning. Litters with a lactation length < 16 days (n = 18,330, 8.0%) or > 28 days (n = 5,031, 2.2 %) were excluded from the analyses. Incorrect or erroneous data, *e.g.*, number of piglets at weaning per litter ≤ 0 (n = 2,699, 2.1%) or > 16 (n = 616, 0.3%), piglet BW_B < 0.8 kg (n = 1,218, 0.5%) or > 2.5 kg (n = 496, 0.2%) were excluded from the analyses. Thus, a total of 28,390 litters (12.4%) were excluded. Therefore, 199,918 litters from 74,088 sows were included in the analyses.

5.3.3 General management

On average, the number of productive sows varied among herds from 263 to 5,240 sows. In all herds, the breed of the sows was LY F1 crossbred females. The gilts and sows were kept in individual crates during gestation. Pregnant sows were moved to the farrowing pens about one week before the expected farrowing date. They were kept in pens with a space allowance of 4.5 m^2 per sow. In general, the gilts were mated at eight months of age with a body weight of ≥ 135 kg at the second or later observed oestrus. Artificial insemination was used for all gilts and sows. Feed was provided twice a day (about 1.5 – 3.5 kg per day) during gestation. The gilts and sows received water *ad libitum* by water nipples. In general, the sows were fed twice a day during lactation with a rice-corn-soybean-chicken ration (about 5 – 6 kg of feed per day). The lactation feed contained 18% crude protein, 3,250 kcal/kg of metabolizable energy and 1.1% lysine (NRC, 2012). The herd health management was supervised by veterinarians. In general, both the replacement gilts and sows were vaccinated against CSFV, ADV, PPV and FMDV. The pregnant females were vaccinated against FMDV before farrowing and against CSFV and PPV after farrowing. Vaccination for ADV was performed in all gilts and sows every four months. These herds were seropositive for PRRS, but the PRRS vaccination schedule differed among herds depending on the strain of the virus and the decision of the herd veterinarians.

5.3.4 Definitions

The NTB was defined as the sum of NBA, SB and MM. Number of littermate pigs was defined as the NBA after cross-fostering (Nuntapaitoon and Tummaruk, 2015). Piglet preweaning mortality was defined as the percentage of NBA, after cross-fostering, which died during the period from birth to weaning. Piglet preweaning mortality at the individual sow level was calculated as: piglet preweaning mortality (%) = (number of littermate pigs – number of piglets at weaning) / number of littermate pigs.

5.3.5 Classifications

In the statistical analyses, sows were classified into three groups according to parity numbers, *i.e.*, 1, 2 – 5 and 6 – 9. Average BW_B of the piglets was classified into three groups, *i.e.*, low (0.80 – 1.30 kg), medium (1.30 – 1.79 kg) and high (1.80 – 2.5 kg). Number of littermate pigs was classified into four groups, *i.e.*, 1 – 7, 8 – 10, 11 – 12 and 13 – 15 piglets. Size of the herd was classified into three groups, *i.e.*, small (263 – 999 sows, n = 27 herds), medium (1,000 – 1,800 sows, n = 11 herds), and large (> 1,800 sows, n = 9 herds).

5.3.6 Statistical analysis

Statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA). Descriptive statistics were carried out using MEANS and FREQ procedures. Pearson correlations were conducted to analyse the associations between piglet preweaning mortality and reproductive parameters including NTB, NBA, number of littermate pigs per litter, number of piglets at weaning per litter and piglet BW_B. Normality of the variables was determined using the residual plot under the general linear model procedure. Kurtosis, skewness and Kolmogorov-Smirnov statistics were used to determine normality of the dependent variables. Due to a skewed distribution of piglet preweaning mortality (Figure 13), the original data were log transformed before being analyzed. The factors and interactions included in the statistical model were tested for significance and omitted from the model in a stepwise fashion, leaving only factors and interactions with a significance level of $P < 0.10$. Additionally, a general linear model procedure (PROG GLM) was performed to analyse the various factors influencing piglet preweaning mortality. Piglet preweaning mortality was regarded as the dependent variable in each general linear model. The statistical models included number of littermate pigs (1 – 7, 8 – 10, 11 – 12 and 13 – 15), BW_B classes (low, medium, high), parity number (1, 2 – 5 and –69), farrowing month, farrowing year, herd size (small, medium and large), herd nested within herd size, and two ways interactions. Least-square means were obtained from statistical models and were compared by Tukey-Kramer test. Values with $P < 0.05$ were regarded as statistically significant.

5.4 Results

5.4.1 Descriptive statistics

Descriptive statistics, including arithmetic means, medians, standard deviations and ranges of sow reproductive performances, are presented in Table 11. On average, NTB, NBA and the number of piglets at weaning per litter were 11.8 ± 2.6, 10.8 ± 2.5 and 9.7 ± 1.8 piglets, respectively. The number of littermate pigs averaged 11.0 ± 1.8 (range 5 – 16 piglets). On average, piglet preweaning mortality was 11.2% (median = 9.1%) and varied among herds from 4.8% to 19.2%.

Table 11 Descriptive statistics for the reproductive data of 199,918 litters from 74,088 sows farrowed between 2007 to 2013, in 47 commercial swine herds in Thailand

Variables	Mean ± SD	Median	Range
Parity number	3.3 ± 2.0	3.0	1.0 – 14.0
Total number of piglets born per litter	11.8 ± 2.6	12.0	6.0 – 38.0
Number of piglets born alive per litter	10.8 ± 2.5	11.0	0.0 – 37.0
Number of litter mate pigs per litter	11.0 ± 1.8	11.0	5.0 – 16.0
Mummified foetuses per litter, %	2.4 ± 7.1	0.0	0.0 – 100.0
Stillborn piglets per litter, %	5.1 ± 8.4	0.0	0.0 – 94.1
Piglet birth weight, kg	1.5 ± 0.3	1.5	0.8 – 2.5
Lactation length, days	22.9 ± 2.3	23.0	16.0 – 28.0
Piglet preweaning mortality, %	11.2 ± 13.2	9.1	0.0 – 93.8
Number of piglets at weaning per litter	9.7 ± 1.8	10.0	1.0 – 16.0
Body weight of piglets at weaning, kg	6.9 ± 1.1	6.8	3.0 – 15.0

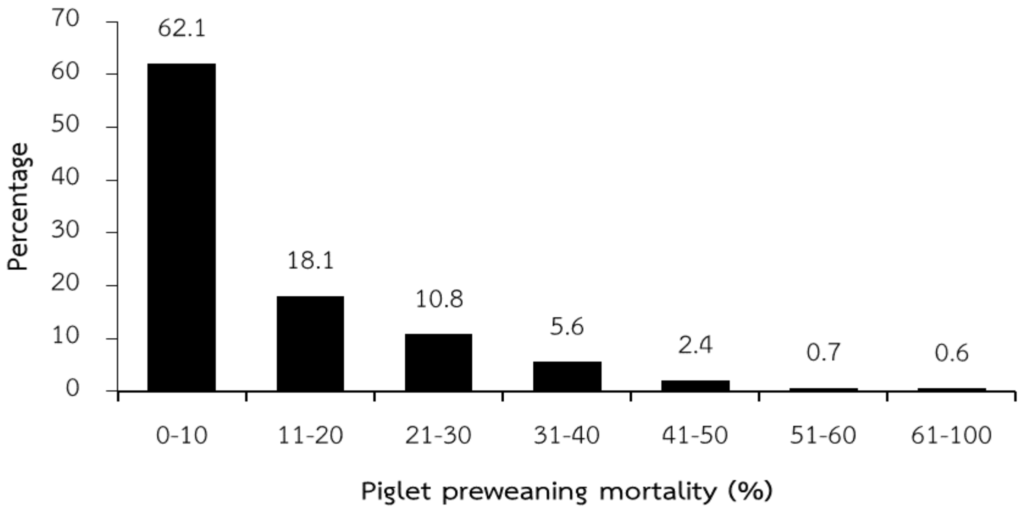

Figure 13 Frequency distribution of piglet preweaning mortality (%) in 199,918 litters from 74,088 Landrace × Yorkshire crossbred sows in 47 commercial swine herds in Thailand, during 2007 - 2013.

Figure 13 illustrates the frequency distribution of piglet preweaning mortality. As can be seen from the figure, 62.1% of the litters had a piglet preweaning mortality rate of 0–10% and 18.1% of the litters had a piglet preweaning mortality rate of 11 – 20%. Among all the litters, 19.8% had piglet preweaning mortality greater than 20%. Characteristics of the litters with a preweaning mortality rate of 0 – 10%, 11 – 20% and > 20% are demonstrated in Table 12. As can be seen from the table, the litters with a high preweaning mortality rate (> 20%) tended to be older, had larger NTB, NBA and number of littermate pigs, and had a lower piglet BW_B compared to the litters with low and/or moderate preweaning mortality rates (Table 12).

Table 12 Characteristics of the litters with preweaning mortality rates of 0 – 10%, 11 – 20% and above 20%

Parameter	Piglet preweaning mortality		
	0 – 10% (n = 121,068)	11 – 20% (n = 35,326)	> 20% (n = 38,573)
Total number of piglets born per litter	11.4^{c}	12.1^{b}	13.0^{a}
Number of piglets born alive per litter	10.5^{c}	11.2^{b}	12.1^{a}
Number of littermate pigs per litter	10.5^{c}	11.2^{b}	12.2^{a}
Piglet birth weight, kg	1.60^{a}	1.50^{b}	1.49^{c}

$^{a, b, c}$ Different superscripts indicate significant difference within the row ($P < 0.05$)

5.4.2 Correlations

Piglet preweaning mortality (log transformation) significantly correlated with both the number of littermate pigs and the piglet BW_B. As the number of littermate pigs increased, piglet preweaning mortality also increased ($r = 0.390$, $P < 0.001$). On the other hand, piglet preweaning mortality decreased when the piglet BW_B increased ($r = -0.119$, $P < 0.001$). Additionally, when piglet preweaning mortality increased, the number of piglets at weaning also decreased ($r = -0.359$, $P < 0.001$). Piglet preweaning mortality was also positively associated with NTB ($r = 0.277$, $P < 0.001$) and BA ($r = 0.311$, $P < 0.001$). Correlations between piglet preweaning mortality and all reproductive parameters, by herd size, are presented in Table 13. As can be seen from the table, statistically significiant correlations among the litter characteristics (*e.g.*, piglet BW_B and number of littermate pigs) and preweaning mortality were observed in all categories of herd size ($P < 0.001$).

5.4.3 Factors influencing piglet preweaning mortality

Multiple analyses of variance revealed that the number of littermate pigs, piglet BW_B, parity number, farrowing month, farrowing year, herd size, and herd nested within herd size significantly influenced piglet preweaning mortality ($P < 0.001$).

Table 13 Pearson's correlation coefficients (r)[1] between piglet preweaning mortality and associated factors in 199,918 litters, by herd size

Variables	Herd size			All
	Small (n=48,376)	Medium (n=41,069)	Large (n=110,473)	
Total number of piglets born per litter	0.245	0.260	0.245	0.277
Number of piglets born alive per litter	0.414	0.324	0.269	0.311
Number of littermate pigs per litter	0.414	0.377	0.376	0.390
Piglet birth weight, kg	– 0.135	– 0.052	– 0.096	– 0.119
Number of piglets at weaning per litter	– 0.318	– 0.389	– 0.380	– 0.359

[1]All correlation coefficients (r) are significant at $P < 0.001$

Table 14 illustrates the influence of the number of littermate pigs on piglet preweaning mortality. It was found that litters with 13 – 16 littermate pigs had a higher piglet preweaning mortality than litters with 5 – 7, 8 – 10 and 11 – 12 littermate pigs (20.8%, 7.8%, 7.2% and 11.2%, respectively; $P < 0.001$). On average, piglet preweaning mortality in large sized herds was higher than in small and medium sized herds (13.6%, 10.6% and 11.2%, respectively; $P < 0.001$). The preweaning mortality rates in each category of herd size and number of littermate pigs are presented in Table 15. It was found that among litters with 11 – 12 littermates, small and medium sized herds had a lower piglet preweaning mortality than large sized herds (10.5%, 10.2% and 13.3%, respectively, $P < 0.001$). Interestingly, in all categories of herd size, piglet preweaning mortality was increased almost two times when the number of littermates increased from 11 – 12 to 13 – 16 piglets (Table 15).

Table 14 Piglet preweaning mortality (%) in litters with different numbers of littermate pigs (least-square means ± SEM)

Number of littermates pigs	Number of litters	Piglet preweaning mortality (%)
5 – 7	6,688	7.8 ± 0.2^{a}
8 – 10	69,394	7.2 ± 0.1^{b}
11 – 12	83,361	11.2 ± 0.1^{c}
13 – 16	35,521	20.8 ± 0.1^{d}

[a, b, c] Different superscripts letters indicate significant differences within the column ($P < 0.001$)

Table 15 Piglet preweaning mortality (%) in litters with different numbers of littermate pigs, as a function of herd size (least-square means ± SEM)

Number of littermate pigs	Herd size					
	n	Small	n	Medium	n	Large
5 – 7	1,332	$6.2 \pm 0.3^{b,D}$	988	$7.9 \pm 0.4^{b,C}$	4,368	$9.4 \pm 0.2^{a,C}$
8 – 10	13,413	$6.2 \pm 0.1^{b,C}$	14,522	$6.4 \pm 0.1^{b,D}$	41,459	$8.9 \pm 0.1^{a,D}$
11 – 12	18,593	$10.5 \pm 0.1^{b,B}$	19,521	$10.2 \pm 0.1^{b, B}$	45,247	$13.0 \pm 0.1^{a,B}$
13 – 16	13,086	$19.3 \pm 0.1^{b,A}$	5,214	$20.2 \pm 0.2^{b,A}$	17,221	$23.0 \pm 0.1^{a,A}$

[a, b] Different superscripts (lowercase letters) indicate significant differences within the row ($P < 0.05$)

[A, B, C, D] Different superscripts (capital letters) indicate significant differences within the column ($P < 0.05$)

On average, the litters with low piglet BW_B had a higher piglet preweaning mortality than the litters with medium and high piglet BW_B (12.8%, 12.1% and 10.5%, respectively; $P < 0.001$). The influence of BW_B on piglet preweaning mortality, as a function of herd size, is demonstrated in Figure 14. Piglet preweaning mortality decreased when the piglet BW_B increased, in all categories of herd size (Figure 14). Furthermore, piglets with BW_B of 0.80 – 1.30 kg in large sized herds had a higher risk of mortality than small and medium sized herds (15.3%, 10.9% and 12.2%, respectively, $P < 0.001$) (Figure 14).

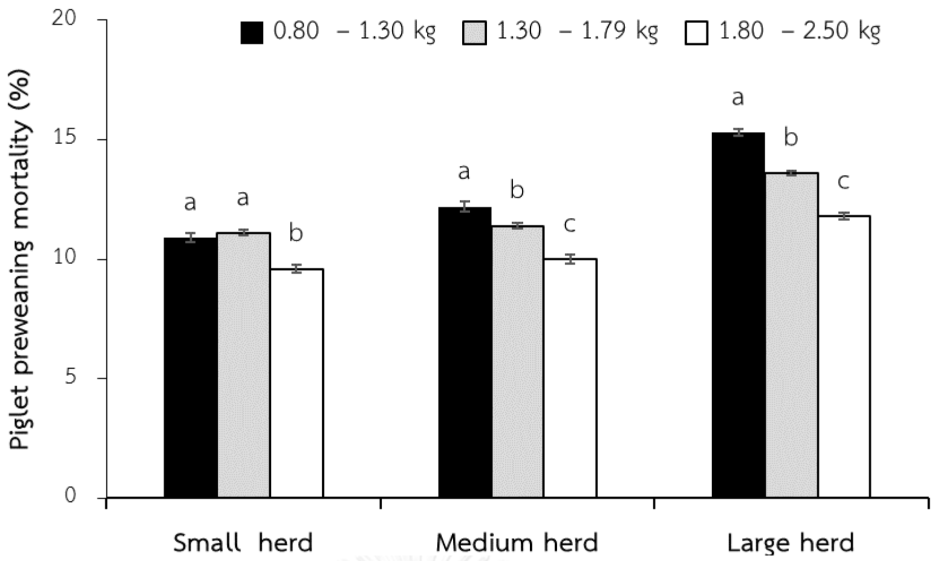

Figure 14 Piglet preweaning mortality (%) in different categories of piglet birth weight, as a function of herd size

a,b,c Different superscript letters indicate within group significant differences ($P < 0.05$)

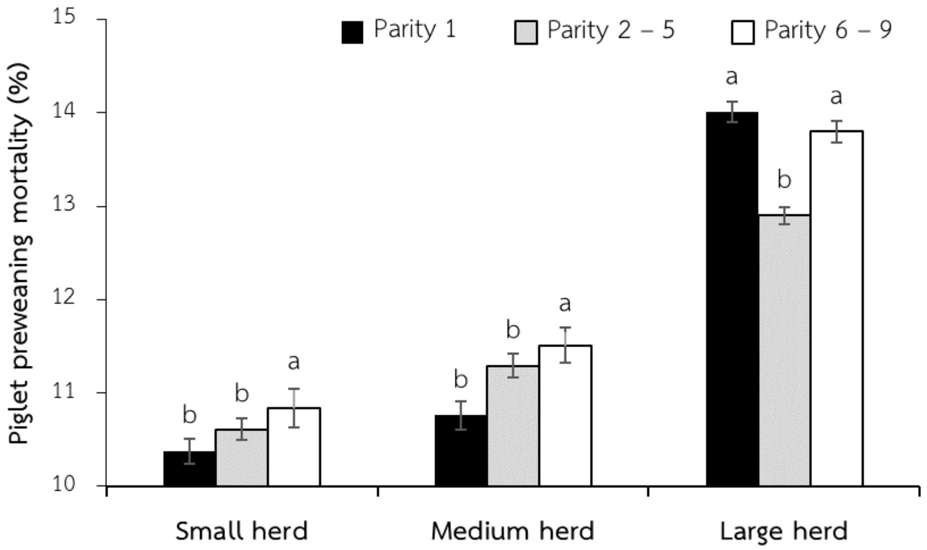

Figure 15 Piglet preweaning mortality (%) in sow parity numbers 1, 2 – 5 and 6 – 9 by herd size

a,b,c Different superscript letters indicate within group significant differences ($P < 0.05$)

On average, piglet preweaning mortality was 11.7%, 11.6% and 12.1% for sow parity numbers 1, 2 – 5 and 6 – 9, respectively ($P < 0.001$). Piglet preweaning mortality by sow parity number and herd size is presented in Figure 15. As can be seen from the figure, sow parity numbers 6 – 9 had a higher piglet preweaning mortality than sow parity numbers 1 and 2 – 5, in small and medium sized herds ($P < 0.001$), but not in large herds ($P > 0.05$).

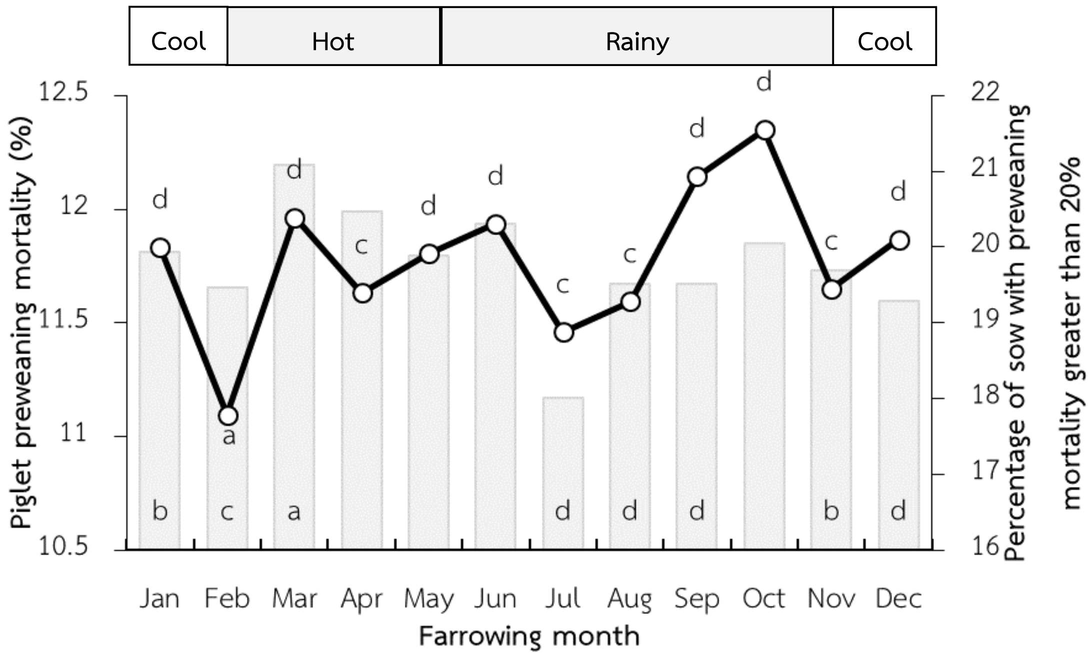

Figure 16 Piglet preweaning mortality (%) by farrowing month (line), and the percentage of sow with piglet preweaning mortality greater than 20% (bar)

The level of significance is $P < 0.05$ between a and b, $P < 0.01$ between a and c, and $P < 0.001$ between a and d.

Farrowing month influenced piglet preweaning mortality (Figure 16). As shown in the figure, piglet preweaning mortality varied among farrowing months from 11.1% in Februray to 12.3% in October ($P < 0.01$). The highest percentage of sows with piglet preweaning mortality rates greater than 20% was observed in March (Figure 16). Likewise, the piglet preweaning mortality varied among farrowing years from 10.9% in 2008 to 13.5% in 2010 ($P < 0.001$).

5.5 Discussion

The present study demonstrates the occurrence of piglet preweaning mortality in commercial swine herds in Thailand based on a relatively large number of sample size. Our findings are based on 199,918 litters from 47 commercial swine herds. To our knowledge, this is the largest sample size investigating factors associated with piglet preweaning mortality in Thailand. The study revealed some important risk factors associated with piglet preweaning mortality under field conditions. The risk factors can be categorized into three main clusters, *i.e.,* piglet factors (*e.g.*, piglet BW_B), sow factors (*e.g.*, number of littermate pigs and sow parity number) and environmental factors (*e.g.*, farrowing month, farrowing year and herd size).

During recent years there has been a steady increase in the LS at birth in modern swine genetics. The farrowing duration and the risk of postpartum complications (*e.g.*, the retention of placenta) is also increased (Bjorkman et al., 2017). As a consequence, in practice, the number of littermate pigs (*i.e.,* the NBA after cross-fostering) tends to be increased. In the present study, litters with 13 – 16 littermate pigs had up to 20.8% piglet preweaning mortality, and a similar pattern was found in all categories of herd size (variation ranged from 19.3% to 23.0% in small and large herds, respectively). This finding indicates a tendency for increased piglet preweaning mortality in modern swine production systems. This is in agreement with a previous study done in a commercial swine herd in Thailand (Nuntapaitoon and Tummaruk, 2015). On average, highly prolific sows produce greater than 16 NBA (Malmkvist et al., 2012). This causes an extended farrowing duration, which affects both the sow's health and the piglet's vitality (Tummaruk and Sang-Gassanee, 2013; Bjorkman et al., 2017). The prolonged farrowing duration induces stressful conditions, which increases cortisol and impairs physiological status of the sows (Malmkvist et al., 2012). Tummaruk and Sang-Gassanee (2013) demonstrated that the percentage of sows with fever after farrowing increased when the farrowing duration increased, leading to lactation problems. Furthermore, stress can reduce appetite and body reserve mobilization of sows (Nardone et al., 2010). This can also cause a subsequent high loss of back fat during lactation, which affects both the sow's health and the piglet's growth performance. Thus, special care of sows with a high NBA and/or a high number of littermate pigs should be considered. It has been suggested that supportive treatment of sows with amino acids and vitamins significantly improves the appetite of postpartum sows, which may decrease postpartum disorder and piglet preweaning mortality (Tummaruk, 2013).

In general, old sows (*i.e.,* parity number above six) have a long farrowing duration due to excessive fat and low uterine muscle contraction. This may increase the risk of intra-partum hypoxia in late-born piglets (Zaleski and Hacker, 1993b). Furthermore, old sows have a relatively high variation of within–litter piglet BW_B (Wolf et al., 2008; Wientjes et al., 2012). Old sows usually also have a reduced number of functional teats and low colostrum production (Devillers et al., 2007; Vasdal and Andersen, 2012). Therefore, piglets reared by old sows might have a high risk of preweaning mortality. As such, both farrowing supervision and postpartum care of newborn piglets should be performed carefully in old sows.

The present study demonstrated that low BW_B piglets had a high preweaning mortality, in accordance with previous studies (Roehe and Kalm, 2000; Wolf et al., 2008; Nuntapaitoon and Tummaruk, 2015). This may be due to small piglets having low energy storage and a lower capacity to maintain their body temperature postpartum, making them more susceptible to hypothermia (Herpin et al., 2002; Wolf et al., 2008). Moreover, small piglets may have low colostrum and milk consumption because they are not able to compete with the heavier littermate pigs (Le Dividich et al., 2005). Therefore, they might receive a suboptimal level of passive immunity. This indicates that small piglets need help as soon as possible after birth. Our previous study has demonstrated that oral supplementation with an energy product or milk replacer within 12 h after birth, in piglets with a $BW_B < 1.35$ kg, significantly improves their survival rate as well as the levels of IGF-I and IgG in the piglets (Muns et al., 2017).

Environmental factors, including farrowing month and farrowing year, significantly influenced piglet preweaning mortality in the current study. Sows that farrowed in October had a high preweaning mortality. This is the period of seasonal change from rainy to cool season (October) in Thailand. This indicates that care of newborn piglets should be emphasized during seasonal change periods. An increase in cortisol after heat stress increases catecholamines and reduces oxytocin, resulting in an increased farrowing duration and decreased milk production (von Borell et al., 2007). High piglet mortality may occur in stressed sows during some periods of the year, especially in large sized herds. Based on the present data set, the proportion of sows having high piglet preweaning mortality (*i.e.,* above 20%) was 19.8%. This proportion was highest in the sows that farrowed in March (21.1%), which is the first month of the hot season in Thailand. Therefore, these groups of litters need special care.

Herd size was significantly associated with piglet preweaning mortality. The herd effect represented various environmental factors, *e.g.*, housing, facilities and stockpersons. Our study found that large sized herds had higher piglet preweaning mortality than small and medium sized herds. The effect of herd size on piglet preweaning mortality may be related to post-partum management and the quality of stockpersons. In small commercial herds in Thailand, the herd owner usually manages and takes care of the sows and piglets by themselves, while medium and large sized herds use various types of stockpersons. Additionally, the number of sows farrowed per day in a small herd is less than that in a large sized herd. Therefore, the farrowing supervision in small herds might be better than in large herds.

5.6 Conclusion

In commercial swine herds in the tropics, piglet preweaning mortality averaged 11.2% and varied among herds from 4.8% to 19.2%. The litters with 13 – 16 littermate pigs had piglet preweaning mortality of up to 20.8%. Piglets with low BW_B and piglets born from old sows had a higher risk of preweaning mortality. Management strategies for reducing piglet preweaning mortality in tropical climates should be emphasized in litters with a high number of littermate pigs, low piglet BW_B, old sows and large herd sizes.

Chapter VI

Newborn traits associated with preweaning growth and survival in piglets

(Major revision in Asia – Australian Journal Animal Science)

6.1 Abstract

Piglet preweaning mortality is an important variable indicating the efficacy of farrowing management and animal well-being during lactation. The present study determined the association of certain newborn traits measured soon after birth with piglet preweaning mortality and growth. In total, 805 piglets born from 57 multiparous sows were investigated. Their HR, $SatO_2$, blood glucose concentration and RT24h were recorded. Birth order, sex, skin color, integrity of the umbilical cord, time from birth until first attempts to stand and birth intervention were monitored. Piglets were weighed at 0, 7 and 21 days after birth in order to evaluate their postnatal growth. Piglet preweaning mortality for lactation period was 12.6% and cumulative mortality during the first 7 days of age was 8.6%. Piglets with $BW_B < 1.30$ kg had higher ($P < 0.001$) mortality rate than piglets with $BW_B \geq 1.80$ kg (19.0% vs 3.3%) and piglets with BW_B 1.30 – 1.79 kg (4.0%). Piglet with RT24h < 37.0 °C had higher ($P < 0.001$) mortality rate (86.2%) than piglets with RT24h > 38.5 °C (3.9%, $P < 0.001$). Until 7 days after birth, a higher ($P < 0.001$) proportion of piglets that attempted to stand after 5 min (38.5%) died compared to piglets that attempts to stand within 1 min (6.3%) and within 1 – 5 min (9.2%) after birth. A higher proportion of piglets with pale skin color died compared to piglets with normal skin color (26.7% vs 7.7%, $P < 0.001$). Piglet BW_B, blood glucose concentration and the NBA were correlated with ADG7 and ADG21 ($P < 0.05$). In conclusion, low BW_B and low RT24h compromise piglet survival during the lactation period.

6.2 Introduction

In modern swine industry, producers expect up to 30 pigs weaned per sow per year (Knox, 2005). However, in practice, a high proportion of piglet mortality occurs during preweaning period (Nuntapaitoon and Tummaruk, 2015). Thus, factors associated with piglet preweaning mortality are becoming a major concern in swine industry worldwide (Muns et al., 2016). One of main reason for a high proportion of piglet preweaning mortality is the use of high prolific sow genetics, which improved the NBA among swine commercial herds worldwide during the past 10 years (Knox, 2005). Litter size is an important sow factor related to piglet survival and growth (Nuntapaitoon and Tummaruk, 2015). Nuntapaitoon and Tummaruk (2015) demonstrated that piglet preweaning mortality in the litter with 13 – 15 littermate pigs (24.1%) was significantly higher than the litter with 1 – 7 (11.9%), 8 – 10 (11.8%) and 11 – 12 (14.6%) littermate pigs, respectively. Large LS also increases the body weight variation among the piglets within litter (Shankar et al., 2009). Hence, the proportion of piglets with low body weight is also increased (Campos et al., 2012). Vallet and Miles (2012) observed that low BW_B piglets had a higher risk of being crushed due to their slower speed of movement and reflexive actions. Intra-partum hypoxia is a main factor influencing piglet vitality as it damages the foetal central nervous system (Herpin et al., 1996). Thus, several indicators can be used in newborn piglets to evaluate the level of intra-partum hypoxia suffered during the birth process. In addition, piglet vitality determines their capacity to suckle and compete for a teat and is also positively correlated with piglet growth and survival until weaning (Muns et al., 2013). One reason for reduced piglet vitality might be the umbilical cord supplies nutrients and oxygen from the dam to the foetus. Umbilical cord damage might be related to nutrients and oxygen supplies via umbilical cord from dam to fetus. Blood oxygen, blood glucose concentration, and time to stand after birth have been used as indirect measures of intra-partum hypoxia and neonatal piglet viability (Panzardi et al., 2013).

Factors influencing piglet preweaning mortality under field conditions include sow factors (*e.g.*, breed, parity, nutritional status, farrowing duration, maternal behavior and LS), piglet factors (*e.g.*, BW_B, birth order and sex) and environmental factors (*e.g.*, ambient temperature and stocking density) (Panzardi et al., 2013; Nuntapaitoon and Tummaruk, 2015). To our knowledge, the most studies for risk factors associated with piglet preweaning mortality were performed in cold or moderate climates (Baxter et al., 2008; Pedersen et al., 2013; Decaluwé et al., 2014). Additional information in hot and humid climate countries is required to improve farrowing management and care of newborn piglets. The objective of the present study was to determine the effects of piglet neonatal traits and physiological characteristics measured soon after birth on their preweaning survival and growth.

6.3 Materials and methods

6.3.1 Animal care

The experiment followed the guidelines documented in The Ethical Principles and Guidelines for the Use of Animals for Scientific Purposes edited by the National Research Council of Thailand, and was approved by the Institutional Animal Care and Use Committee (IACUC) in accordance with the university regulations and policies governing the care and use of experimental animals (Approval no. 1431063).

6.3.2 Herd and management

The present study was carried out in a 3,500-sows commercial swine herd in the western part of Thailand between June and August 2013. The average ambient temperature during the experimental period ranged from 25.8 °C to 30.0 °C. The minimum and maximum temperature ranged from 21.1 °C to 26.3 °C and from 28.1 °C to 37.6 °C, respectively. The average relative humidity varied from 72.0% to 96.0%. Sows were kept in individual crates (1.2 m^2) during gestation in a conventional open-housing system and were provided with fans and individual water sprinklers to reduce the impact of high ambient temperature. During gestation, sows were fed a commercial gestation diet that met or exceed their nutritional requirement estimates (NRC, 2012). Feed was provided twice a day following a standardised feeding pattern, resulting in an average of 2.5 kg per sow per day. During lactation, sows were fed twice a day with a commercial lactation diet, increasing the daily amount of feed offered, until *ad* *libitum* feed was reached after one week of lactation. The animals were received water *ad libitum* in a continuous water channel. Pregnant sows were moved to the farrowing house about one week before their expected farrowing date. Sows were kept in individual farrowing crates (1.2 m^2) placed at the centre of the pens with a space allowance of 4.2 m^2. The pens were fully slatted with concrete at the centre for sows and with steel slats at both sides of the farrowing crate for piglets. Each pen was provided with a creep area for piglets (0.60 m^2) placed on the floor on one side, covered by a plastic plate and heating lamp during the first week after farrowing. The heating lamp was usually turned on during the night or when the environment temperature fell below 30 °C. The temperature in the creep area was between 30 – 36 °C.

6.3.3 Supervision of parturition process

The parturition process was carefully supervised by the first author (M. Nuntapaitoon). Briefly, sows were interfered with as little as possible during parturition, and birth intervention was performed only when dystocia was clearly identified. Dystocia was considered when an interval of > 30 min elapsed from the birth of the last piglet, and when the sow showed intermittent straining accompanied by paddling of the legs or when the sow expelled small quantities of foetal fluid together with marked tail switching for > 30 min without any piglet being born. Routine procedures performed on piglets included weighing, tail docking, tooth clipping and one mL (200 mg) iron supplement administered intramuscularly (Gleptosil®, Alstoe Ltd. Animal Health, Leicestershire, England) on the day of birth. Piglets were orally administered a coccidiocide of 20 mg/kg body weight (Baycox® (Toltrazuril 5.0% oral suspension), Bayer Inc., Mississauga, ON, Canada) to control neonatal coccidiosis at three days of age. In total, 805 piglets born from 57 LY crossbred sows were included. The mean parity number was 4.0 ± 1.6 (ranged 2 – 7). Lactation length was on an average of 23.0 ± 2.0 days.

6.3.4 Data collection

The following reproductive variables of the sows were recorded: farrowing duration (*i.e.*, time between the first and last born piglets), NTB, NBA SB and MM and number of piglets at weaning per litter. Piglets' HR and $SatO_2$ were monitored within 5 min after birth by using a veterinary pulse oximetry (EDAN VE-H100B Pulse Oximeter, Edan Instrument Inc®, CA, USA). Thereafter, blood samples for glucose analysis were collected from piglets within 5 – 10 min after birth (*i.e.,* before first suckling). A small amount of blood sample (a mixture of venous and arterial blood) was obtained from the cut umbilical cord. Few drops of blood sample were used to determined blood glucose concentration by using a portable test kit of human glucometer (Accu-Chek® Performa, Roche, Mannheim, Germany). Birth order, birth interval (the time elapsed between each piglet born), sex, and time elapsed from birth until first attempts to stand (3 groups: < 1 min, 1 – 5 min, and > 5 min) were recorded for each piglet. Also, birth assistance was recorded (yes or no) if required by piglets. Skin color of the piglets was recorded at birth and was classified into two groups (normal or pale). Integrity of the umbilical cord of each piglet was examined and classified into two groups (intact or broken). Rectal temperature was measured at 24 h after birth with a digital thermometer (Microlife®, Microlife AG Swiss Corporation, Widnau, Switzerland, with a display resolution of 0.01 °C and ± 0.1 °C accuracy). All piglets were individually identified by an ear tattoo. Body weight of the piglets was measured immediately at birth. Litters were equalized to 13 or 14 piglets per litter after 24 h and within 48 h after birth. Litter size was defined as the number of piglets after cross-fostering. Piglets were weighed again at days 7 and 21 after birth. Mortality rate of the piglets was also determined at 7 and 21 days of lactation. Creep feeding and drinking water were provided to the piglets from 7 days of age until weaning.

6.3.5 Statistical analysis

All statistical analyses were performed using SAS 9.0 (SAS Inst. Inc., Cary, NC). Descriptive analysis (mean ± SD, median and range) and frequency analysis were obtained for all reproductive parameters. To identify the potential indicators for piglet mortality, ADG7 and ADG21, each recorded factor was individually tested using univariate analyses. Continuous variables indicating the neonatal piglet characters (*i.e.*, NTB, NBA, LS, birth order, BW_B, birth interval, HR, $SatO_2$ and blood glucose concentration) were compared between piglets dying and surviving at days 7 and 21 of lactation by using Student's *t* test (PROC TTEST). The association between categorical variables (*i.e.*, sex, skin color, attempts to stand, umbilical cord integrity and birth assistance) and the piglet mortality (dead or alive) were analyzed using Chi-square test. The effect of these categorical variables on ADG7 and ADG21 was analyzed using the PROG GLM of SAS. Pearson's correlation was performed to study collinearity among the continuous variables in the univariate models.

For multivariate analyses, generalised linear mixed models (GLMMIX macro) with the dependent variable (mortality) modeled as a binary outcome (dead or alive) was conducted. Factors with significant levels of $P < 0.10$ were included in the final models. Highly correlated variables were not including in the same multivariate analyses models. Then, the final multivariate GLMMIX models for piglet mortality at days 7 and 21 of lactation included BW_B classes (< 1.30, 1.30 – 1.79 and ≥ 1.80 kg) and RT24h classes (< 37.0, 37.0 – 38.5 and > 38.5 ºC). The classification of the independent variables was made according to frequency distribution with some minor adjustment based on biological reliability. Similarly, general linear mixed models (PROC MIXED) were conducted to analyze ADG7 and ADG21. The final multivariate MIXED models for ADG7 and ADG21 included BW_B classes (< 1.30, 1.30 – 1.79 and ≥ 1.80 kg), blood glucose concentration classes (≤ 24 and > 24 mg/dL), NBA classes (< 12, 12 – 14 and ≥ 15 piglets/litter), sex and attempts to stand (< 1, 1 – 5 and > 5 min). In all models, sow or litter were introduced as a random effect. Least-squares means were obtained from each class of the variables and were compared using Tukey-Kramer adjustment for multiple comparisons. $P < 0.05$ was regarded to be statistically significance and $0.05 < P < 0.01$ is considered tendency.

6.4 RESULTS

Of the 805 piglets, 81 were SB (10.1%), 34 were MM (4.2%) and 690 were NBA (85.7%). Descriptive statistics of newborn piglet traits and piglet performance are presented in Table 16. On average (means ± SD), NTB, NBA and the number of piglets at weaning were 14.2 ± 3.7, 12.1 ± 3.4 and 11.7 ± 1.7 piglets/litter, respectively. The duration of farrowing averaged 217.8 ± 83.7 min, and the average birth interval between piglets was 16.4 ± 24.1 min. Overall, piglet preweaning mortality was 12.6% and cumulative mortality at day 7 was 8.6%.

Table 16 Descriptive statistics of 690 piglets evaluated at birth and during the lactation period

Variables	N	Mean ± SD	Median	Range
Birth weight, kg	690	1.49 ± 0.38	1.48	0.46 – 2.71
Heart rate, bpm	685	66.2 ± 33.20	57.0	23.0 – 250
Glucose, mg/dL	687	49.1 ± 17.72	47.0	11.0 – 159
Oxygen saturation, %	685	91.2 ± 8.85	92.0	10.0 – 100
Rectal temperature at 24 h, °C	670	38.7 ± 0.57	38.7	35.5 – 40.3
Weight at day 7, kg	632	2.67 ± 0.71	2.7	0.75 – 4.64
Weight at day 21, kg	602	6.09 ± 1.51	6.1	1.88 – 10.07
ADG at day 7, g/d	632	163.7 ± 67.32	164.6	-7.9 – 340.7
ADG at day 21, g/d	602	216.8 ± 63.05	213.3	24.0 – 376.9

6.4.1 Univariate analyses

6.4.1.1 Factors associated with piglet preweaning mortality until day 7 after birth

Factors influencing piglet preweaning mortality rate until day 7 (PWM7) after birth are presented in Table 17. Both BW_B and RT24h influenced PWM7 ($P < 0.001$). Piglets that died before day 7 of life had a lower birth interval (9.5 vs 14.9 min, P = 0.005) and were reared in litters with a higher LS (13.7 vs 13.2 piglets/ litter, P = 0.038).

The NTB, NBA, birth order, HR, $SatO_2$, and blood glucose concentration did not influence piglet survival ($P > 0.05$, Table 17).

Table 17 Potential indicators for piglet preweaning mortality (means ± SEM) comparing surviving piglets from birth to day 7 of lactation (n = 631) with dying piglets (n = 59)

Variables	Surviving	Dying	*P* value
Total number of piglets born per litter	14.9 ± 0.14	15.6 ± 0.43	0.171
Number of piglets born alive per litter	13.0 ± 0.12	13.3 ± 0.45	0.491
Litter size after cross-fostering	13.2 ± 0.07	13.7 ± 0.22	0.038
Birth interval, min	14.9 ± 0.80	9.5 ± 1.72	0.005
Birth weight, kg	1.52 ± 0.01	1.11 ± 0.05	< 0.001
Birth order	7.5 ± 0.18	8.5 ± 0.59	0.130
Heart rate, bpm	66.5 ± 1.34	62.5 ± 3.68	0.381
Glucose, mg/dl	49.3 ± 0.70	47.8 ± 2.69	0.605
Oxygen saturation, %	91.3 ± 0.36	90.4 ± 0.99	0.458
Rectal temperature at 24 h, ºC	38.7 ± 0.02	38.2 ± 0.14	< 0.001

A higher proportion of piglets with pale skin color died compared to piglets with normal skin color (26.7% vs. 7.7%; $P < 0.001$, Table 18). A higher proportion of piglets the attempted to stand after 5 min (38.5%) died compared to piglets the attempted to stand within 1 min (6.3%, $P < 0.001$) and within 1 – 5 min (9.2%, $P < 0.001$). Birth intervention, sex and umbilical cord integrity had no effect on piglet mortality until day 7 after birth ($P > 0.05$).

Table 18 Potential categorical indicators for piglet preweaning mortality from birth to 7 days of lactation

Variables	Preweaning mortality, %	*P* value
Skin color		< 0.001
Pale	26.7^{a}	
Normal	7.7^{b}	
The attempted to stand		< 0.001
With in 1 min	6.3^{c}	
1 – 5 min	9.2^{b}	
After 5 min	38.5^{a}	
Sex		
Male	8.0	0.611
Female	9.1	
Umbilical cord integrity		0.614
Integrity	8.9	
Broken	7.8	
Birth intervention		0.239
Yes	5.1	
No	9.0	

$^{a, b, c}$ Values with different superscripts within the same variable differ significantly ($P < 0.05$)

6.4.1.2 Factors associated with piglet preweaning mortality until day 21 after birth

Factors influencing piglet preweaning mortality rate until day 21 (PWM21) after birth are presented in Table 19. Both BW_B and RT24h strongly influenced PWM21 (P < 0.001). Piglets that died before day 21 of life were born from sows with a higher NTB, were reared in litters with a higher LS, and had lower birth intervals (P < 0.05, Table 19). Birth order, HR, $SatO_2$ and blood glucose concentration did not influence piglet survival (P > 0.05, Table 19).

Table 19 Potential indicators for piglet preweaning mortality (means ± SEM) comparing surviving piglets from birth to day 21 of lactation (n = 603) with dying piglets (n = 87)

Variables	Surviving	Dying	*P* value
Total number of piglets born per litter	14.9 ± 0.14	15.9 ± 0.33	0.010
Number of piglets born alive per litter	12.9 ± 0.12	13.7 ± 0.32	0.028
Litter size after cross-fostering	13.2 ± 0.07	13.6 ± 0.18	0.042
Birth interval, min	15.2 ± 0.83	9.3 ± 1.37	< 0.001
Birth weight, kg	1.53 ± 0.01	1.16 ± 0.05	< 0.001
Birth order	7.5 ± 0.19	8.1 ± 0.45	0.319
Heart rate, bpm	66.9 ± 1.39	61.4 ± 2.71	0.076
Glucose, mg/dL	49.5 ± 0.71	46.6 ± 2.13	0.156
Oxygen saturation, %	91.2 ± 0.37	91.3 ± 0.80	0.872
Rectal temperature at 24 h, °C	38.7 ± 0.02	38.3 ± 0.10	< 0.001

A higher proportion of piglets with pale skin color died compared to piglets with normal skin color (36.7% vs. 11.5%; P < 0.001, Table 20). A higher proportion of piglets the attempted to stand after 5 min (41.0%) died compared to piglets the attempted to stand within 1 min (10.8%, P < 0.001) and within 1 – 5 min (10.8%, P < 0.001). Sex, umbilical cord integrity and birth intervention had no effect on PWM21 (P > 0.05).

Table 20 Potential categorical indicators for piglet preweaning mortality from birth to 21 days of lactation

Variables	Preweaning mortality, %	*P* value
Skin color		< 0.001
Pale	36.7^{a}	
Normal	11.5^{b}	
Attempted to stand		< 0.001
With in 1 min	10.8^{b}	
1 – 5 min	10.8^{b}	
After 5 min	41.0^{a}	
Sex		
Male	13.6	0.424
Female	11.6	
Umbilical cord integrity		0.691
Integrity	13.0	
Broken	11.9	
Birth intervention		0.074
Yes	6.3	
No	13.4	

$^{a, b}$ Values with different superscripts within the same variable differ significantly (P < 0.05)

6.4.1.3 Factors associated with average daily gain until day 7 after birth

Piglet BW_B (P < 0.001) and blood glucose concentration (P < 0.001) positively influenced piglet average daily gain (ADG) (Table 21). Piglets born from sows with higher NTB, higher NBA and reared in litters with higher LS had a lower ADG7 (P < 0.001). Piglets without birth intervention had lower growth than piglets with birth intervention (161.1 ± 2.8 vs 182.4 ± 7.7 g/day, P = 0.010). Male piglets had higher growth than female piglets (169.1 ± 3.7 vs 157.6 ± 3.9 g/day, P = 0.032). Piglets with attempts to stand after 5 min (127.1 ± 13.6 g/day) had lower growth than piglets with attempts to stand within 1 min (165.9 ± 2.9 g/day, P = 0.006) or within 1 – 5 min (156.3 ± 13.6 g/day, P = 0.071).

Table 21 Pearson's correlations among the most significant potential predictor measured during farrowing and soon after birth and average daily gain (ADG) of the piglets from birth until 7 and 21 days of age

	NTB	NBA	LS	BI	BW_B	BO	HR	GLU
NBA	0.798***							
LS	0.551***	0.612***						
BI	-0.138***	-0.128***						
BW_B	-0.309***	-0.348***	-0.259***	0.180***				
BO	0.320***	0.302***	0.176***		-0.111**			0.085*
HR	-0.092*	-0.077*						
$SatO_2$							-0.179***	
GLU	-0.118**	-0.136***		0.146***	0.187***			
RT24h					0.128***			
ADG7	-0.272***	-0.283***	-0.162***		0.430***	-0.078*		0.172***
ADG21	-0.197***	-0.284***	-0.222***		0.431***	-0.095*		0.106**

Significance levels: *P<0.05, **P<0.01, ***P<0.001. Abbreviations: NTB, Total number of piglets born per litter; NBA, number of piglets born alive per litter; LS, litter size after cross fostering; BI, Birth interval; BW_B, Birth weight; BO, Birth order, HR, Heart rate; $SatO_2$, Blood oxygen saturation; GLU; Blood glucose concentration; RT24h, Rectal temperature at 24 h after birth; ADG7, average daily gain from birth until day 7; ADG21, average daily gain from birth until day 21

6.4.1.4 Factors associated with average daily gain until day 21 after birth

Piglet BW_B (P < 0.001) and blood glucose concentration (P = 0.009) positively influenced piglet ADG21 (Table 21). Piglets born from sows with higher NTB, NBA, and LS had lower ADG21 (P < 0.001). Piglets without birth intervention had lower growth than piglets with birth intervention (214.3 ± 2.7 vs 235.1 ± 7.3 g/day, P = 0.008).

6.4.2 Multivariate analyses

6.4.2.1 Piglet preweaning mortality

The final multivariate model for PWM7 included BW_B and RT24h (*P* < 0.001). At day 7, the piglets with BW_B < 1.30 kg had a higher (*P* < 0.001) mortality rate (19.0%) than the piglets with BW_B ≥ 1.80 kg (3.3%) and piglets with BW_B 1.30 – 1.79 kg (4.0%, Figure 17). The piglets with RT24h < 37.0 °C had a higher (*P* < 0.001) PWM7 (86.2%) than the piglets with RT24h 37.0 – 38.5 °C (7.3%,) and RT24h > 38.5 °C (3.9%, Figure 18).

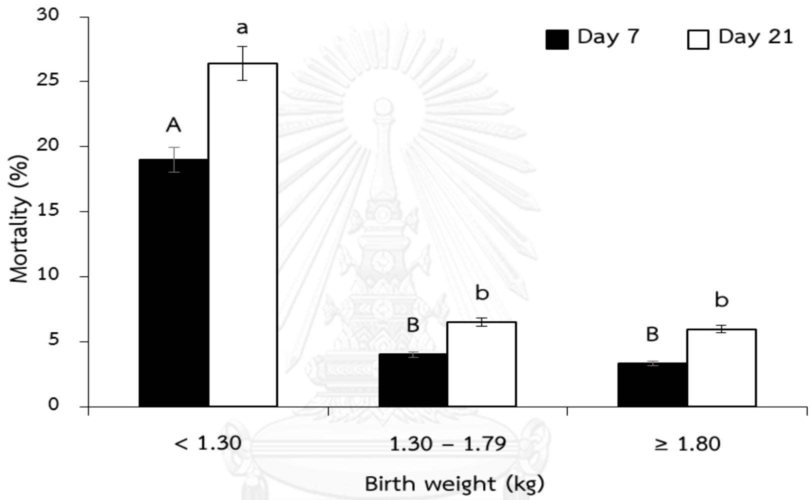

Figure 17 Percentage of mortality at days 7 and 21 for all piglets classified into low (< 1.30 kg, n = 216), medium (1.30 – 1.79 kg, n = 323) and high (≥ 1.80 kg, n = 151) birth weight categories.

[A, B, a, b] Values with different superscripts within the same day differ significantly (P < 0.05)

Factors influencing PWM21 included BW_B (*P* < 0.001) and RT24h (*P* < 0.001). At day 21, the piglets with BW_B < 1.30 kg had a higher (*P* < 0.001) mortality rate (26.4%) than the piglets with BW_B ≥ 1.80 kg (6.0%) and the piglets with BW_B 1.30 – 1.79 kg (6.5%, Figure 17). The piglets with RT24h < 37.0 °C had a higher (*P* < 0.001) PWM21 (89.7%) than the piglets with RT24h 37.0 – 38.5 °C (12.9%) and RT24h > 38.5 °C (7.0%, Figure 18).

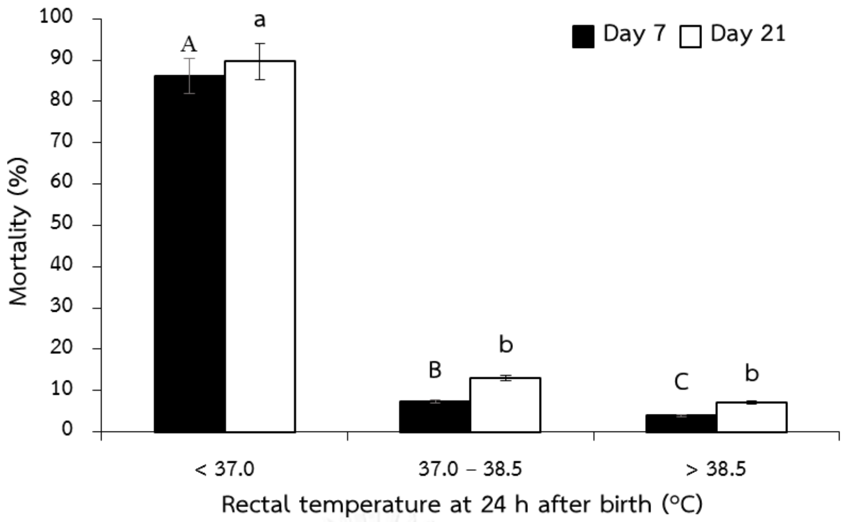

Figure 18 Percentage of mortality at days 7 and 21 for all piglets classified into low (< 37.0 °C, n = 29), medium (37.0 – 38.5 °C, n = 248) and high (> 38.5 °C, n = 413) rectal temperature categories at 24 h after birth

$^{A, B, C, a, b, c}$ Values with different superscripts within the same day differ significantly ($P < 0.05$)

6.4.2.2 Average daily gain

The final multi-covariate model for ADG7 included BW_B ($P < 0.001$), blood glucose concentration ($P < 0.001$), NBA ($P = 0.025$), sex ($P = 0.087$) and attempts to stand ($P = 0.093$). At day 7, the piglets with $BW_B < 1.30$ kg had a lower ADG than the piglets with $BW_B \geq 1.80$ kg ($P < 0.001$) and the piglets with BW_B 1.30 – 1.79 kg ($P < 0.001$, Table 22). The piglets with a blood glucose concentration of ≤ 24 mg/dL had a lower ADG7 than the piglets with a blood glucose concentration of > 24 mg/dL ($P < 0.001$). Furthermore, the piglets with a low NBA (< 12 piglet/litter) had a higher ADG7 the piglets with 12 – 14 NBA ($P = 0.087$) and the piglets with ≥ 15 BA ($P = 0.030$). The male piglets tended to have a higher ADG7 than the female piglets ($P = 0.087$). The piglets that stood within 1 min tended to have a higher ADG7 than the piglets that stood after 5 min ($P = 0.075$).

Factors influencing ADG21 of the piglets included BW_B ($P < 0.001$), NBA ($P < 0.001$), and blood glucose concentration ($P = 0.042$). At day 21, the piglets with a BW_B of < 1.3 kg had a lower ADG than the piglets with a BW_B of ≥ 1.80 kg ($P < 0.001$) and the piglets with a BW_B 1.30 – 1.79 kg ($P < 0.001$) (Table 22). The piglets from litters with a low NBA (< 12 piglets/ litter) had a higher ADG21 than those from litters with a NBA of 12 – 14 (P < 0.001) and ≥ 15 (P < 0.001). The piglets with a blood glucose concentration of ≤ 24 mg/dL had a lower ADG21 than the piglets with a blood glucose concentration of > 24 mg/dL (P = 0.042).

Table 22 Predictive factors included in the final models for average daily gain (least-square means ± SEM) from birth until 7 and 21 days of life

Variables	Average Daily Gain, g/d	
	Day 7	Day 21
Number of piglets born alive per litter, piglets		
< 12	150.6 ± 11.09^{a}	226.8 ± 9.88^{a}
12 – 14	126.4 ± 11.39^{b}	190.6 ± 9.60^{b}
≥ 15	121.3 ± 11.16^{b}	192.8 ± 9.94^{b}
Birth weight, kg		
< 1.30	88.9 ± 9.72^{c}	165.5 ± 9.01^{c}
1.30 – 1.79	145.3 ± 9.52^{b}	210.5 ± 8.45^{b}
≥ 1.80	164.2 ± 10.59^{a}	234.2 ± 9.40^{a}
Glucose, mg/dL		
≤ 24	107.8 ± 15.32^{b}	190.3 ± 15.95^{b}
> 24	157.8 ± 6.16^{a}	220.6 ± 4.99^{a}
Sex		
Male	136.5 ± 9.45^{A}	NS
Female	129.1 ± 9.53^{B}	NS
Attempt to stand, min		
< 1	141.8 ± 8.27^{A}	NS
1 – 5	140.2 ± 10.78^{AB}	NS
> 5	116.4 ± 13.87^{B}	NS

$^{a, b, c}$ Values with different superscripts within the same column differ significantly (P < 0.05)

$^{A, B}$ Values with different superscripts within the same column is tendency (0.05 < P < 0.01)

NS: Not significant difference

6.5 DISCUSSION

The main objective of this study was to determine the effect of certain newborn piglet traits measured soon after birth on piglet preweaning mortality and growth. As expected, BW_B and RT24h were the most influential postnatal survival factors at both day 7 and at weaning. Furthermore, BW_B, NBA and blood glucose concentration significantly influenced piglet growth during the whole lactation period, while sex and time spent attempted to stand had some impact on their growth up to day 7.

In agreement with our results, many studies have identified piglet BW_B as the main predictor for both survival and growth during lactation (Panzardi et al., 2013; Rootwelt et al., 2013). Piglet BW_B is positively associated with their physiological maturity and, in turn, correlates with different physical and physiological parameters such as colostrum intake capacity and thermoregulation ability (Muns et al., 2016). Small piglets usually have decreased viability and a lower capacity to compete for a teat (Tuchscherer et al., 2000). Johansen et al. (2004) found that piglets with a low BW_B often have lower ADG in the suckling period. In addition, low BW_B piglets are less able to maintain body temperature (Theil et al., 2012) which leads to starvation, lethargy and increased risk of crushing by the sow. Therefore, lower BW_B piglets may also show a low nutritional status and poor passive immunity (Quiniou et al., 2002). In agreement with our results, rectal temperature after birth was identified as an important indicator for piglet survival (Tuchscherer et al., 2000; Panzardi et al., 2013), indicating that piglets with low rectal temperature after 24 h might have lower thermoregulation abilities. Thermoregulation is a crucial physiological event for all newborn piglets. The piglets that die during the first days of life are not able to maintain optimal rectal temperature during the first 24 h of life (Baxter et al., 2008). In the present study, RT24h was significantly associated with mortality rate but was not related with ADG. In contrast, Panzardi et al. (2013) identified RT24h as an indicator for piglet growth at weaning. Likewise, Pedersen et al. (2015) found that piglets with low RT24h had low ADG from birth to weaning.

In the current study, NBA was observed to strongly influenced piglet growth. Likewise, other studies found that NBA negatively correlated with the piglet weaning weight (Pedersen et al., 2015). This might be due to the fact that there is also an increase in the number of small piglets in the litter with an increased NBA (Quesnel et al., 2008). Competition between littermates might have a negative impact on piglet colostrum consumption, especially in the small piglets, resulting in reduced growth during lactation (Muns et al., 2016). Moreover, NBA was not related with mortality in the present study, whereas in our previous study, there was a positive relationship between the number of piglets in the litter and piglet mortality (Nuntapaitoon and Tummaruk, 2015). Nonetheless, Muns et al. (2013) and Pedersen et al. (2015) found a relationship between NBA and piglet growth, but not between NBA and mortality rate.

In the present study, blood glucose concentration at birth was a significant predictor for piglet ADG7 and ADG21 but not for piglet mortality. Accordingly, studies failed to demonstrate a correlation between blood glucose concentration in newborn piglet and their survival (Tuchscherer et al., 2000; Baxter et al., 2008; Rootwelt et al., 2013). However, Panzardi et al. (2013) found that either too low (24 – 30 mg/dL) or too high (45 – 162 mg/dL) levels of blood glucose in neonatal pigelts were associated with an increased preweaning mortality. In the present study ,piglets with high glucose concentrations at birth might have a high energy reserves and, subsequently, enhanced capacity for suckling and growth. This implies that some source of glucose or energy supplementation in neonatal piglets maybe needed to improve the suckling capacity and growth performance in the neonatal piglets.

In the multivariate models for ADG7, time from birth to first attempts to stand was also identified as a predictive factor. In the present study, piglets spending > 5 min from birth to first attempts to stand had low ADG. Decaluwé et al. (2014) also found that piglets spending a long time from birth to suckling had a lower ADG during the lactation period than those spending a short time from birth to suckling. Moreover, neonatal piglets spending a short time from birth to first attempts to stand resulted in a low preweaning mortality (Baxter et al., 2008; Panzardi et al., 2013). However, Leenhouwers et al. (2001) found no relationship between time from birth to first attempts to stand and piglet mortality rate during the first week of lactation. Nonetheless, time elapsed from birth to first suckling significantly influences colostrum consumption of the piglets (Devillers et al., 2004). Therefore, “the time elapsed from birth to first suckling" has been included in a formula for estimating colostrum consumption in piglets (Devillers et al., 2004). In the present study, piglets spending a short time period from birth to first attempts to stand are probably faster at first suckling, thus increasing their colostrum consumption. The colostrum consumption of the neonatal piglets significantly influences the piglet survival and passive immunity (Devillers et al., 2011). Therefore, in practice, newborn piglets spending more than 5 min from birth to first attempt to stand need special cares.

6.6 Conclusion

Low BW_B and low RT24h compromise piglet survival during the lactation period in tropical conditions. In addition, piglets in the litters with a high number of NBA and piglets with low BW_B and/or low blood glucose concentration have reduced body weight growth during lactation.

Chapter VII

Factors influencing colostrum consumption by piglets and their relationship with survival and growth in tropical climates

(Major revision in Livestock Science)

7.1 Abstract

Inadequate colostrum consumption increases preweaning mortality and reduces body weight gain. The aim of the present study was to determine which factors influence piglet colostrum consumption and to study their relationship with survival and growth in tropical climates. At birth, 1,018 piglets from first to seventh parity sows were monitored for HR, $SatO_2$, blood glucose concentration, birth order, birth interval, sex, standing time, integrity of the umbilical cord and RT24h. Piglets were weighed at birth and postnatal days one and 21. The mortality rate of piglets was determined on 21 days of lactation. On average, individual colostrum consumption was 426 g. Litters with less than 12 NBA, a low BW_B, birth order greater than nine or standing time greater than 5 min had significantly lower colostrum consumption (P < 0.001) compare to those with a greater NBA, higher BW_B and shorter standing time. Sows with a low litter birth weight had low colostrum yield (P < 0.001). High mortality at 21 days postnatal was found for piglets with colostrum consumption less than 400 g and RT24h less than 38.5 °C (P < 0.05). Moreover, piglets with colostrum consumption less than 400 g and low BW_B had reduced ADG (P < 0.001). In conclusion, the NBA, BW_B, RT24h, birth order and standing time influenced piglet colostrum consumption, with litter birth weight representing the most influential factor for colostrum yield in a tropical climate.

7.2 Introduction

Colostrum represents a rich source of nutrients, immunoglobulins, enzymes and hormones (Rooke and Bland, 2002), and plays a key role in thermoregulation and passive immunity acquisition of piglets (Devillers et al., 2011). Moreover, colostrum is reported to stimulate brain protein synthesis and brain development during early postnatal life (Pierzynowski et al., 2014). The survival and growth of piglets has been positively associated with colostrum consumption (Decaluwé et al., 2014). Quesnel et al. (2012) observed that colostrum consumption is highly variable among littermates, ranging from 0 to 700 g/kg.

The huge variation in colostrum consumption and limited capacity for colostrum production by sows highlight the importance of a more comprehensive understanding of the factors that affect colostrum consumption. Piglets with low vitality at birth have a longer interval from birth until their first suckle, with an impaired ability to suckle properly (Amdi et al., 2013). Moreover, the degree of intrapartum asphyxia and the umbilical characteristics of piglets have also been used to reflect their vitality after birth (Trujillo-Ortega et al., 2007). Damage to the umbilical cord can lead to intrapartum hypoxia, reducing piglet vitality and colostrum consumption (Devillers et al., 2007; Panzardi et al., 2013).

The sow's parity number, backfat thickness and LS can also affect the consumption by piglets (Quesnel, 2011; Decaluwé et al., 2013). Previous studies have reported that sows in parities two to three tend to produce more colostrum than primiparous and older sows (Devillers et al., 2007; Decaluwé et al., 2013). In addition, colostrum yield of the sow seems to be limited and poorly influenced by sow body condition before farrowing and the process of farrowing (Quesnel, 2011). Furthermore, one third of sows do not produce sufficient amount of colostrum (Decaluwé et al., 2013). Earlier studies demonstrated that sow body weight prior to farrowing, litter birth weight and the NBA are positively correlated with colostrum and milk production (Declerck et al., 2015; Vadmand et al., 2015). The mammary glands are thought to be modified tubular sweat glands (Frandson et al., 2009). Thus, high ambient temperatures could be expected to increase the amount of blood directed toward the subcutaneous tissue surrounding the mammary glands, rather than increasing the nutrient supply to the mammary epithelium, particularly in sows reared in a tropical climate, which may consequently impair the production of colostrum and milk.

In larger litters, an increased number of fights between littermates during suckling was found to reduce colostrum consumption, enhance the risk of starvation, and increase piglet mortality before weaning (Milligan et al., 2002; Nuntapaitoon and Tummaruk, 2015). Additionally, while the rectal temperature of neonatal piglets is dependent on the environmental temperature (Kammersgaard et al., 2011), colostrum also plays an essential role in enabling thermoregulation (Devillers et al., 2007). Piglets with a high rectal temperature in their first day of postnatal life were reported to have lower mortality (Panzardi et al., 2013). Knowledge of factors that influence colostrum consumption and colostrum yield are important to reduce preweaning mortality and increase growth of piglets; however, this remains to be clarified under hot climatic conditions. The objective of the present study was to evaluate which traits of newborn piglets in a tropical climate are important for piglet colostrum consumption and sow colostrum yield, which in turn affect preweaning mortality and piglet growth.

7.3 Materials and methods

7.3.1 Animals and general management

The experiment followed the guidelines documented in the Ethical Principles and Guidelines for the Use of Animals for Scientific Purposes of the National Research Council of Thailand, and was approved by the Institutional Animal Care and Use Committee (IACUC), in accordance with the regulations and policies of the university governing the care and use of experimental animals (Approval number 1431063).

The present study was performed on a commercial swine herd in the western part of Thailand between June and August 2013. The number of productive sows in the herd was 3500. The average ambient temperature during the experimental period ranged from 25.8 to 30.0 °C. The minimum daily temperature ranged from 21.1 to 26.3 °C, and maximum daily temperatures from 28.1 to 37.6 °C. The average relative humidity varied between 72.0% and 96.0%.

Sows were kept in individual crates (1.2 m^2) in a conventional open-housing system during gestation, and provided with fans and individual water sprinklers to reduce the impact of high ambient temperature. Pregnant sows were moved to the farrowing house approximately 1 week before their expected farrowing date. In the farrowing house, sows were individually kept in farrowing crates (1.2 m^2) that were placed at the centre of a 4.2 m^2 pens. The pens were fully slatted with concrete in the centre for the sows, and contained steel slats on both sides of the farrowing crate for the piglets. Each pen was provided with a creep area for piglets (0.60 m^2), which was placed on the floor on one side of the farrowing crate and covered with a plastic plate without any heating source. During gestation, sows were fed a commercial gestation diet to meet or exceed their nutritional requirements (NRC, 2012). Feed was provided twice a day following a standardised feeding regimen, resulting in an average weight gain of 2.5 kg per sow per day. During lactation, sows were fed twice a day with a commercial lactation diet to meet or exceed their nutritional requirements (NRC, 2012). The daily amount of feed offered increased depending on the LS and body condition of the sow, until *ad libitum* feeding was reached after one week of lactation. The animals received *ad libitum* water in a continuous feed and water channel.

The parturition process was carefully supervised. Interference with sows was kept to a minimum during parturition. Birth intervention was performed only when dystocia was clearly identified. Dystocia was considered when an interval of 30 min elapsed from birth of the last piglet, accompanied by the sow showing intermittent straining with padding of the legs, or with the sow expelling small quantities of fetal fluid, together with marked tail switching without the birth of any piglets. Routine procedures performed on piglets included weighing, tail docking, tooth clipping and intramuscular administration of a one mL iron supplement (Gleptosil®, Alstoe Ltd. Animal Health, Leicestershire, England) on the day of birth. Piglets were also orally administered coccidiocide (Baycox®, Bayer Pharma AG, Berlin, Germany) and intramuscularly administered an antibiotic on postnatal day three. The mean lactation length was 23 ± 2 days.

7.3.2 Data collection

A total of 1160 piglets born from 85 LY crossbred sows (first to seventh parity) were included in this study. The following reproductive variables of sows were recorded: farrowing duration (time between first- and last-born piglets, NTB, NBA, SB, MM, and the number of piglets at weaning per litter. Within 5 min of birth, the piglets were monitored for HR and $SatO_2$ by veterinary pulse oximetry of the left ear using a neonatal probe (EDAN VE-H100B Pulse Oximeter; Edan Instrument Inc®, CA, USA). Blood samples for glucose evaluation were collected from the proximate part of the umbilical cord of piglets before their first suckling, and contained a mixture of venous and arterial blood. Blood glucose concentration was evaluated using a portable human glucometer (Accu-Chek® Performa; Roche, Basel, Switzerland). The umbilical cord was tied and cut five cm from the abdominal wall.

For each piglet, the birth order, birth interval (time elapsed between the birth of each piglet), sex and standing time (time elapsed from birth until their first attempt to stand) were recorded. We also recorded whether piglets required birth assistance. The skin colour of piglets was recorded at birth and classified into two groups (normal or pale). The integrity of the umbilical cord of each piglet was examined and classified into two groups (intact or broken). Rectal temperature was measured 24 h after birth (RT24h) with a digital thermometer (Microlife®; Microlife AG Swiss Corporation, Widnau, Switzerland; display resolution of 0.01 °C with ± 0.1 °C accuracolostrum yield). All piglets were individually identified by an ear tattoo. The BW_B of piglets was measured immediately after birth and again 24 h after the first born piglet (range 18 to 24 h after birth). The sum of BW_B for all the NBA piglets in the litter was defined as the litter birth weight. Cross-fostering was performed 24 to 48 h after birth, and the number of piglets within each litter was adjusted to 12 to 14 piglets per litter. The LS was defined as the number of piglets per litter after cross-fostering. Piglets were weighed again at 21 days of lactation, at which stage any piglet mortality was recorded. The backfat thickness of the sows was measured at the last rib, 65 mm from the dorsal midline, using A-mode ultrasonography (Renco Lean-Meater®; Minneapolis, MN, USA). The backfat measurement was performed in each sow at farrowing.

The individual colostrum consumption of each piglet was estimated by a previously reported equation (Theil et al., 2014a): colostrum consumption (g) = $-106 + 2.26WG + 200BW_B + 0.111D - 1414WG/D + 0.0182WG/BW_B$, where WG is piglet weight gain (g), BW_B is birth weight (kg), and D is the duration of colostrum suckling (min). The colostrum yield of the sows was defined as the sum of individual colostrum consumption of all piglets in the litter.

7.3.3 Statistical analysis

All statistical analyses were performed using SAS 9.0 (SAS Inst. Inc., Cary, NC, USA). Descriptive statistics and frequency tables were generated for continuous and categorical data, respectively. To identify the potential indicators for colostrum consumption, each recorded factor was subjected to univariate analysis using a generalised linear model (PROG GLM). Categorical variables (*i.e.,* sex, skin colour, standing time, integrity of the umbilical cord and birth intervention) were individually tested using logistic regression analyses (PROC GENMOD).

Continuous variables (*i.e.,* NTB, NBA, BW_B, birth interval, RT24h, HR, piglet blood glucose concentration and birth order) were measured for collinearity using Pearson's correlation. The categories for NBA and BW_B were based on our previous study (Nuntapaitoon and Tummaruk, 2015). The three classes created for NBA were: less than 12 piglets/litter, 12 – 14 piglets/litter, and more than 14 piglets/litter. For BW_B, the categories were: low (less than 1.30 kg), medium (1.30 – 1.79 kg) ,and high (more than 1.79 kg). The categories forstanding time (less than 1 min, 1 – 5 min, and more than 5 min) and birth order (less than or equal to ninth, and greater than ninth) were based on Panzardi et al. (2013). The categories for RT24h and litter birth weight were created by frequency analysis. The three classes of RT24h were: less than 38.5 °C, 38.5 – 38.8 °C, and more than 38.8 °C. The litter birth weight of sows was classified into three groups: low (less than 16.0 kg), medium (16.0 – 20.0 kg) ,and high (more than 20.0 kg).

The possible physiological factors (*i.e*., sow parity, backfat thickness before farrowing, farrowing time, NBA, BW_B, litter birth weight, birth interval, birth order, HR, blood glucose concentration, $SatO_2$, RT24h, birth intervention, skin colour, standing time, sex and integrity of the umbilical cord) were included in the logistic regression models as independent variables. The statistical models included colostrum consumption and colostrum yield as fixed effects. The sow identification number were included in the model as a random effect. Colostrum consumption and colostrum yield were analyzed using the generalised linear mixed model procedure (PROC MIXED) of SAS. The mixed models were included both fixed and random effects, and used restricted maximum likelihood (REML) as the estimation method. Non-significant factors with $P > 0.10$ were removed from the models in a stepwise fashion. The fixed effects in the final models included effects of NBA, BW_B, birth order and standing time on colostrum consumption, and effects of NBA and litter birth weight on colostrum yield. Sow identification numbers were added into the statistical model as a random effect when analyzing piglet colostrum consumption and sow colostrum yield. The independent variables of PWM21 and ADG21 included colostrum consumption and the factors found to influence colostrum consumption in the final model, were analyzed with two-way interactions using generalised linear mixed model procedures (GLIMMIX macro and PROC MIXED, respectively) of SAS. Colostrum consumption was classified into two groups: less than 400 g and more than 400 g. In addition, multiple ANOVA was used to evaluate the effect of BW_B, litter birth weight or RT24h (regression) on colostrum consumption, colostrum yield, PWM21 and ADG21 after birth. Least-squared means were obtained from statistical models. Values with $P < 0.05$ were regarded as being statistically significant.

7.4 Results

Descriptive statistics for sow reproductive performance and piglet performance are presented in Table 23. From the 1,160 piglets included in the experiment, 96 were stillborn (8.4%), 46 were mummified (4.0%), and 1,018 were NBA (87.7%). On average, the duration of farrowing was 213 ± 80 min with a birth interval of 15.7 ± 22.2 min. Thecolostrum yield was 4,957 ± 1,228 g (range 1,694 – 7,319 g). Piglet preweaning mortality amounted to 127 piglets (12.5%) and the number of dead on one day and 21 days of lactation was 31 (3.1%) and 96 (9.4%) piglets, respectively. The mean colostrum consumption for each piglet was 426 ± 5 g, with 6.6% of piglets having ingested less than 200 g, 38.6% ingested between 200 and 400 g, and 54.8% ingested more than 400 g of colostrum (Figure 19).

Table 23 Descriptive statistics of 85 sows and 1,018 piglets evaluated at birth and during the lactation period in a commercial swine herd in Thailand.

Variables	n	Mean ± SD	Range
Sow data			
Parity	85	3.0 ± 1.9	1 – 7
Backfat thickness at farrowing (mm)	85	15.0 ± 3.1	8 – 22
Backfat thickness at weaning (mm)	85	12.1 ± 2.4	7 – 19
Relative loss of backfat (%)	85	18.9 ± 8.9	0 – 41.2
Number of total born piglets	85	13.8 ± 3.5	7 – 21
Number of piglets born alive	85	12.0 ± 3.1	4 – 19
Litter size	85	12.9 ± 1.5	9 – 16
Number of piglets at weaning per litter	85	11.6 ± 1.6	7 – 15
Farrowing birth interval, min	85	15.7 ± 22.2	0 – 38
Farrowing time, min	85	213.2 ± 80.0	71 – 558
Gestation length, day	85	115.2 ± 1.0	113 – 118
Piglet data			
Birth weight, kg	1,018	1.5 ± 0.36	0.5 – 2.7
Heart rate, bpm	1,009	64.8 ± 31.75	23 – 250
Blood glucose, mg/dL	1,018	51.7 ± 25.56	10 – 485
Oxygen saturation, %	1,009	91.6 ± 8.26	10 – 100
Weight at day 1, g	987	1.6 ± 0.39	0.4 – 2.9
Weight at day 7, g	932	2.6 ± 0.66	0.7 – 4.6
Weight at day 21, g	891	5.9 ± 1.43	1.9 – 10.1
ADG day 0 to 1, g/day	987	84.7 ± 79.19	0 – 545.0
ADG day 1 to 7, g/day	932	156.2 ± 63.9	– 16.4 – 340.7
ADG day 1 to 21, g/day	891	207.6 ± 60.47	24.0 – 376.9

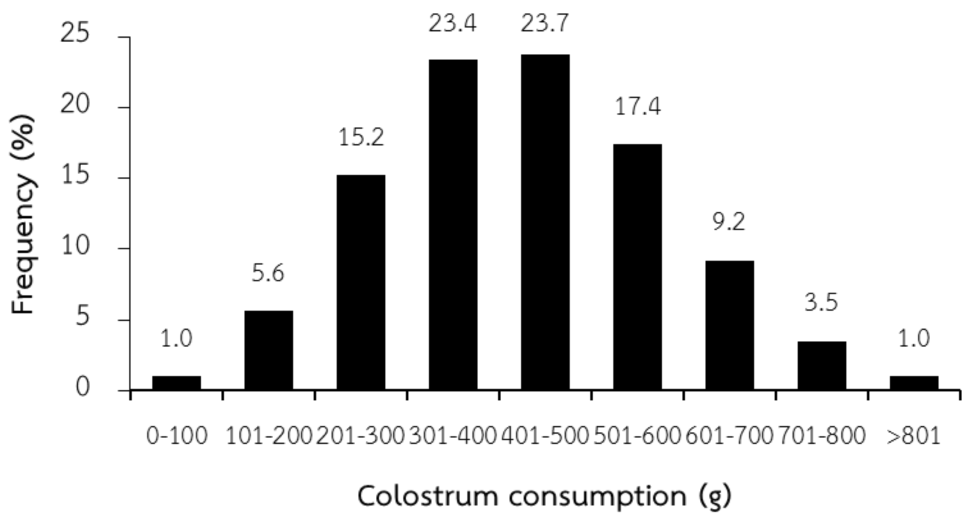

Figure 19 Frequency distribution of individual colostrum consumption (g) in 987 neonatal piglets (excluding 31 piglets that died before 24 h) born from 85 Landrace × Yorkshire crossbred sows in a commercial swine herd in Thailand.

7.4.1 Factors associated with colostrum consumption

7.4.1.1 Univariate analysis

Colostrum consumption was influenced by NBA, BW_B, birth interval, birth order, HR, piglet blood glucose concentration, birth intervention and standing time ($P < 0.05$; Table 24). The correlation analysis showed colostrum consumption to be positively correlated with BW_B, birth interval, RT24h, HR, and piglet blood glucose concentration (Table 25). On the other hand, colostrum consumption was negatively correlated with NTB, NBA and birth order. Sow parity, farrowing time, sow backfat thickness at farrowing, $SatO_2$, skin colour, sex and integrity of umbilical cord were not found to be correlated with colostrum consumption ($P > 0.10$). The regression analysis showed a relationship between colostrum consumption and NBA, BW_B, birth order and blood glucose concentration (Figure 20).

Table 24 Significance levels (*P* value) of factors influencing colostrum consumption and colostrum yield from the univariate analysis under the generalised linear model procedure

Variables	Colostrum consumption	Colostrum yield
Sow parity number	0.29	0.47
Backfat before farrowing	0.74	0.43
Farrowing time	0.50	0.45
Number of piglets born alive	< 0.001	< 0.001
Litter piglet birth weight	NA	< 0.001
Piglet birth weight	< 0.001	NA
Birth interval	0.021	NA
Birth order	< 0.001	NA
Heart rate	0.020	NA
Blood glucose concentration	0.007	NA
Blood oxygen saturation	0.27	NA
Birth intervention	0.006	NA
Skin colour	0.93	NA
Standing time	< 0.001	NA
Sex	0.13	NA
Integrity of umbilical cord	0.11	NA

NA ,not available

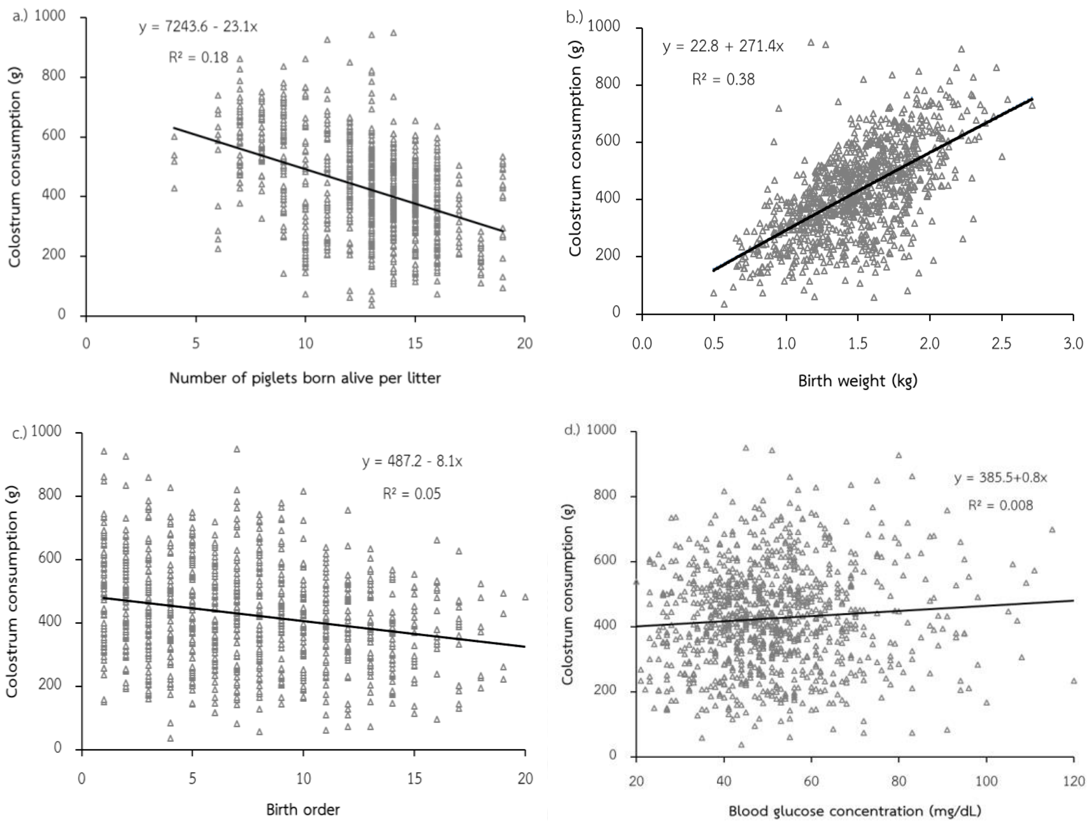

Figure 20 Relationship between colostrum consumption and (a) number of piglets born alive, (b) birth weight, (c) birth order and (d) piglet blood glucose concentration in 987 neonatal piglets (excluding 31 piglets that died before 24 h)

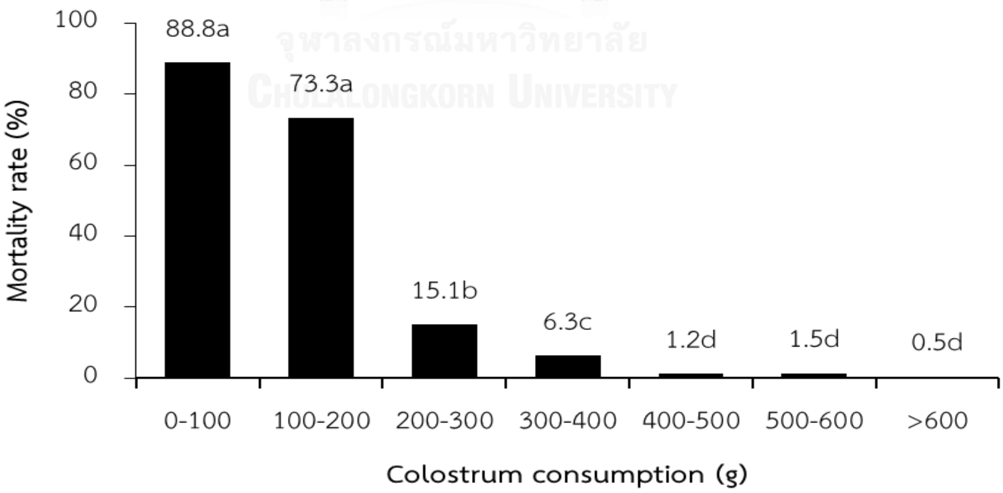

Figure 21 Influence of colostrum consumption (g) on preweaning mortality in 987 piglets during the lactation period from 85 Landrace × Yorkshire crossbred sows in a commercial swine herd in a tropical climate

Different superscript letters indicate significant differences (*P* < 0.05)

Table 25 Pearson's correlation coefficients (*r*) among factors associated with colostrum consumption in neonatal piglets

	NTB	NBA	BW_B	BI	BO	RT24	HR	Glu
NBA	0.823***							
BW_B	-0.282***	-0.331***						
BI	-0.139***	-0.126***	0.164***					
BO	0.328***	0.311***	-0.**102					
RT24			0.126***					
HR	-0.092**	-0.082**						
Glu	-0.124***	-0.121***	0.137***	0.159***	0.106***			
CC	-0.345***	-0.424***	0.615***	0.074*	-0.234***	0.258***	0.074*	0.086**

Significance levels: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$. Abbreviations: NTB, total piglets born; NBA, piglets born alive; BW_B, birth weight; BI, birth interval; BO, birth order; RT24, rectal temperature 24 h after birth; HR, piglet heart rate; Glu, piglet blood glucose concentration; CC, colostrum consumption.

7.4.1.2 Final multivariate model

The final multi-covariate model for colostrum consumption included NBA ($P < 0.001$), BW_B ($P < 0.001$), birth order ($P < 0.001$) and standing time ($P = 0.002$). Colostrum consumption decreased when NBA, birth order or standing time increased. On the other hand, colostrum consumption increased as BW_B increased (Table 26).

Table 26 Results of multiple analyses of variance (ANOVA) using the general linear mixed model procedure (PROC MIXED) for factors influencing piglet colostrum consumption

Variables	n	Colostrum consumption, g
Number of piglets born alive per litter		
< 12	272	460^{a}
12 – 14	421	402^{b}
≥ 15	293	369^{b}
Piglet birth weight, kg		
< 1.30	290	305^{c}
1.30 – 1.79	498	425^{b}
≥ 1.80	198	501^{a}
Birth order		
< 9	675	423^{a}
≥ 10	311	397^{b}
Standing time, min		
< 1	858	437^{a}
1 – 5	89	412^{b}
> 5	39	382^{b}

Different superscript letters within the column indicate significant differences ($P < 0.05$)

7.4.2 Factors associated with colostrum yield

7.4.2.1 Univariate analysis

Colostrum yield was influenced by NBA and litter birth weight ($P < 0.001$). However, sow parity, sow backfat thickness at farrowing and farrowing time were not correlated with colostrum yield ($P > 0.10$; Table 24).

7.4.2.2 Final multivariate model

Litter birth weight was found to influence colostrum yield (*P* = 0.012). The colostrum yield of sows with a low litter birth weight (4,975 ± 1,321 g) was lower than that for sows with a medium litter birth weight (6,009 ± 1,343 g; *P* = 0.001) or a high litter birth weight (6,548 ± 1,321 g; *P* < 0.001).

7.4.3 Association between colostrum consumption and mortality at day 21 postnatal period

Piglets with colostrum consumption greater than 400 g had a lower mortality rate (Figure 21). Piglets that died before 21 days had a lower colostrum consumption than piglets that survived until weaning (Figure 22). The factors found to significantly influence preweaning mortality in the final model included BW_B (*P* < 0.001), colostrum consumption (*P* < 0.001), RT24h (*P* = 0.030), birth intervention (*P* = 0.017), skin colour (*P* = 0.045) and the interaction between colostrum consumption and RT24h (*P* = 0.045 ; Table 27).

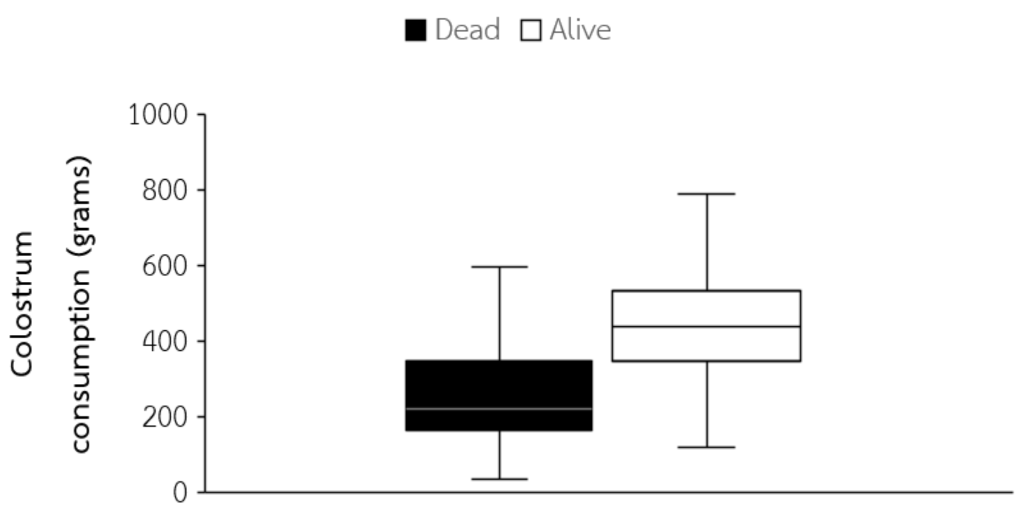

Figure 22 Colostrum consumption of piglets that had died or survived by 21 days of the lactation period.

Table 27 Results of multiple analyses of variance (ANOVA) using the generalised linear mixed model procedure (PROC GLIMMIXED) for factors influencing piglet preweaning mortality.

Variables	n	Preweaning mortality,%	95% CI
Piglet birth weight, kg			
< 1.30	290	9.9^{a}	5.0 – 18.9
1.30 – 1.79	499	3.0^{b}	1.4 – 6.1
≥ 1.80	198	2.7^{b}	1.1 – 6.5
Colostrum consumption, g			
≤ 400	446	10.3^{a}	5.3 – 19.1
> 400	541	1.8^{b}	0.8 – 3.9
Rectal temperature 24 h after birth, °C			
< 38.5	338	6.8^{a}	3.2 – 13.6
38.5 – 38.8	333	2.6^{b}	1.1 – 5.9
≥ 38.9	316	4.7^{ab}	2.2 – 9.6
Birth intervention			
Yes	127	2.4^{b}	0.9 – 6.8
No	860	7.6^{a}	4.5 – 12.6
Skin colour			
Normal	948	2.8^{b}	1.6 – 5.0
Pale	39	6.7^{a}	2.6 – 16.4

Different superscript letters within the column indicate significant differences ($P < 0.05$).

Moreover, the amount of colostrum consumption influenced RT24h (Figure 23), with RT24h increasing with higher colostrum consumption. Piglets with colostrum consumption less than 400 g and RT24h less than 38.5 °C (5.17%) had a higher rate of preweaning mortality compared to the other piglets (Figure 24).

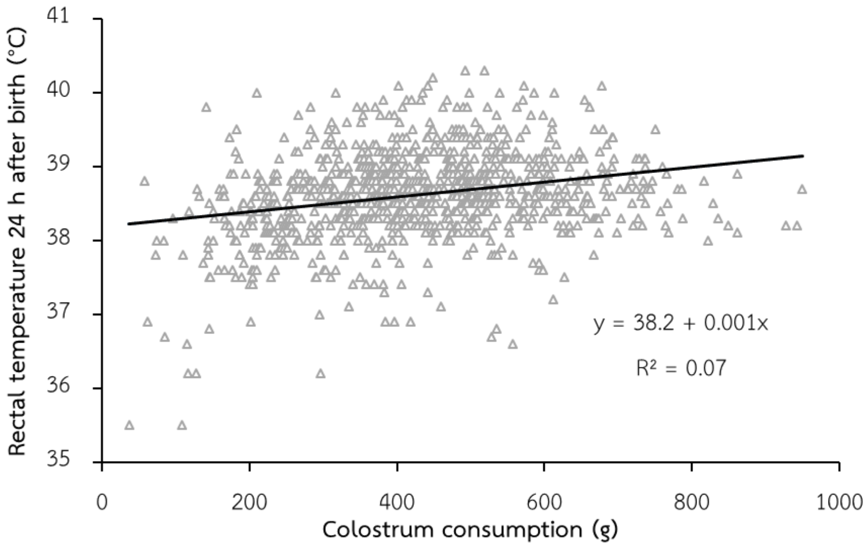

Figure 23 Influence of colostrum consumption on rectal temperature 24 h after birth.

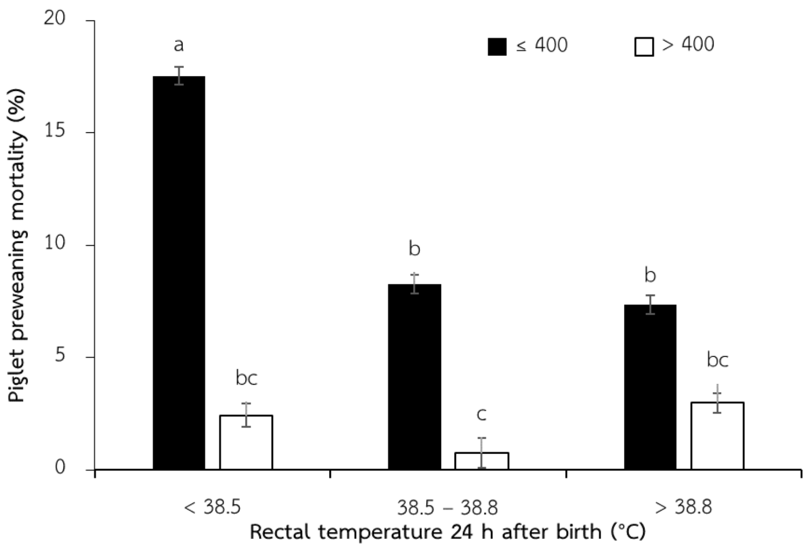

Figure 24 Influence of colostrum consumption (< 400 or > 400 g) on preweaning mortality for different classes of rectal temperature determined 24 h after birth (< 38.5, 38.5 – 38.8, and > 38.8 ℃)

Different superscript letters indicate significant differences ($P < 0.05$)

7.4.4 Association between colostrum consumption and average daily weight gain until day 21 postnatal

The factors found to influence ADG21 in the final model included NBA (P < 0.001), BW_B (P < 0.001), colostrum consumption (P < 0.001), and the interaction between BW_B and colostrum consumption (P = 0.018; Table 28). An influence of colostrum consumption on ADG21 by BW_B classes is evident in Figure 25, which shows that piglets with colostrum consumption equal to or less than 400 g had a lower ADG21 than piglets with colostrum consumption more than 400 g in all BW_B classes (P < 0.05). Moreover, piglets with colostrum consumption more than 400 g and a high BW_B (246 g/day) had higher ADG21 than piglets with colostrum consumption greater than 400 g and a low or medium piglet BW_B (200 and 227 g/day, respectively; P < 0.001).

Table 28 Results of analyses of variance (ANOVA) using the general linear mixed model procedure (PROC MIXED) for factors influencing average daily weight gain at postnatal day 21.

Variables	n	Average daily gain at 21 days, g/d
Number of piglets born alive per litter		
< 12	257	218[a]
12 – 14	385	187[b]
≥ 15	247	202[ab]
Birth weight, kg		
< 1.30	226	183[b]
1.30 – 1.79	472	211[a]
≥ 1.80	191	213[a]
Colostrum consumption, g		
≤ 400	362	181[b]
> 400	527	224[a]

Different superscript letters within the column indicate significant differences (P < 0.05)

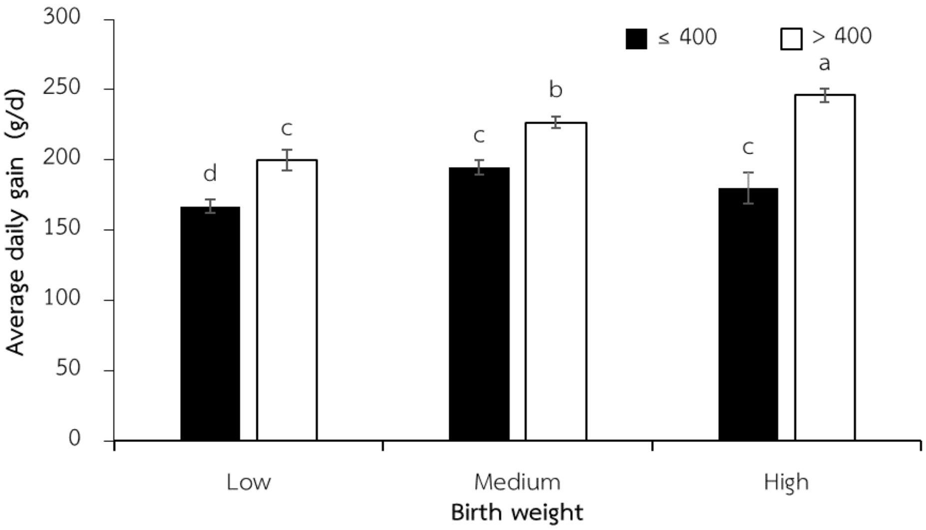

Figure 25 Influence of colostrum consumption (< 400 or > 400 g) on average daily weight gain until 21 days after birth for piglets classified into low (< 1.30 kg), medium (1.30 – 1.79 kg) and high (< 1.79 kg) birth weight classes

Different superscript letters indicate significant differences (*P* < 0.05)

7.4.5 Regression analysis

All of the regression models related to colostrum consumption, colostrum yield, PWM21 and ADG21 included BW_B (Table 29). Results indicated that 38% of the variation in colostrum consumption was explained by BW_B, showing a positive regression coefficient of 0.271. There was a positive regression coefficient between litter birth weight of live-born piglets and colostrum yield. In contrast, the regression coefficients for piglet BW_B, RT24h and colostrum consumption were negatively correlated with mortality. Overall, BW_B, RT24h and colostrum consumption explained 14% of the variability in PWM21, and BW_B and colostrum consumption explained 27% of the variability in ADG21.

Table 29 Regression models determined through stepwise regression with a backward elimination approach for colostrum consumption (CC), colostrum yield (CY), preweaning mortality (PWM21) and average daily weight gain during 21 days (ADG21) after birth.

Regression model	R^2
CC (g) = 22.8 + 271 × piglet birth weight (kg)	0.38
CY (g/day) = 1596 + 194 × total litter weight at birth (kg)	0.46
PWM21 (%) = 2.3 - 0.1 × piglet birth weight (kg) - 0.05 × RT24h (°C) - 0.0004 × CC (g)	0.14
ADG21 (g/day) = 93.3 + 20.9 × piglet birth weight (kg) + 0.18 × CC (g)	0.27

7.5 Discussion

7.5.1 Colostrum consumption, ability to thermoregulate and neonatal piglet mortality

Colostrum consumption is crucial for the survival and growth of piglets in commercial herds. In the present study, piglet mortality decreased with increasing intake of colostrum until 400 g, above which piglet mortality was consistently below 2%. From these findings, we can conclude that 400 g of colostrum consumption per piglet during the first 24 h after birth is recommended to minimize the risk of death and to enhance growth performance until weaning. The recommended colostrum consumption from this study is considerably greater than that previously reported by Quesnel et al. (2012), who found that 200 g of colostrum was required to reduce piglet mortality. The reason for this discrepancy is mainly due to differences in the prediction equations used by the two studies. The prediction model used in the current study has recently been shown to be more reliable, and this model estimates colostrum consumption approximately 50% higher than when the equation developed by Devillers et al. (2004) is used.

Rectal temperature in piglets after the colostral period is associated with the amount of colostrum consumed (Tuchscherer et al., 2000). Colostrum plays an important role in the thermoregulation of piglet during the neonatal period (Rooke and Bland, 2002). The energy obtained from colostrum promotes maintenance of body temperature. This is in agreement with current findings, whereby piglets ingesting more colostrum had higher RT24h. Rectal temperature after the colostrum period is related to mortality before weaning. In the current study, we found that piglets with low colostrum consumption and a rectal temperature less than 38.5 °C 24 h after birth had greater mortality (up to 17.5%). From these findings, we can be concluded that 400 g of colostrum consumption per piglet during the first 24 h after birth, and rectal temperature of more 38.5 °C 24 h after birth are recommended in order to reduce piglet mortality. Therefore, management strategies for increasing colostrum consumption during the colostral period should be prioritized.

7.5.2 Colostrum consumption and growth performance of piglets during lactation

Colostrum is important for piglet growth performance and health during the lactation period (Rooke and Bland, 2002; Le Dividich et al., 2005). Current findings indicated that piglets consuming more than 400 g of colostrum, and this higher growth rate was especially evident in high BW_B piglet. High BW_B piglets therefore seem to have a greater ability to consume, digest or utilize colostrum for growth than low BW_B piglets (Quesnel et al., 2012; Amdi et al., 2013; Ferrari et al., 2014). Piglets with high colostrum consumption were previously reported to show greater growth performance both before and after weaning (Declerck et al., 2016; Krogh et al., 2016b; Muns et al., 2016). Present results confirm that piglet BW_B and colostrum consumption influenced piglet growth during the lactation period.

7.5.3 Factors affecting colostrum consumption and colostrum yield

7.5.3.1 Number of live-born piglets

A larger LS increases the number of fights between piglets at suckling, increasing the risk of starvation and crushing of small piglets. Consequently, LS is an important factor for neonatal piglet survival (Milligan et al., 2002). In the present study, piglets in smaller litters had greater colostrum consumption. Likewise, an earlier study reported that LS is negatively correlated with colostrum consumption (Andersen et al., 2011).

Muns et al. (2016) reported that individual colostrum consumption was reduced in larger litters, especially in low BW_B piglets. Moreover, in high competition litters, piglets were observed to squealed more intensely before and after udder stimulation and during suckling. It was previously found that the squealing of piglets terminates suckling, and this especially during the first 24 h postpartum (Illmann et al., 2008). As a result, piglets likely do not consume an adequate amount of colostrum. Additionally, colostrum production is highly variable among sows (Quesnel, 2011). In the present study, litter weight at birth influenced sow colostrum yield. Moreover, NBA tended to be related with increased colostrum yield. Previous studies showed that colostrum yield is related to LS and BW_B (Devillers et al., 2007; Quesnel, 2011; Declerck et al., 2015), and is also associated with within-litter BW_B variation (Farmer et al., 2006a; Devillers et al., 2007; Quesnel, 2011). Moreover, Vadmand et al. (2015) reported a positive relationship between litter weight at birth and total sow colostrum yield. From those and current findings, it is apparent that management of highly prolific sows is important for increasing colostrum consumption in piglets and colostrum production in sows. In a recent study, Muns et al. (2017) reported that energy boosters can increase the immunity and reduce mortality of piglets. Moreover, oral supplementation with colostrum, split suckling and cross-fostering are management strategies that may enhance colostrum consumption and improve the survival and growth performance of piglets (Donovan and Dritz, 2000; Cecchinato et al., 2008; Muns et al., 2014b).

7.5.3.2 Piglet birth weight

Piglet BW_B was positively related to the amount of colostrum ingested by newborn piglets. In the present study, BW_B and litter weight at birth were the most influential factors for colostrum consumption by piglets and colostrum production in lactating sows, respectively. Results of the present study showed that piglets with high BW_B (more than 1.80 kg) consumed 1.6 times more colostrum (501 vs 303 g) than piglets weighing less than 1.30 kg at birth. Moreover, the regression analysis indicated that every 100 g increase in piglet BW_B was associated with a 27 g increase in ingested colostrum. Many studies reported the use of different approaches to enhance either piglet BW_B or colostrum consumption, for instance, arginine supplementation in gestation diets (Che et al., 2013). Feeding a high-fibre diet to late pregnant sows may favour the consumption of colostrum in small piglets (Loisel et al., 2013); however, this is not likely to be a good solution for tropical climates as a greater fibre intake increases sow heat production and reduces sow appetite (Danielsen and Vestergaard, 2001).

7.5.3.3 Birth order and standing time

Piglet birth order and standing time were negatively associated with colostrum consumption in the present study. In contrast, others reported no relationship between birth order and colostrum consumption (Devillers et al., 2004; Devillers et al., 2007; Declerck et al., 2016). Late-born piglets may suffer from intrapartum hypoxia as a result of uterine contractions, especially during prolonged farrowing, which may cause low viability (Herpin et al., 1996). A longer interval between birth and first suckling (*i.e*., standing time) was observed in late-born piglets (Tuchscherer et al., 2000; Baxter et al., 2008; Mota-Rojas et al., 2012). Accordingly, in the present study, birth order was positively associated with standing time, and both traits were negatively associated with colostrum consumption. Indeed, it is known that individual colostrum consumption depends on the piglet’s ability to reach the teat and suckle. A reduced standing time may result in a shorter interval between birth and first suckling. In the present study, piglets with a standing time of less than 1 min ingested 55 g more colostrum (equivalent to a 14% increase) when compared to piglets with a standing time of more than 5 min. Piglets born later with a shorter standing time also had a shorter interval between birth and first suckling. However, piglets born later acquired a lower level of immunity from colostrum due to decreased colostrum quality (Klobasa et al., 2004).

Piglets are often hypoglycaemic during the postpartum period due to a lack of hepatic enzymes (Odle et al., 2005). In the present study, piglet blood glucose concentration and $SatO_2$ immediately after birth were not associated with total colostrum consumption. However, the blood glucose concentration tended to be positively associated with colostrum consumption. As piglets with a high blood glucose level have adequate energy reserves, this may be associated with good suckling ability (Baxter et al., 2008). In the present study, birth intervention was usually applied when the birth interval exceeded 30 min, and therefore, few hypoxic piglets were identified in this study. However, in practical pig production, hypoxia may be more prominent, as farrowing are not always supervised.

7.5.4 Limiting factors affecting colostrum yield

Colostrum production in sows is highly variable due to differences in breed, nutrition, sows, litter and farrowing characteristics, hormonal status and environmental factors (Quesnel, 2011; Theil et al., 2014a; Declerck et al., 2015; Vadmand et al., 2015). The effect of temperature is of particular concern regarding colostrum production in tropical climates because heat stress may affect the endocrine status of the sow. Heat stress may increase the level of cortical hormones and influence the oxytocin released during parturition (Malmkvist et al., 2009), and subsequently increase farrowing duration and reduce colostrum production. Furthermore, the high temperatures characteristic of tropical climates may result in decreased blood supply to the mammary epithelium. In pigs, mammary glands are modified sweat glands (Frandson et al., 2009), and blood may be directed toward the subcutaneous tissue rather than the mammary epithelium when the sow body temperature becomes too high. Knowledge on the impact of temperature on mammary blood flow and colostrum production is currently lacking. The positive association between LS and colostrum consumption suggests that colostrum removal is likely a limiting factor for sow colostrum yield. To our knowledge, no comprehensive studies on the limiting factors of colostrum yield have been performed in a tropical climate.

7.6. Conclusion

Increasing colostrum consumption is crucial to reduce piglet preweaning mortality. In tropical conditions, high LS and low BW_B compromised colostrum consumption by piglets, thereby reducing their ability to thermoregulate, reducing piglet growth and increasing piglet mortality during lactation. Management actions performed the first day after birth aimed at increasing colostrum consumption of individual piglets (*i.e.,* cross-fostering, feeding low BW_B piglets with colostrum collected from other sows, split suckling or helping piglets with warmed and dry areas) could substantially increase piglet colostrum consumption and reduce mortality.

Chapter VIII

L-arginine supplementation in sow diet during late gestation decrease stillborn piglet, increase piglet birth weight and increase immunoglobulin G concentration in colostrum

(Submitted in Theriogenology)

8.1 Abstract

Arginine enhances growth of placenta, fetal development and mammary gland proliferation. The present study aims to determine the effect of *L*-arginine HCl supplementation in sow diet during late gestation on piglet characteristics at birth, colostrum consumption, concentration of IgG in colostrum, milk yield, ADG7, ADG21, PWM7 and PWM21, 166 sows were allocated into four groups, *i.e.,* CON (n = 66), ARG-0.5 (n = 42), ARG-1.0 (n = 41) and ALA (n = 17). The sows in each group were fed with a conventional gestation diet (CON) or the same diet supplemented with 0.5% *L*-arginine HCl (ARG-0.5), 1.0% *L*-arginine HCl (ARG-1.0) or 1.7% *L*-alanine (ALA, isonitrogenous with ARG-1.0). The feeding protocol was carried out from 85 days of gestation until farrowing. The proportion of live-born piglets, BW_B, within-litter variation of BW_B, proportion of piglets with BW_B above 1.35 kg, proportion of growth-restricted piglets (defined as BW_B below 1.0 kg), $SatO_2$ and HR were determined in 2,292 newborn piglets from 166 litters. Colostrum consumption of each individual piglets and the colostral concentration of IgG was determined. The milk yield between 0 – 7 and 7 – 21 days and relative backfat loss were estimated in each individual sow. The piglet mortality and body weight was determined at 7 and 21 days of life. On average, the NBA was 12.4. The proportion of stillborn piglets, piglets with BW_B above 1.35 kg and growth-restricted piglets were 6.9%, 62.7% and 14.0%, respectively. The PWM7 and PWM21 were 8.5% and 12.4%, respectively. Compared to the ALA group, ARG-0.5 increased the proportion of live-born piglets per litter (+9.8%, $P < 0.001$), reduced stillborn (-8.3%, $P < 0.001$) and tended to increase the proportion of piglets with BW_B

above 1.35 kg (+6.4%, P = 0.08). Compared to the CON group, ARG-0.5 increased BW_B (+7.0%, P < 0.001), increased $SatO_2$ (+3%, P < 0.001) and reduced HR (-20%, P < 0.001) and tended to reduce the relative backfat loss (-4.4%, P = 0.06). No difference between ARG-1.0 and ARG-0.5 was observed among these traits. Other traits including within-litter variation of BW_B, growth-restricted piglets, ADG, piglets preweaning mortality, colostrum consumption and milk yield were not affected by treatment (P > 0.05). The colostral concentration of IgG at one h after onset of farrowing in ARG-1.0 sows (116 mg/mL) was higher than CON, ARG-0.5 and ALA sows (85, 74 and 78 mg/mL, respectively; P < 0.05). In conclusions, dietary *L*-arginine HCl supplementation in late gestating sows favourably increased proportion of live-born piglets, BW_B, $SatO_2$ and IgG concentration in the sow colostrum.

8.2 Introduction

Piglet BW_B is one of the most important factors determining piglet preweaning mortality as low BW_B piglets have a higher risk of mortality than high BW_B piglets (Nuntapaitoon and Tummaruk, 2015; Muns et al., 2016). The use of high prolific sows in swine industry worldwide results in an increased number of piglets with intrauterine growth restriction (Amdi et al., 2013). Fetal growth restriction is a consequence of inadequate blood supply and undersupply of nutrients among fetuses within the uterus (Père and Etienne, 2000). As a consequence, the proportion of small piglets at birth and within-litter variation of BW_B are increased.

Arginine is an important amino acid for protein synthesis and it is a component of tissue growth (Wu et al., 1999). In addition, arginine is the precursor for nitric oxide and polyamine synthesis (Wu and Morris, 1998). Nitric oxide and polyamines are important for angiogenesis and embryogenesis. Thus, arginine enhances the growth of the placenta, fetal development and mammary gland proliferation (Reynolds and Redmer, 2001; Wu et al., 2004a; Kim and Wu, 2009). Studies have demonstrated that 1.0% *L*-arginine HCl supplementation during 30 to 114 days of gestation in both sows (Mateo et al., 2008) and gilts (Che et al., 2013) enhances their reproductive performances, *i.e.*, NBA and litter birth weight. Furthermore, arginine can improve immune response as indicated by an increased level of serum immunoglobulin in sows (Che et al., 2013).

Quesnel et al. (2014) demonstrated that supplementation of *L*-arginine HCl during the last third of gestation reduced the within-litter variation of BW_B. Indeed, placenta development occurs from 20 to 70 days and the fetuses grow rapidly from 70 to 114 days of gestation (Bazer and Johnson, 2014). We hypothesized that *L*-arginine HCl supplementation in late gestating sows may increase BW_B, decrease within-litter variation of BW_B and increase colostrum consumption of the piglets. It is currently unknown whether *L*-arginine HCl supplementation improves BW_B, neonatal piglet survival and piglet daily gain during lactation. The present study aims to determine the effect of *L*-arginine HCl supplementation in the sow diet during late gestation on the piglet characteristics at birth, colostrum consumption, concentration of IgG in colostrum, milk yield, ADG during lactation and piglet preweaning mortality.

8.3 Materials and methods

8.3.1 Animals and general management

The experiment followed the guidelines documented in The Ethical Principles and Guidelines for the Use of Animals for Scientific Purposes edited by the National Research Council of Thailand, and was approved by the Institutional Animal Care and Use Committee (IACUC) in accordance with the university regulations and policies governing the care and use of experimental animals (Approval number 1431063).

The present study was carried out in a commercial swine herd in the western part of Thailand between May and August 2015. There were 3,500 productive sows in the herd. The breed of the sows was LY F1 crossbred and the parity numbers of sows were parity one (n = 64), 2 – 3 (n = 37), 4 – 5 (n = 24) and 6 – 9 (n = 22). The average ambient temperature during the experimental period ranged from 28.8 °C to 30.7 °C. The minimum and maximum temperature ranged from 25.0 °C to 25.8 °C and from 34.6 °C to 37.5 °C, respectively. The average relative humidity varied from 71.0% to 76.0%. Sows were kept in individual crates (1.2 m^2) during gestation in a conventional open-housing system equipped with fans and water sprinklers to reduce the impact of high ambient temperature. During gestation, sows were fed a commercial gestation diet to meet or exceed the nutritional requirements (NRC, 2012). Feed was provided twice a day following a standardised feeding pattern, resulting in an average of 2.5 kg of feed per sow per day. The animals received water *ad libitum* in a continuous feed and water channel. During lactation, sows were fed twice a day with a commercial lactation diet to meet or exceed their nutritional requirements (NRC, 2012), increasing the daily amount of feed offered according to LS and body condition of the sow, until *ad libitum* was reached after one week of lactation. Composition and nutrient contents of the gestation and lactation diets are presented in Table 30. The sows received routine vaccinations, *i.e.,* classical swine fever, foot and mouth disease, porcine parvovirus, Aujeszky's disease and porcine reproductive and respiratory syndrome.

Pregnant sows were moved to the farrowing house about one week before their expected farrowing date. Sows were kept in individual farrowing crates (1.2 m^2) placed at the centre of the pens with a total space allowance of 4.2 m^2. The pens were fully slatted with concrete at the centre for sows and with steel slats at both sides of the farrowing crate for piglets. Each pen was provided with a creep area for piglets (0.60 m^2) placed on the floor on one side, covered by a plastic plate without any heating source. The parturition process was supervised. The sows were interfered with as little as possible during parturition, and birth intervention was performed only when dystocia was clearly identified. Routine procedures performed on piglets included weighing, tail docking, tooth clipping and one mL (200 mg) iron supplement administered intramuscularly (Gleptosil®, Alstoe Ltd. Animal Health, Leicestershire, England) on the first day of life and male piglets were castrated on day five of age. Piglets were orally administered a coccidiocide (Baycox®, Bayer Pharma AG, Berlin, Germany). Lactation length was 23.0 ± 2.0 days.

Table 30 Composition and nutrient levels of diets (On average, sow fed 2.5 and 6.0 kg/d in gestating and lactating period, respectively)

Items	Gestation diet, g/kg	Lactation diet, g/kg
Ingredients		
Soybean meal	180	220
Broken rice	430	400
Rice bran	280	120
Rice brans solvent meal	80	-
Steamed beans meal	-	100
L-Lysine HCl (99.0%)	0.5	0.7
DL-Methionine (99.0%)	0.05	0.2
L-Threonine (99.0%)	-	0.7
L-Valine (98.5%)	-	0.2
L-Tryptophan (99.0%)	-	0.2
Salt	4	3
Limestone	25	7
$CaHPO_4$	-	22
$Ca(H_2PO_4)_2$	4	-
Milk	-	150
Analyzed composition		
Dry matter (%)	93.8	94.1
Crude protein (%)	19.7	23.7
Metabolizable energy (KJ/kg)	3,475	3,811

8.3.2 Experimental design

In total, 166 sows were allocated into four groups, *i.e*., CON (n = 66), ARG-0.5 (n = 42), ARG-1.0 (n = 41) and ALA (n = 17). The sows in each group were fed with a conventional gestation diet (CON) and the same diet supplemented with 0.5% *L*-arginine HCl (ARG-0.5), 1.0% *L*-arginine HCl (ARG-1.0) and 1.7% *L*-alanine (ALA, isonitrogenous with ARG-1.0), respectively. The feeding protocol were carried out from 85 days of gestation until farrowing. The *L*-arginine HCl and *L*-alanine (Ajinomoto Inc., Tokyo, Japan) were fed to the sows as a top dressing.

Piglet characteristics at birth including the proportion of live-born and stillborn piglets, BW_B, within-litter variation of BW_B, proportion of growth-restricted piglets, $SatO_2$ and HR were determined in 2,232 newborn piglets. Colostrum consumption of each individual piglets was determined. Concentration of IgG in the sow colostrum at one and six h after farrowing was measured. The piglet body weight was recorded at 7 and 21 days, the ADG7 and ADG21 calculated, and the piglet mortality determined at 7 and 21 days of life. Milk yields of each individual sow was estimated at d 0 – 7 and 0 – 21 after farrowing (Hansen et al., 2012).

8.3.3 Sow and piglet data

The following reproductive variables of the sows were recorded: farrowing duration, NTB, NBA, SB, MM, number of piglet weaned per litter, backfat thickness before farrowing and at weaning. All piglets were individually identified by ear tattoo. Body weight of the piglets was measured at birth and at 24 h of life in order to estimate colostrum consumption of each individual piglet (see below). The body weight of the piglets was measured again at 7 and 21 days of lactation. At birth, the proportion of BW_B above 1.35 kg and the proportion of growth restricted piglets were determined. The "growth-restricted piglet" was defined as the piglets with a BW_B below 10^{th} percentiles of NBA (D'Inca et al., 2010), corresponding to a threshold of 1.0 kg. Within 5 min after birth, the piglets were monitored for HR and $SatO_2$ at the left ear by veterinary pulse oximetry using a neonatal probe (EDAN VE-H100B Pulse Oximeter, Edan Instrument Inc®, CA, USA). Piglet mortality was recorded at 7 and 21 days of lactation. Total mortality was defined as the number of stillborn piglets plus the preweaning piglet mortality until 21 days.

The individual colostrum consumption of piglets was estimated from their BW_B, weight gain during the colostrum period and time (in minutes) each piglet was able to suckle colostrum. The colostrum consumption was estimated according to a recently published prediction equation (Theil et al., 2014a): Colostrum consumption (g) = -106 + 2.26WG + $200BW_B$ + 0.111D - 1,414WG/D + $0.0182WG/BW_B$; where WG = weight gain (g), BW_B = birth weight (kg), D = duration of colostrum suckling (min). The sum of colostrum consumption of all piglets within a litter was defined as the colostrum yield of the sow. The sow milk yield was estimated from LS and weight gain at d 0 – 7 and 0 – 21 after farrowing. The sow milk yield was estimated according to a recently published prediction equation (Hansen et al., 2012). The backfat thickness of the sows were measured at the level of the last rib at about 6 to 8 mm from midline using A-mode ultrasonography (Renco Lean-Meater®, Minneapolis, MN., USA.). The backfat measurement was performed in each sow at farrowing and at weaning. Backfat loss is defined as the difference between backfat thickness at farrowing and at weaning in each sow. The relative loss of backfat (%) is defined as the backfat loss (mm) divided by backfat thickness at farrowing and multiplied by 100.

8.3.4 Collection of colostrum and determination of immunoglobulin G

The colostrum samples were collected manually around one and six h after onset of parturition from all functional mammary glands. Colostrum samples from all teat were pooled, kept in a clean bottle (30 mL) and were stored at 4 °C on ice in a foam box during collection process. Colostrum was centrifuged at 15,000 ×g for 20 min at 4 °C (Centrifuge 5810 R, Eppendorf AG, Hamburg, Germany). The fat was discarded and the remaining liquid were collected. Thereafter, the liquid part was diluted 1: 500,000 with sample conjugate diluent (50 mM Tris buffer, 0.14 M NaCl, 1% BSA and 0.05% Tween 20). Immunoglobulin G was determined by using ELISA (ELISA Quantitation Kit, Bethyl Laboratories Inc., Texas, USA). Briefly, 100 µl of anti-IgG antibody was added into each well and incubated at room temperature (25 °C) for 60 min and washed five times with washing buffer (50 mM Tris buffer, 0.14 M NaCl and 0.05% Tween 20). After that, a 200 µl of blocking solution (50 mM Tris buffer, 0.14 M NaCl and 1% BSA) was added into each well and incubated at room temperature (25 °C) for 30 min and washed five times with the washing buffer. Thereafter, a 100 µl of standard solution or colostrum sample were added into each well and incubated at room temperature (25 °C) for 60 min and washed five times with washing buffer. The concentrations of IgG in the standard solutions were 500.0, 250.0, 125.0, 62.5, 31.25, 15.6 and 7.8 ng/mL. All the samples were analyzed in duplicates. After that, a 100 µl of the horseradish peroxidase and antibody were added. The plates were incubated for 60 min at room temperature and were washed five times with the washing buffer. A 100 µl of TMB substrate solution was added into each well and incubated in the dark at room temperature. After 15 min, the colorimetric reaction produced a blue product, which turned yellow when the reaction was terminated by adding 100 µl of 0.18 M sulfuric acid. The absorbance was recorded at 450 nm using ELISA plate reader (Tecan Sunrise™, Männedorf, Switzerland). The IgG concentration in the colostrum samples were quantified by interpolating their absorbance from the standard curve generated in parallel with the colostrum samples. The inter- and intra-assays coefficient of variation were 2.6% and 2.2%, respectively.

8.3.5 Statistical analyses

All statistical analyses were performed using SAS 9.0 (SAS Inst. Inc., Cary, NC). Descriptive analysis and frequency tables were conducted for continuous and categorical data, respectively. Continuous dependent variables of sows including NTB, NBA, litter birth weight, within-litter variation of BW_B, relative backfat loss, colostrum yield, concentration of IgG in colostrum and milk yield at 0 – 7 and 0 – 21 days after farrowing were analyzed by using the general linear models (GLM) procedure of SAS. In the IgG concentration model, treatment (CON, ARG-0.5, ARG-1.0 and ALA) and collecting time (one and six h) and interaction between treatment and collecting time were included as fixed effect.

Variables of piglets including BW_B, $SatO_2$, HR, colostrum consumption, ADG7 and ADG21 were analyzed by using General Linear Mixed Model (MIXED) procedure of SAS. In all the models, parity number of sows (1, 2 – 3, 4 – 5, 6 – 9), treatment (CON, ARG-0.5, ARG-1.0 and ALA) and interaction between parity and treatment were included as fixed effects. Sow ID was added in the statistical model as a random effect. Binomial traits including NBA, SB, PWM7, PWM21, total mortality, proportion of piglets with BW_B above 1.35 kg and growth-restricted piglet (proportion of piglets weighing less than 1.0 kg) were analyzed by using logistic regression analysis (PROC GENMOD of SAS). In all the models, treatment (CON, ARG-0.5, ARG-1.0 and ALA) were included as fixed effect. Least-squares means were obtained from statistical models and were compared by Tukey-Kramer test. Values with $P < 0.05$ were regarded as statistically significant.

8.4 Results

8.4.1 Descriptive statistics

Descriptive statistics, including means, standard error and range of sow reproductive performance traits are presented in Table 31. On average, NTB and NBA were 13.7 ± 0.3 and 12.4 ± 0.2, respectively. The average milk yield between 0 – 7 and 7 – 21 days were 6.3 and 7.8 kg/d, respectively. The proportion of stillborn piglet, proportion of piglets with BW_B above 1.35 kg and proportion of growth-restricted piglets were 6.9%, 62.7% and 14.0%, respectively. The average BW_B, $SatO_2$, HR and colostrum consumption were 1.45 ± 0.01 kg, 91 ± 0.2%, 69 ± 1.0 bpm and 433 ± 3.0 g, respectively. Piglet with colostrum consumption greater than 400 g was 55.6%. On average, PWM7 and PWM21 were 8.5% and 12.4%, respectively. Individual ADG7 and ADG21 was 144 ± 1.0 and 179 ± 1.0 g/day, respectively.

Table 31 Descriptive statistics of sow and piglet performance

Variables	Means ± S.E.M.	Range
Sows (n = 166)		
Gestation length, d	114.8 ± 0.1	112 – 119
Parity number	3.0 ± 0.2	1 – 9
Bacfat thickness before farrowing, mm	14.5 ± 0.2	6 – 24.5
Bacfat thickness after farrowing, mm	12.3 ± 0.2	5 – 19
Farrowing time, min	238 ± 11	75 – 1,093
Total number of piglet born/ litter	13.7 ± 0.3	4 – 23
Number of piglets born alive/ litter	12.4 ± 0.2	3 – 18
Litter size[1]	12.8 ± 0.2	10 – 19
Number of weaned piglets/litter	11.4 ± 0.2	4 – 16
Colostrum yield, kg	5.2 ± 0.1	1.4 – 8.0
Immunoglobulin G concentration, mg/mL	76.5 ± 2.7	25.5 – 146.3
Milk yield between 0 – 7 days, kg	44.2 ± 0.5	30.0 – 57.8
Milk yield between 7 – 21 days, kg	163.1 ± 2.0	96.7 – 223.2
Average milk yield between 0 – 7 days, kg/d	6.3 ± 0.1	4.3 – 8.3
Average milk yield between 7 – 21 days, kg/d	7.8 ± 0.1	4.6 – 10.6
Piglets (n = 2,292)		
Birth weight, kg	1.45 ± 0.01	0.44 – 2.77
Blood oxygen saturation, %	91 ± 0.2	29 – 100
Heart rate, bpm	69 ± 1.0	27 – 299
Colostrum consumption, g	433 ± 3	51 – 1,117
ADG7, g/d	143 ± 1	0 – 384
ADG21, g/d	179 ± 1	11 – 385

[1]Litter size = number of piglets after cross-fostering

8.4.2 Sow characteristics

The relative backfat loss in ARG-1.0 sows (11.8%) was lower than CON (16.9%, $P=0.019$) but did not differ in ARG-0.5 (12.6%) and ALA sows (13.5%; Table 32). No effects of *L*-arginine HCl supplementation on NTB, NBA, litter birth weight, within litter variation of BW_B, colostrum yield, milk yield between 0 – 7 and 7 – 21 days were found (Table 32).

Table 32 Reproductive data of sows (*i.e.*, number of total piglet born per litter (NTB), number of piglet born alive per litter (NBA), litter birth weight, within-litter variation of birth weight (BW_B) , colostrum yield, average milk yield between 0 – 7 and 7 – 21 days and relative backfat loss by treatment groups (least-squares means)

Variables	CON	ARG-0.5	ARG-1.0	ALA	RMSE[1]	*P* value
Number of sows	66	42	41	17		
NTB	13.5	13.1	14.4	14.2	3.34	0.28
NBA	12.3	12.2	13.2	11.8	2.90	0.23
Litter birth weight	19.0	19.3	20.1	19.8	4.21	0.57
Within-litter variation of BW_B	20.4	18.4	19.7	19.7	6.52	0.50
Colostrum yield	5.2	5.3	5.4	4.9	1.26	0.60
Average milk yield between 0 – 7 days	6.2	6.4	6.4	6.3	0.82	0.87
Average milk yield between 7 – 21 days	8.1	7.6	7.6	7.6	1.08	0.16
Relative back fat loss	16.9^{a}	12.6^{ab}	11.8^{b}	13.5^{ab}	14.2	0.014

[1]RMSE: root-mean-square error

$^{a, b}$ Different superscript letters within rows indicate significant difference ($P < 0.05$)

The proportion of stillborn piglet per litter in CON (6.6%), ARG-0.5 (5.3%) and ARG-1.0 sows (4.9%) was lower than that observed for ALA sows (13.6%, $P < 0.001$; Table 33). In contrast, no effect of dietary treatments on the proportion of mummified fetuses per litter was found ($P > 0.05$).

Table 33 Effect of dietary treatment on the proportion of live-born piglet per litter (BA%), the proportion of stillborn piglet per litter (SB%), the proportion of mummified fetus per litter (MM%), piglet preweaning mortality during 0 – 7 (PWM7) and 0 – 21 days (PWM21) and total mortality

Variables	CON	ARG-0.5	ARG-1.0	ALA	*P* value
BA%	90.6[a]	92.7[a]	91.4[a]	82.6[b]	< 0.001
	(88.5 – 92.3)	(90.3 – 94.6)	(88.8 – 93.4)	(77.3 – 86.9)	
SB%	6.6[b]	5.3[b]	4.9[b]	13.6[a]	< 0.001
	(5.2 – 8.4)	(3.7 – 7.5)	(3.4 – 7.0)	(9.9 – 18.6)	
MM%	2.8	2.0	3.7	3.7	0.30
	(1.9 – 4.1)	(1.1 – 3.6)	(2.5 – 5.6)	(1.9 – 7.0)	
PWM7, %	7.4	7.0	10.7	10.5	0.07
	(5.8 – 9.4)	(5.1 – 9.6)	(8.4 – 13.6)	(6.0 – 15.6)	
PWM21, %	11.1	11.5	14.8	14.0	0.19
	(9.1 – 13.5)	(9.0 – 14.6)	(12.0 – 18.0)	(9.8 – 19.5)	
Total	18.1[b]	16.1[b]	18.9[b]	26.2[a]	0.01
mortality,%	(15.7 – 20.8)	(13.2 – 19.4)	(15.9 – 22.4)	(20.9 – 32.2)	

[1] Data was analyzed by the GENMOD procedure to account for binomially distributed data and hence the 95% lower and upper confidence limits are presented in parenthesis

[a, b] Different superscript letters within rows indicate significant difference (*P* < 0.05)

The proportion of piglets with BW_B above 1.35 kg were highest in ARG-0.5 sows (67.1%), lowest in CON sows (59.7%, *P* = 0.005) with ALA sows (60.7%) and ARG-1.0 sows (64.0%) being intermediate (Figure 26). No effect of dietary treatment on the number of growth-restricted piglets was found (*P* > 0.05; Figure 27).

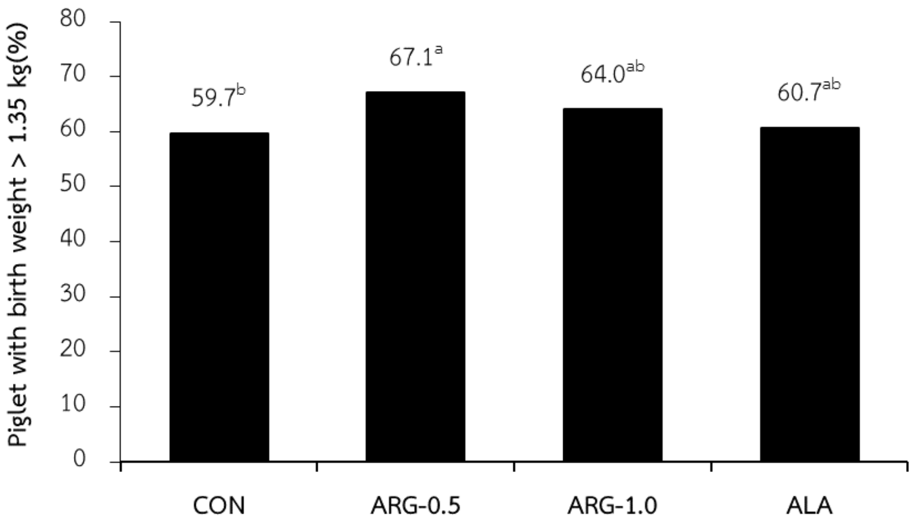

Figure 26 Proportion of the piglet birth weight (kg) above 1.35 kg by treatment groups, *i.e.*, CON, ARG-0.5, ARG-1.0 and ALA

Different superscript letters within rows indicate significant difference ($P < 0.05$)

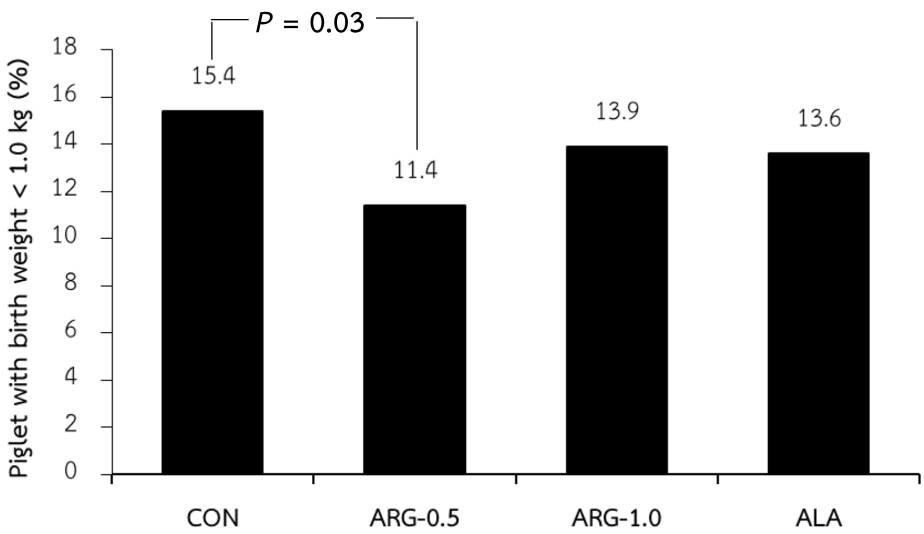

Figure 27 Treatment effect on the proportion of growth-restricted piglets (birth weight below 1.0 kg) per litter by treatment groups, *i.e.*, CON, ARG-0.5, ARG-1.0 and ALA

Piglet preweaning mortality at 7 days of lactation in the CON (7.4%) and ARG-0.5 sows (7.0%) tended to be lower than for ARG-1.0 sows (10.7%) and for ALA fed sows (10.5%, *P* = 0.07). At 21 days of age, the preweaning mortality was still approximately 3.0%-units higher in ARG-1.0 (14.8%) and ALA sows (14.0%) as compared with CON (11.1%) and ARG-0.5 sows (11.5%), although the difference was not statistically significant (*P* = 0.19). Total piglet mortality in ARG-0.5 sows (16.9%) was lower than ALA sows (26.2%, *P* = 0.001) with CON sows (18.1%) and ARG-1.0 sows (18.9%) being intermediate (Table 33).

8.4.3 Piglets characteristics

On average, BW_B in ARG-0.5 sows (1.53 kg) was higher than CON sows (1.43 kg, $P < 0.001$) and ALA sows (1.45 kg, $P = 0.02$), but did not differ compared with ARG-1.0 (1.48 kg, $P > 0.05$). Piglets from ARG-0.5 sows had higher $SatO_2$ (91%) than CON sows (88%, $P < 0.001$), but lower than piglets from ALA sows (93%, $P = 0.01$) and did not differ compared to ARG-1.0 (92%, $P > 0.05$; Table 34). Heart rate in ARG-0.5 sows (66 bpm) was lower than CON sows (83 bpm, $P < 0.001$) but did not differ from ARG-1.0 and ALA sows (66 bpm and 58 bpm, respectively; $P > 0.05$). The ADG7 and ADG21 did not differ among the treatments ($P > 0.05$; Table 34).

Table 34 Effect of treatment on piglet performances (*i.e.*, piglet birth weight, blood oxygen saturation, heart rate, colostrum consumption and average daily gain at 7 and 21 days of life) (least-squares means)

Variables	CON	ARG-0.5	ARG-1.0	ALA	*P* value
Number of piglets	905	553	592	242	
Piglet birth weight, kg	1.43^{b}	1.53^{a}	1.48^{ab}	1.45^{b}	0.001
Blood oxygen saturation, %	88^{c}	91^{b}	92^{ab}	93^{a}	< 0.001
Heart rate, bpm	83^{a}	66^{b}	66^{b}	58^{b}	< 0.001
Colostrum consumption, g	437	448	451	452	0.32
ADG7, g/d	150	145	148	157	0.18
ADG21, g/d	190	185	186	186	0.09

Different superscript letters within rows indicate significant difference ($P < 0.05$)

8.4.4 Colostrum yield, colostrum consumption, immunoglobulin G concentrations in colostrum and milk yield

No effect of dietary treatment on colostrum yield, colostrum consumption and milk yield was found ($P > 0.05$). The concentrations of IgG in the colostrum at one h after onset of farrowing in ARG-1.0 sows (116 mg/mL) was higher than CON, ARG-0.5 and ALA sows (85, 74 and 78 mg/mL, respectively; $P < 0.05$; Figure 28). At six h, the concentration of IgG in ARG-1.0 sows (81 mg/mL) did not differ from CON, ARG-0.5, and ALA sows (80, 61 and 60 mg/mL, respectively; $P > 0.05$).

8.5. Discussion

This study was carried out with high prolific sows which on average gave birth to 13.7 total born and 12.4 live-born piglets per litter. The percentage of stillborn piglets averaged 6.6% and sows weaned 11.4 piglets per litter.

8.5.1 Dietary impact on foetal development

The fetal growth is rapid during the last trimester of gestation in sows (Bazer and Johnson, 2014) and hence it is likely that sow nutrition during this period is important for fetal growth and development. During the last decade, several studies reported that *L*-arginine HCl supplementation during gestation increased sow and piglet performances. Arginine improve piglet BW_B and within-litter variation of BW_B (Mateo et al., 2008; Berard et al., 2010; Gao et al., 2012; Quesnel et al., 2014). Moreover, the NBA was increase in supplemented sows (Mateo et al., 2008; Berard et al., 2010; Gao et al., 2012; Che et al., 2013). The mode of action is believed to be due to the fact that arginine is the precursor for nitric oxide and polyamine, which are key factors for angiogenesis of the placenta and embryo/ fetal development (Reynolds and Redmer, 2001; Wu et al., 2004a).

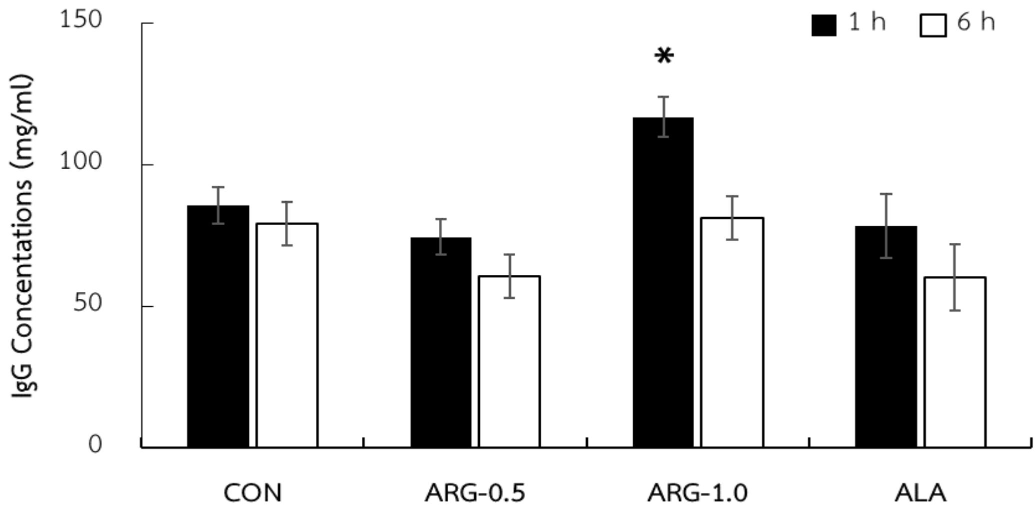

Figure 28 Immunoglobulin G concentration at 1 and 6 h after onset of farrowing by treatment groups, *i.e*., CON, ARG-0.5, ARG-1.0 and ALA

* indicate significant difference among the diets at 1 h ($P < 0.05$)

High piglet BW_B is important to reduce the piglet mortality during suckling period (Roehe and Kalm, 2000; Chris et al., 2012; Nuntapaitoon and Tummaruk, 2015). Piglet BW_B is positively related with piglet ability to thermoregulate, and to their vitality and colostrum consumption (Muns et al., 2016). Studies reported that dietary *L*-arginine HCl supplementation increases the piglet BW_B and reduces within-litter variation (Berard et al., 2010; Gao et al., 2012; Che et al., 2013). In the current study, *L*-arginine HCl supplementation during the last trimester of gestation increased piglet BW_B by 100 g (6.5%) in sows fed 0.5% *L*-arginine HCl as compared with control sows. Piglets from sows fed 1.0% had an intermediate BW_B while those born from sows fed alanine were comparable to control piglets. This suggests that *L*-arginine HCl supplementation in sow diet during late gestation increased the placental blood flow and thereby enhanced fetal development. In contrast to a previous study, which reported that supplementation of *L*-arginine HCl during the last third of pregnancy reduced within-litter variation of BW_B (Quesnel et al., 2014), we found no dietary impact on within-litter variation of BW_B.

In the present study we defined growth-restricted piglets as those being born with a weight below 1.0 kg, which amounted to 14.0% of all piglets. Growth-resticted piglets have been shown to have insufficient colostrum consumption, an elevated risk of mortality and low growth rate (Wu et al., 2006; Amdi et al., 2013). The high incidence of low BW_B piglets likely reflects IUGR (Wu et al., 2008). The supplementation of 0.5% *L*-arginine HCl reduced the proportion of growth-restricted piglet in current study and increased the proportion of piglets with BW_B above 1.35 kg. These dietary effects may likely be brought about by an increased placental blood flow, which then allowed more nutrients and oxygen to be transferred across the placenta. High BW_B of piglets is advantageous for their survival rate during the suckling period, as shown by Panzardi et al. (Panzardi et al., 2013). Thus, the present study indicates that 0.5% dietary *L*-Arginine HCl supplementation during late gestation may be an effective approach to increase the proportion of piglets with a BW_B above 1.35 kg and reduce the proportion of growth-restricted piglets with BW_B below 1.0 kg.

8.5.2 Dietary impact on farrowing process

The proportion of stillborn piglets was lowest in sows fed *L*-arginine HCl or the control diet (4.9 to 6.6%) whereas it was doubled (13.6%) in sows supplemented with alanine. Hypoxia in newborn piglets may cause death before, during or start of the birth process. Arginine plays an important role to regulate placental-fetal blood flow, which affects nutrients and oxygen transfer to the fetuses via umbilical cord (Wu and Meininger, 2000; Bird et al., 2003). In line with this, we found that $SatO_2$ was increased in sows supplemented with *L*-arginine HCl during gestation and the low frequency of stillborn piglets from sows supplemented with *L*-arginine HCl may be explained by an increased uterine blood flow, which in turn likely delivered more oxygen and nutrients for the uterus during intensely labour. However, other mechanisms may likely also be involved as this can only explain why the frequency of stillborn was low in arginine supplemented sows. In contrast, the proposed mechanism cannot explain why control sows had a low frequency of stillborn piglets and why alanine supplemented sows had a high frequency of stillborn piglets, as the observed $SatO_2$ in the sows were lowest in control fed sows and highest in alanine fed sows. The frequency of stillborn piglet is associated with genetic-, maternal-, piglet related and environmental factors (Vanderhaeghe et al., 2013). Among the piglet related factors, low BW_B has been reported to increase the proportion of stillborn piglets (Cozler et al., 2002) and another study reported that low BW_B piglets have small umbilical cords, which may be more susceptible to umbilical rupture during uterine contractions (Curtis, 1974). However, the piglet BW_B in the present study was lowest in piglets from sows fed control and alanine diets and the BW_B seems not to be a plausible explanation for the low frequency observed in control sows or the high frequency observed in alanine fed sows. The HR of newborn piglets was higher when born from sows fed the control diet as compared with the three other diets. It is at present unclear why, and deserves further attention in the future, but it seemed not to be associated with the observed rate of stillbirth.

8.5.3 Dietary impact on preweaning mortality and colostrum production

The piglet preweaning mortality tended to be three percent units higher when sows were fed 1.0% arginine or alanine as compared with 0.5% arginine or control diet. At 21 days of lactation, the piglet mortality showed the same pattern, although it should be stressed that the preweaning mortality from birth to 21 days of lactation only differed numerically (P = 0.19). On average, 50 – 80% of the piglet's mortality occurs during 0 – 7 days after birth (Shankar et al., 2009) from low viability, crushing and disease (Vaillancourt et al., 1990), and this is in line with the observations in the present study (61 to 75%). The elevated preweaning mortality in litters from sows fed 1.0% arginine or alanine may be associated with the numerically higher NTB observed for 1.0% arginine fed sows and maybe farrowing problems for the alanine fed sows as suggested by the high incidence of stillborn piglets. It should be noted that most piglets die within the first two to three days (Koketsu et al., 2006) and within that period some piglets are cross-fostered to other sows. Thus, some litters receive cross-fostered piglets whereas others do not. Consequently, it is indeed very difficult to design an experiment that specifically aims at evaluating the short-term survival during the first critical days after parturition.

A high colostrum consumption is important to ensure piglet survival during the first critical days after birth. Quesnel and coworkers (2012) reported that the piglet mortality was around or less than 10% if the colostrum consumption exceeded 200 g, whereas the piglet mortality exceeded 60% if the colostrum consumption was below 100 g. Nuntapaitoon et al. (2015) found a similar pattern under tropical conditions. Increasing the colostrum production by dietary means may be a way to increase the colostrum consumption above a critical threshold. However, no differences were observed in the present study among the four dietary groups. In line with that, addition of 25 g arginine per day was also not found to increase the colostrum consumption of piglets or colostrum yield of sows in a recent study (Krogh et al., 2016a). Colostrum consumption is limited by piglet BW_B and vitality at birth (Quesnel et al., 2012; Amdi et al., 2013; Nuntapaitoon and Tummaruk, 2015; Declerck et al., 2016). Colostrum consumption has been shown to relate with many factors such as LS, piglet vitality, piglet BW_B, piglet birth order and physiological parameters such as RT24h and time elapsed from birth until their first attempt to stand (Devillers et al., 2007; Quesnel et al., 2012). Recently it was shown that the colostrum consumption was limited by the intake capacity of piglets (Krogh, 2016) when sows gave birth to less than 15 liveborn piglets, whereas the sow became a limiting factor for litters larger than 15 piglets, and may explain why no differences were observed in the present study. Potential ways to increase colostrum consumption should be clarified because a high colostrum intake is a major determinant of piglet survival and it is expected that the sow colostrum yield will be a limiting factor in the near future due to selection of large litters.

Concentration of IgG in colostrum is associated with concentration of IgG in sows and in piglets and consequently affects survival of piglet (Kielland et al., 2015). Arginine regulates nitric oxide synthesis, which stimulates T cell receptor expression, T-lymphocyte proliferation and B cell development (Li et al., 2007). Previous studies have shown that dietary *L*-arginine HCl supplementation in gestating sows increased serum IgG in sow (Che et al., 2013), and increased concentrations of nutrients and IGF-1 in the colostrum (Krogh et al., 2016a). In line with these findings, the present study showed that *L*-arginine HCl increased IgG level in colostrum in supplemented sows.

Therefore, *L*-arginine HCl supplementation in gestating sows may be advantageous for enchancing piglet immune status and in turn the piglet survival.

8.5.4 Dietary impact on lactation performance

Lactation performance of sows influences piglet growth and survival. Quality and quantity of colostrum and milk are crucial for piglets in this period. Arginine is the precursor for the synthesis of nitric oxide and a recent study showed that arginine may increase the mammary plasma flow by 30% (Krogh et al., 2017) although it did not increase the milk production (Krogh et al., 2016a). As the mammary gland is a modified sweat gland, it was interesting to investigate the impact of dietary arginine on sow performance under tropical conditions. However, no differences in milk production were observed, neither during the first 7 days of lactation, nor from 7 to 21 days. The daily piglet gain was approximately 50 to 60 g lower as compared with piglets from a similar study carried out under temperate condition (Krogh et al., 2016a), caused by a considerably higher milk production of sows in the latter study. These observations suggest that sow milk yield is rather low in Thailand and it is likely explained by the low feed intake of sows due to tropical temperatures.

Piglet mortality is highly correlated with piglet BW_B and piglet viability (Nuntapaitoon and Tummaruk, 2015; Muns et al., 2016). A positive effect of piglet BW_B on preweaning survival has been observed (Nuntapaitoon and Tummaruk, 2015). In the present study, *L*-arginine HCl supplemented sows had higher proportion of piglet BW_B above 1.35 kg and fewer growth-restricted piglet than other groups. A tendency of reduced piglet mortality at the first 7 days of life was found in this group but mortality of piglet at 21 days after birth was not statistically different. It was previously shown that *L*-arginine HCl supplementation during late gestation is ineffective to reduce long-term piglet mortality. Moreover, the concentrations of *L*-arginine HCl in the sow milk were much lower than other amino acids in all days of lactation (Krogh et al., 2017). Therefore, *L*-arginine HCl transfer from mother to offspring may be insufficient for supporting proper daily gain of the piglets.

Lactating sows are catabolic because their feed intake is insufficient to cover their nutrient requirements and therefore body fat and body protein are mobilized to support nutrient for milk production. The mobilisation of body protein and fat was not detected in the present study but the relative backfat loss indicate that body fat was indeed mobilized. The change in backfat (~2 mm) of sows in tropical climate in the present study was comparable to the back fat loss observed in high-producing Danish sows with a much higher milk production (mean 12 to 13 kg/d) than sows in the present study. These observations strongly suggest that feed intake is the limiting factor for sow productivity. In the present study arginine decreased the relative back fat mobilization as compared with the control group. Milk production is positively associated with body mobilization (Strathe et al., 2016) and this dietary effect may suggest that arginine indeed is detrimental to sow milk production in tropical climate, which is supported by the numerically lower milk yield found for sows fed arginine.

8.6. Conclusions

Dietary *L*-arginine HCl supplementation in late gestating sow increased proportion of live-born piglets, increased piglet BW_B and piglet $SatO_2$ at birth, and enhanced IgG concentration in the sow colostrum but sow milk production was not enhanced.

Chapter IX

General discussion and conclusion

This is the first report on piglet preweaning mortality in swine commercial herds in Thailand. The thesis addressed some factors influencing piglet mortality in tropical climate and dietary supplementation in gestating sow for reducing piglet preweaning mortality during lactation. The present work review some current knowledge concerning important non-infectious causes of piglet preweaning mortality focusing on the main factors found under commercial conditions. Furthermore, the study aims to highlight the most common management interventions performed around farrowing and their impact on piglet preweaning mortality. In Chapter III and IV, study some sow, piglet and environmental factors which may be responsible for piglet mortality during lactation in a commercial swine herd were studied. Moreover, we studied effect of herd size on piglet preweaning mortality in 47 commercial swine herds in Thailand (Chapter V). Piglet factors influenced their mortality and performance were demonstrated in Chapter VI; we also studied the real impact of newborn traits on colostrum consumption and production and its relation with survival and growth (Chapter VII). Finally, we have tried to improve piglet characteristics and immunoglobulin in sow colostrum by supplementing in gestating sows that can contribute to decision-making in commercial swine herds (Chapter VIII).

9.1 Factor influencing piglet preweaning mortality in tropical climate

Differentiation of genetic, management and climate among commercial swine herd worldwide affected piglet mortality and performance before weaning. For instance, in cool climate, heat sources are most necessary in newborn piglets because of low ambient temperature, especially in winter/ or cool season. On the other hand, in tropical climate, heat stress in farrowing sow was indicated influenced farrowing process and subsequence impaired piglet survival. Therefore, factor influencing on piglet preweaning mortality in each region in the world should be observed. Factor influencing in cool climate were revealed in many studies (Koketsu et al., 2006; Odehnalova et al., 2008; Li et al., 2010). Nonetheless, no comprehensive study on piglet preweaning mortality in tropical climate was reported. Accordingly, this thesis was presented for improving piglet performance in lactation period. From our retrospective studies, many data were collected from many farms which located in different part of Thailand. These data represent swine population in Thailand as tropical climate. More than 199,918 litters from 74,088 sows were included in present study. Therefore, factors influencing piglet preweaning mortality were analyzed from these data, which is a well-expressed population. From this study, factor influencing piglet preweaning was shown in Figure 29.

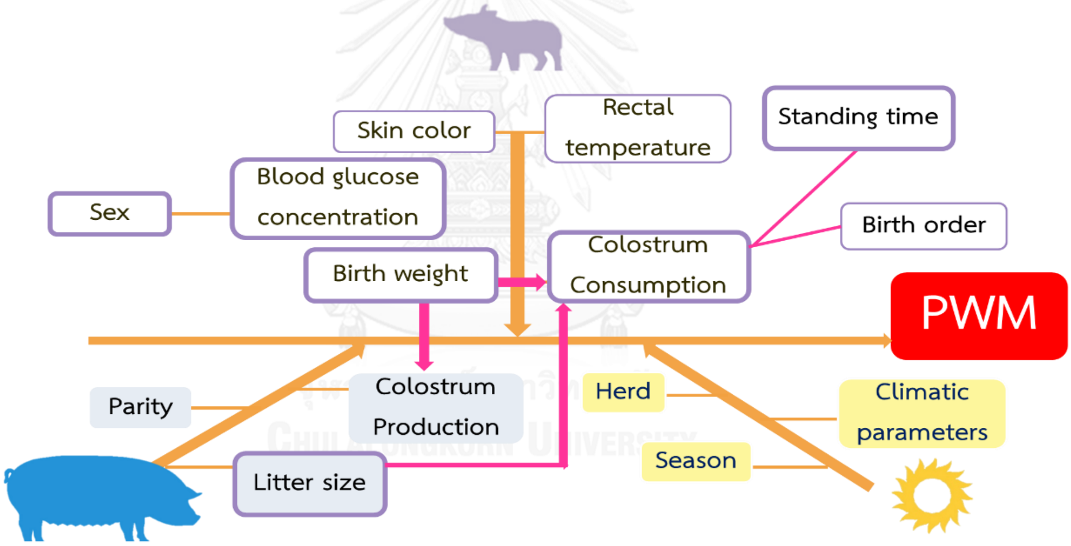

Figure 29 Factor influencing piglet preweaning mortality in tropical climate

9.1.1 Piglet

Piglet factor is most importance for piglet survival both cool and tropical climate. Our retrospective and cohort studies confirmed that BW_B is a crucial role of piglet mortality (Chapter III, V, VI and VII) as accordance with many previous studies (Roehe and Kalm, 2000; Tuchscherer et al., 2000; Le Dividich et al., 2005). Moreover, piglet BW_B influenced colostrum consumption and substantially RT24h, mortality and growth in lactation period in present study. We found that low BW_B piglets consumed 1.6 time less colostrum than high BW_B piglets (Chapter VII). Furthermore, piglet with high colostrum consumption had high RT24h and low preweaning mortality (Chapter VII). The relationship between piglet BW_B, colostrum consumption, RT24h and piglet preweaning mortality was described that low BW_B piglets have longer time to reach the teat and first suckle (Le Dividich et al., 2005), thus those piglets have low colostrum consumption. Colostrum promotes maintenance of body temperature which show high rectal temperature in piglet after consumed colostrum. It is implied that high RT24h indicated adequate colostrum consumption in piglets for survival and growth (Panzardi et al., 2013; Pedersen et al., 2015). Furthermore, other newborn traits are significant parameters at birth on piglet growth. Chapter VI demonstrated that blood glucose concentration predicts growth performance. In agreement with previous study reported that glucose level related with growth performance and piglet BW_B before birth (Roehe and Kalm, 2000). However, piglet factors influenced piglet mortality and growth did not improve those factors after piglet born. Management strategies in farrowing house to improve piglet preweaning mortality are crucial technique in piglets that have low BW_B, low blood glucose concentration, low RT24h, high standing time or pale skin colour. Farrowing supervising protocols were investigated in many studies. The objective of studies aims to ensure a proper level of colostrum consumption by the piglets. Moreover, Therefore, special care in neonatal piglet in farrowing time should be emphasized, especially in low piglet $BW_{B,}$ low blood glucose concentration, low RT24h, high standing time or pale skin colour.

9.1.2 Sow

Sow parity number is important factor influencing piglet mortality which were reported in many studies (Knol et al., 2002; Koketsu et al., 2006; Li et al., 2010; Carney-Hinkle et al., 2013; Muns et al., 2015) There are contradictory because of different conditions and breed of studies sows. In our study, sow parity number 1 and more than 6 have higher piglet preweaning mortality than sow parity number 2 – 5 in all farm. Moreover, we found that piglet preweaning mortality in each sow parity number wase related other factors (*i.e.,* the number of littermate pigs, BW_B, climatic parameters and herd size) (Chapter III, IV and V). Therefore, it is difficult to confirm that tendency of sow parity number on piglet preweaning mortality.

Most of hyperprolific sows were reared in commercial swine farms worldwide including Thailand. Piglet preweaning mortality rate remains crucial problem. In present study found that number of littermate pigs was associated with piglet preweaning mortality (Chapter III and V). The litter with more than 13 littermate pigs had two times more mortality than the litter with less than 10 littermate pigs (Chapter III). Prolonged farrowing time in large LS affected both sows and piglets. In sow, long time of farrowing duration increases health problem of sow in lactation period (Malmkvist et al., 2012; Tummaruk and Sang-Gassanee, 2013). In piglet, prolonged farrowing time may increase degrees of asphyxia in piglet and subsequently detrimented suckling behavior of piglet.

9.1.3 Environment

High ambient temperature and high relative humidity is general condition in tropical climate (*i.e.,* Thailand). Data from meteorological station were analyzed in present study. No effect of season on piglet preweaning mortality was observed (Chapter IV) because of a few differentiations of temperature in this area. Cimatic parameters were performed in many previous studies on sow performance in Thailand (Tummaruk et al., 2004; Suriyasomboon et al., 2006). However, no comprehensive study on piglet preweaning mortality were reported. Relationship between sow parity and climatic parameters was shown in our studies (Chapter IV), it was indicated that effect of temperature and humidity on piglet preweaning mortality was higher influence sows than piglets, especially in first 7 days after birth. High temperature induces stressful condition in sows. On the other hand, high temperature is benefit in piglets. Stress sow have inappropriate nest-buliding behavior, farrowing process and lactating performance (Jarvis et al., 1997; Peltoniemi and Oliviero, 2015). Moreover, these situations were increase in large herd size (Chapter V). Housing, facilities and quality of stockpersons should be concerned in large size herd. Intensive husbandry in animal production influence the nature and frequency of human-sow relationship

(Muns and Tummaruk, 2016a). Furthermore, sow per person ratio in herds is crucial keys for reducing piglet mortality.

9.2 Management strategies for improving piglet survival and growth

Sufficient colostrum consumption is keyword for detrimenting piglet preweaning mortality. Improving piglet BW_B increased colostrum consumption, reduced piglet mortality and increased growth performance (Chapter VII). Increasing piglet BW_B and increasing mammary gland development in sow must be performed in prenatal period. Feed restriction in gestating sow may provide insufficient energy supplied and lead to decrease piglet growth and colostrum production. Effect of arginine supplementation on piglet BW_B and mammary gland development was reported (Gao et al., 2012; Che et al., 2013; Krogh et al., 2017). In present study, arginine improved foetal development, farrowing process, piglet and sow performance (Chapter VIII). Although, arginine supplementation in last third of gestating sow increase piglet BW_B by 100 g (6.5%), no effect on piglet mortality, colostrum and milk production was observed. Therefore, other strategies after farrowing should be collaborated for reducing piglet mortality.

In peri- and post-partum period, increasing piglet mortality and the colostrum consumption of individual piglets should be performed in the first day after birth. Risk piglet (*i.e.,* low BW_B, low blood glucose concentration, high standing time and late-born piglet) must be helped from stock person. Muns and Tummaruk (2016a) reviewed strategies in farrowing house to reduce piglet mortality and increase growth performance. It is demonstrated that oral supplement, farrowing supervision, cross-fostering, creep feeding and human-animal interaction improve piglet survival. Recent study reported that energy supplementation in low BW_B piglet increased their survival and improved their IGF-I or IgG levels during lactation (Muns et al., 2017). Moreover, supportive treatment in some sows improves health of sow and reducing piglet mortality (Tummaruk, 2013). In farm conditions, however, the assessment of preweaning deaths strongly depends on the farmer’s skills and observations. Cross-fostering has a strong impact on piglet survival and performance (Muns et al., 2014b).

The cross-fostering strategies were reported in many studies (Milligan et al., 2001; Deen and Bilkei, 2004; Kilbride et al., 2014; Muns et al., 2014b). We recommended that number of littermate pigs was below 13 piglets per litter (Chapter III). The litters with more than 13 littermate pigs and with the BW_B below 1.3 kg, old sows and large herd size should be emphasized.

In general, the optimum temperature in sow is 22 °C whereas the lower critical temperature of newborn piglet is 34 °C (Herpin et al., 2002; Bloemhof et al., 2008). High differentiation of optimal temperature between sow and piglet in farrowing pen is difficult management for reduced piglet preweaning mortality. Furthermore, daily fluctuations in ambient temperature and other climatic parameters could not control, especially in tropical environment condition. Therefore, it has no absolute strategies to reduce piglet preweaning mortality in the open-housing system. Consequently, the proper housing of pregnant sows should be emphasized, especially in gilts. We suggest that reducing piglet mortality strategies should be concern both piglet, sow and environmental factors.

9.3 Conclusions

Base on the results of our studies and their interpretation we have obtained the following conclusions:

- On average, piglet preweaning mortality was 11.2% – 14.5% with a median of 10.0% and varied among herds from 4.8% to 19.2% under commercial swine herds in the tropic
- A 49.1% and 21.6% had a piglet preweaning mortality rate of 0 – 10% and 11 – 20%, respectively.
- Piglet BW_B is most importance factors influencing piglet preweaning mortality and individual colostrum consumption

- High NBA, low BW_B and low RT24h, compromise piglet colostrum consumption, survival and growth during the lactation period.
- Piglet in the litters with a high NBA and piglets with low BW_B and/or low blood glucose concentration had low ADG during suckling period.
- The influence of temperature and humidity on preweaning mortality was more importance in the primiparous during 0 – 7 days postpartum.
- Piglet preweaning mortality in large size herds was higher than small and medium size herds.
- *L*-arginine increased NBA (+9.8%), increased BW_B (+7.0%), increased $SatO_2$ (+3%) and reduced stillborn (-8.3%)
- *L*-arginine tended to increase the proportion of piglets with BW_B above 1.35 kg (+6.4%)
- *L*- arginine reduced the backfat loss of sows and increased colostrum concentration of IgG
- Low BW_B piglets are not recommended to be reared by old sows.
- Management actions performed the first day after birth aimed at increasing the colostrum consumption of individual piglets could substantially increase piglet colostrum consumption and reduce mortality.
- Management strategies for reducing piglet preweaning mortality in tropical climate should be emphasized in the litters with more than 13 littermate pigs and with the BW_B below 1.3 kg, old sows and large herd size.

9.4 Research limitations

In chapter V, data were collected from small and medium herd size which did not record the number of cross-fostering piglet. Therefore, analyzed data in this chapter were use the number of piglet born alive per litter instead of the number of littermate pigs. In difference with Chapter III and IV, analyzed data were collected from a commercial swine farm which high quality of recorded reproductive data in this farm. In chapter III-V, herd health, housing, genetics and parturition management which we did not measured, could lead to biased results in the current study. However, the present research provides valuable information on the pattern of piglet preweaning mortality for swine veterinarians and producers to apply to their practices. In chapter Vi and VII, data of newborn traits were collected in another farm in chapter III to V. Moreover, in this farm, a few farrowing supervision and no heat source for helped newborn piglet were included in this study. Differential strategies in farrowing pens should be concerned. Blood oxygen saturation and blood glucose concentration were measured by portable instrument. Although these techniques are convenient and noninvasive, precise results should be concern. In Chapter VIII, *L*-arginine supplementation in late gestating sow were done in different period. Unfortunately, infectious diseases as diarrhea in piglet and circovirus in sows occur during study in arginine supplementation trail. From our results in this chapter, arginine improves BW_B but did not related ADG until weaning.

9.5 Suggestions for further investigations

Blood oxygen saturation and blood glucose concentration should be measured by high precise instruments. Effect of dietary *L*-arginine supplementation should be measure in molecular biology to confirm that arginine improves VEGF, eNOS or others for increasing blood flow in umbilical cord. Moreover, relationship between size of umbilical vessel, umbilical blood flow and BW_B should be further investigate. Relationship between body mobilization and colostrum and milk production have been elucidated, especially in tropical climate. Therefore, understanding insight of factor influencing piglet preweaning mortality in tropical climate and management strategies for reduced piglet mortality in tropical climate should be further investigated.

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APPENDIX

List of publications and conferences

1. **Nuntapaitoon, M.** and Tummaruk, P., 2015. Piglets pre–weaning mortality in a commercial swine herd in Thailand. **Tropical Animal Health and Production.** 47, 1539–1546. Impact factor 0.870
2. Muns, R., **Nuntapaitoon, M.** and Tummaruk, P. 2016. Non–infectious causes of preweaning mortality in piglets. **Livestock Science.** 184, 46–57. Impact factor 1.509
3. Muns, R., **Nuntapaitoon, M.** and Tummaruk, P. 2017. Effect of oral supplementation with different energy boosters in newborn piglets on pre–weaning mortality, growth and serological levels of IGF–I and IgG. **Journal of Animal Science.** 95, 353–360. Impact factor 2.014
4. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2017. Newborn traits associated with preweaning growth and survival in piglets. **Asian-Australasian Journal of Animal Sciences.** (Major revision) Impact factor 0.756
5. **Nuntapaitoon, M.**, Muns, R., Theil, P.K. and Tummaruk, P. 2017. Factors influencing colostrum consumption of piglets and their relationship with survival and growth in tropical climates. **Livestock Science.** (Major revision) Impact factor 1.509
6. **Nuntapaitoon, M.**, Muns, R., Theil, P.K. and Tummaruk, P. 2017. *L*-arginine supplementation in sow diet during late gestation decrease proportion of stillborn piglets and increases piglet birth weight and immunoglobulin G content of colostrum. **Theriogenelogy**. (Submitted) Impact factor 1.838
7. **Nuntapaitoon, M.** and Tummaruk, P. 2016. Factors influencing piglet preweaning mortality in 47 swine commercial herds in Thailand. **Tropical Animal Health and Production.** (Submitted) Impact factor 0.807
8. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2017. Influences of climatic parameters on piglet preweaning mortality in the tropics. **Tropical Animal Health and Production.** (Submitted) Impact factor 0.807

9. **Nuntapaitoon, M.** and Tummaruk, P. 2012. Factors associated with piglet mortality in a conventional open-housed system swine herd in Thailand, Proceeding of the **Genetic Improvement of Livestock and Aquatic Animal in the Tropics** (GILAAT), Bangkok, Thailand, August 24th, 2012. P. 35. (Oral presentation)
10. **Nuntapaitoon, M.** and Tummaruk, P. 2012. Factors influencing percentage of stillborn piglets in a swine commercial herd in Thailand, Proceeding of the **Genetic Improvement of Livestock and Aquatic Animal in the Tropics** (GILAAT), Bangkok, Thailand, August 24th, 2012. P.67. (Poster presentation)
11. **Nuntapaitoon, M.** and Tummaruk, P. 2013. Effect of herd size, season and sow's parity number on piglet pre-weaning mortality in Thailand, Proceeding of the 38th **International Conference on Veterinary Science** (ICVS), Nonthaburi, January 16th–18th, 2013. P.322–324. (Poster presentation)
12. **Nuntapaitoon, M.** and Tummaruk, P. 2013. Piglets pre–weaning mortality rate in a commercial swine herd in Thailand in relation to season, number of litter mates, sow's parity number and piglet's birth weight. Proceeding of the 51st **Kasetsart University Annual Conference**, Bangkok, Thailand, February 5th–7th, 2013. (Oral presentation)
13. **Nuntapaitoon, M.** and Tummaruk, P. 2013. Individual piglet's colostrum intake and colostrum yield in tropical sows. Proceeding of the 6th **Asian Pig Veterinary Society Congress** (APVS), Ho chi minh city, Vietnam, September 23rd–25th, 2013. PO112. (Poster presentation)
14. **Nuntapaitoon, M.** and Tummaruk, P. 2013. Factors influencing individual piglet's colostrum intake. Proceeding of the 6th **Asian Pig Veterinary Society Congress** (APVS), Ho chi minh city, Vietnam, September 23rd–25th, 2013. PO113. (Poster presentation)
15. Tummaruk, P. and **Nuntapaitoon, M.** 2013. Effect of sow's parity number on colostrum yield and individual piglet's colostrum intake. Proceeding of the 6th **Asian Pig Veterinary Society Congress** (APVS), Ho chi minh city, Vietnam, September 23rd–25th, 2013. PO114. (Poster presentation)

16. **Nuntapaitoon, M.** and Tummaruk, P. 2014. Effect of blood glucose concentration on colostrum intake in newborn piglets. Proceeding of the 2nd **Symposium of the Thai Society for Animal Reproduction** (TSAR), Bangkok, Thailand, March 20th–21st, 2014, Thai Journal Veterinary Medicine. 44 (Suppl. 1), 157–158. (Poster presentation)
17. **Nuntapaitoon, M.** and Tummaruk, P. 2014. Neonatal piglet survival associated with blood glucose concentration. Proceeding of the 2nd **Symposium of the Thai Society for Animal Reproduction** (TSAR), Bangkok, Thailand, March 20th–21st, 2014, Thai Journal Veterinary Medicine. 44 (Suppl. 1), 159–160. (Poster presentation)
18. Nuntapaitoon, M. and Tummaruk, P. 2014. Effect of birth intervals on blood oxygen concentration of newborn piglets. Proceeding of the 13rd **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, May 12nd–14th, 2014, P.67–68. (Poster presentation)
19. Nuntapaitoon, M., Choonnasard, A., Prayoonwiwat, N., Wuttiwongtanakorn, P., Vichitvanichpong, S. and Tummaruk, P. 2014. Factors associated with colostrum intake in neonatal piglets. Proceeding of the 23rd **International Pig Veterinary Society Congress**, Cancun (IPVS), Mexico, June 8th–11st, 2014. P.213. (Poster presentation)

20. Tummaruk, P., Nuntapaitoon, M., Choonnasard, A., Prayoonwiwat, N., Wuttiwongtanakorn, P., Vichitvanichpong, S. and Vetchapitak, T. 2014. Effect of induced parturition on the incidences of umbilical rupture, blood oxygen saturation, blood glucose concentration and colostrum intake in neonatal piglets. Proceeding of the 23rd **International Pig Veterinary Society Congress** (IPVS), Cancun, Mexico, June 8th–11st, 2014. P.214. (Poster presentation)
21. Nuntapaitoon, M., Em–on Olanratmanee and Tummaruk, P. 2014. Factors associated with individual colostrum consumption of neonatal piglets under field conditions. Proceeding of the 11st **Annual Meeting of Asian Reproductive Biotechnology Society** (ARBS), Bangkok, Thailand, November 3rd–5th, 2014, P.66. (Poster presentation)

22. **Nuntapaitoon, M.** and Tummaruk, P. 2014. Piglet's colostrum intake associated with daily weight gain and pre-weaning mortality. Proceeding of the 39th **International Conference on Veterinary Science** (ICVS), Nonthaburi, December 16th–18th, 2014, P.52. (Poster presentation)
23. Pearodwong, P., **Nuntapaitoon, M.** and Tummaruk, P. 2014. The association between sperm qualities assessed by CASA and conventional semen evaluations. Proceeding of the 39th **International Conference on Veterinary Science** (ICVS), Nonthaburi, December 16th– 18th, 2014, P. 54. (Poster presentation)
24. Pearodwong, P., **Nuntapaitoon, M.** and Tummaruk, P. 2014. Can CASA Predict Longevity of Extended Boar Semen? Proceeding of the 39th **International Conference on Veterinary Science** (ICVS), Nonthaburi, December 16th– 18th, 2014, P.58. (Poster presentation)
25. Kasuwan, P., Nonthasri, L., Khunpolwattana, S., Sripromkun, A., Nuntapaitoon, M., Ngarmkum, S. and Tummaruk, P. 2015. Effects of micro encapsulated fat filled whey supplementation in the sow diets on milk composition and piglet's growth. Proceeding of the 14th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th– 22nd, 2015, P. 209– 210. (Poster presentation)
26. Nuntapaitoon, M., Muns, R. and Tummaruk, P. 2015. Season influence piglet pre-weaning mortality under tropical climates in different parity number of sows. Proceeding of the 14th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th– 22nd, 2015, P. 263– 264. (Poster presentation)
27. Nuntapaitoon, M., Muns, R. and Tummaruk, P. 2015. Colostrum consumption and newborn traits associated with pre-weaning mortality of piglet under tropical climates. Proceeding of the 14th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th– 22nd, 2015, P. 265– 266. (Poster presentation)
28. **Nuntapaitoon, M.** and Tummaruk, P. 2015. Factor influencing piglet pre-weaning mortality in Thailand. Proceeding of the 1st **Research and Researcher**

Industrial Congress (RRI), Bangkok, Thailand, July 22nd, 2015, P.8. (Oral presentation)

29. Muns, R., **Nuntapaitoon, M.** and Tummaruk, P. 2015. Oral admistration of a fermented potato protein product reduces early pre–weaning mortality in low birth weight piglets. Proceeding of the 7th **Asian Pig Veterinary Society Congress** (APVS), Manila, Philippine, October 25th– 27th, 2015, P.150. (Poster presentation)

30. Nuntapaitoon, M., Muns, R. and Tummaruk, P. 2015. Enhancing Piglet's Birth Weight Using Dietary L– Arginine Supplementation in Multiparous Sows. Proceeding of the 40th **International Conference on Veterinary Science** (ICVS), Nonthaburi, November 11st–13rd, 2015, P.24. (Oral presentation)

31. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Dietary L–Arginine supplementation during late gestation in sows enhance thermoregulatory ability in newborn piglets. Proceeding of the 3rd **Symposium of** the **Thai Society for Animal Reproduction** (TSAR), reproduction, Bangkok, Thailand, January 13rd– 14th, 2016, J. Appli. Anim. Sci. (Suppl.), 2016 9, 25–26. (Poster presentation)

32. **Nuntapaitoon, M.** and Tummaruk, P. 2016. Effect of L– arginine supplementation in the sow's diet during late gestation on number of piglets born alive and birth weight. Proceeding of the 54th **Kasetsart University Annual Conference**, Bangkok, Thailand, February 2nd– 5th, 2016, P. 87. (Poster presentation)

33. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Rectal temperature at 24 hours after birth is associated with piglet pre–weaning mortality. Proceeding of the 15th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th– 22nd, 2016, Thai Journal Veterinary Medicine. 46 (Suppl.), P.183–184. (Poster presentation)

34. Tummaruk, P., Boonnungrod, N., Sutthiya, N., Kumwau, P., Tossakui, P., **Nuntapaitoon, M.** and Muns, R. 2016. Characteristics of stillborn piglets compared to piglets born alive. Proceeding of the 15th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th–22nd,

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36. Jiarpinitnun, P., Sangratkanjanasin, P., Loyawatananan, S., Kumpong, K., **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Effects of carbetocin on farrowing duration and birth interval in newborn piglets. Proceeding of the 15th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th–22nd, 2016, Thai Journal Veterinary Medicine. 46 (Suppl.), P.195–196. (Poster presentation)

37. Boonnungrod, N., Sutthiya, N., Kumwau, P., Tossakui, P., **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Gestation length, farrowing time and neonatal piglet characteristics after induction of parturition by using $PGF_{2\alpha}$ in combination with carbetocin in sows. Proceeding of the 15th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th–22nd, 2016, Thai Journal Veterinary Medicine. 46 (Suppl.), P.199–200. (Poster presentation)

38. Benjangkhaprasert, K., Taemeesupab, C., Wongsirodkul., Maneesiri., P., **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Effect of dietary *L*–arginine supplementation in late gestation sows on number of piglet born alive. Proceeding of the 15th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, April 20th–22nd, 2016, Thai Journal Veterinary Medicine. 46 (Suppl.), P.183–184. (Poster presentation)

39. Tummaruk, P. And **Nuntapaitoon, M.** 2016. Estimation of colostrum consumption of the neonatal piglets in three commercial swine herds in Thailand. The 24th **International Pig Veterinary Society Congress and 8th**

European Symposium of Porcine Health Management (IPVS), Dublin, Ireland, June 7th–10th, 2016, P.115. (Oral presentation)

40. Tummaruk, P., Boonraungrod, N., Sutthiya, N., Koomvan, P., **Nuntapaitoon, M.** and Muns, R. 2016. Control of parturition in sows by using $PGF_{2\alpha}$ in combination with carbetocin. The 24th **International Pig Veterinary Society Congress and 8th European Symposium of Porcine Health Management** (IPVS), Dublin, Ireland, June 7th–10th, 2016, P.381. (Poster presentation)

41. Tummaruk, P. and **Nuntapaitoon, M.** 2016. Induction of parturition by using a single or split–dose of $PGF_{2\alpha}$ in sows. The 24th **International Pig Veterinary Society Congress and 8th European Symposium of Porcine Health Management** (IPVS), Dublin, Ireland, June 7th–10th, 2016, P.392. (Poster presentation)

42. Tummaruk, P. and **Nuntapaitoon, M.** 2016. Colostrum yield in sows after induced parturition by using $PGF_{2\alpha}$. The 24th **International Pig Veterinary Society Congress and 8th European Symposium of Porcine Health Management** (IPVS), Dublin, Ireland, June 7th – 10th, 2016, P.392. (Poster presentation)

43. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Dietary *L*–arginine supplementation during late gestation in sows is associated with their backfat loss during lactation. The 24th **International Pig Veterinary Society Congress and 8th European Symposium of Porcine Health Management** (IPVS), Dublin, Ireland, June 7th–10th, 2016, P.396. (Poster presentation)

44. Muns, R., **Nuntapaitoon, M.** and Tummaruk, P. 2016. Oral supplementation of newborn piglets with Lianol® Colostro to reduce early mortality. The 24th **International Pig Veterinary Society Congress and 8th European Symposium of Porcine Health Management** (IPVS), Dublin, Ireland, June 7th–10th, 2016, P.645. (Poster presentation)

45. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. *L*–arginine supplementation in sow's diet during the last trimester of gestation enhances birth weight and reduces the proportion of small piglets within the litters.

Proceeding of the 18th **International Congress of Animal Reproduction** (ICAR). Tours, France, June 26th–30th, 2016, P.19. (Poster presentation)

46. Tummaruk, P., Nuntapaitoon, M. and Muns, R. 2016. Effect of induced parturition on the incidence of dystocia, proportion of stillborn and colostrum intake in newborn piglets. Proceeding of the 18th **International Congress of Animal Reproduction** (ICAR). Tours, France, June 26th–30th, 2016, P.57–58. (Poster presentation)

47. **Nuntapaitoon, M.** and Tummaruk, P. 2016. Seasonal influence on piglet pre–weaning mortality in swine commercial herds in Thailand with high, moderate and low number of piglets at weaning. Proceeding of **the Reproductive Biotechnology**, Bangkok, Thailand, August 19th, 2016, P. 51. (Poster presentation)

48. **Nuntapaitoon, M.**, Muns, R. and Tummaruk, P. 2016. Influence of piglet's birth weight, sow's parity number, season and herd size on piglet pre–weaning mortality in 46 swine commercial herds in Thailand. Proceeding of the 20th **European Society for Domestic Animal Reproduction** (ESDAR). Lisbon, Portugal, October 27th–29th, 2016. Reproduction of domestic animal. 51 (Suppl. 2), 123. (Poster presentation)

49. **Nuntapaitoon, M.** and Tummaruk, P. 2017. Birth order influences the risk of being stillborn piglet in high prolific sows. Proceeding of the 16th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, March 22nd–24th, 2017, Thai Journal Veterinary Medicine. (Suppl.), P.9–10. (Poster presentation)

50. Tummaruk, P., **Nuntapaitoon, M.** and Muns, R. 2017. Management strategies to reduce piglet preweaning mortality. Proceeding of the 16th **Chulalongkorn University Veterinary Conference** (CUVC), Bangkok, Thailand, March 22nd–24th, 2017, Thai Journal Veterinary Medicine. (Suppl.), S17–S20. (Oral presentation)

VITA

Mrs. Morakot Nuntapaitoon was born on March 5th, 1979 in Bangkok, Thailand. She received the Bachelor's degree (Doctor of Veterinary Medicine, D.V.M.) from the faculty of Veterinary Science, Chulalongkorn University, Thailand in 2003. After graduated, she worked as a production manager in the latest position at FINNOR-ASIA Co., Ltd. for 7 years. That was a great experience about farm management, genetic improvement and semen laboratory in swine farm for her. During 2010-2012, she worked as a product manager at Animal Health Product Co., Ltd. She worked about animal drug registration of the Food and Drug Administration (FDA) and disinfectant registration of the Department of Livestock Development of Thailand (DLD). In 2012, she started a Ph.D. program in Theriogenology at the Department of Obstetrics, Gynaecology and Reproduction, Faculty of Veterinary Science, Chulalongkorn University. She earned a Research and Researchers for Industries (RRI) Ph.D. Scholarship awarded by the Thailand Research Fund under the Office of the Prime minister, Royal Thai government which collaborated with FINNOR-ASIA Co., Ltd. (Code: PHD56I0009) and the 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund). Moreover, she also got an academic scholarship from Huve Pharma Co., Ltd. and Faculty of Veterinary Science, Chulalongkorn University. She got married with Mr. Paiboon Nuntapaitoon in 2009. She has 2 children as boy and girl. All thought the Ph.D. program, she had 3 international publications and 45 proceedings.