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Welfare and management strategies to reduce pre-weaning mortality in piglets

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Certifiquen:

Que la memòria titulada "Welfare and management strategies to reduce pre-weaning mortality in piglets", presentada per Ramon Muns Vila amb la finalitat d'optar al grau de Doctor en Veterinària, ha estat realitzada sota la seva direcció y, considerant-la finalitzada, autoritzen la seva presentació per que sigui jutjada per la comissió corresponent.

I perquè consti als efectes oportuns, firmen la present a Bellaterra, 01 de Maig del 2013

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L'autor va gaudir d'una beca pre-doctoral FI-DGR 2009 de l'Agència de Gestió d'Ajuts Universitaris i de Recerca de la Generalitat de Catalunya per realitzar aquest estudi.

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ABREVATIONS

ADFI: average daily feed intake.

ADG: average daily gain.

BF: back fat

BP: big piglets.

BW: body weight.

COL: orally supplementation with 15 ml of sow colostrum (treatment group).

CON: control group (treatment group).

CV: coefficient of variation

EN: orally supplementation with 3 ml of an energetic product (treatment group).

EU: European Union.

h: hours.

HL: litter standardized by number, with less than 50% of the piglets of the litter being 'small piglets'.

HPA: hypothalamic-pituitary-adrenal axis.

IgG: immunoglobulin G.

LL: litter standardized with most of the piglets of the litter being 'small piglets'.

Lys: lysine.

M: movement capacity.

Min: minutes.

ME: metabolizable energy.

N: number of completed circles around the enclosure.

PEN: gilts loose-housed in pens and slightly overfed during gestation.

r: coefficient of correlation.

R^2: coefficient of determination.

RT: rectal temperature.

S: screaming.

SP: small piglets.

SPLIT: split nursing (treatment group).

STALL: gilts housed in stalls with regular management during gestation.

TH: thyroid hormone.

TRH: tripeptide thyrotropin-releasing hormone.

TSH: thyroid-stimulating hormone.

U: udder stimulation.

"Ben mirat, per parlar de l'essència de les coses sovint només podem fer-ho en termes generals. (...) Com més lluny mirem, més general es fa tot."

Crònica de l'ocell que dóna corda al món (Haruki Murakami)

Chapter 1:

General Introduction

During the last decades, simultaneously with the increasing worldwide demand for high-quality pig meat products, pig production has suffered a great evolution in Europe facing different productive, management and welfare challenges. On one hand, genetic progress has been focussed in high prolific sows and high lean tissue deposition pigs. On the other hand, producers with more knowledge and skills run more technological farms with bigger herds, high pig production flow, and usually in multisite pig production systems; moreover, producers continuously aim their efforts on reducing production costs together with accomplishing consumer's satisfaction. Sow's environment and herd management aspects, such as feeding and health care, have also been improved (Bergsma *et al.*, 2009).

One of the most recent examples of pig production's continuously evolution and production challenges could be the Council Directive 2001/88/EC amending Directive 91/630/EEC Laying Down Minimum Standards for the protection of Pigs in the European Union (EU), which indicates that gestating sows must be kept in groups during a period starting from 4 weeks after the service to 1 week before the expected time of farrowing, replacing the individual stall system widely used. Another example is "The welfare of intensively kept pigs: report of the scientific veterinary committee of the EU" (EUSVC SK. 1997, 30th September), which raises welfare concerns on sows kept in farrowing crates for the whole lactation.

Considering that the average pork consumption in EU was 37 kg per capita in 2009 (Eurostat, 2011), pig production is necessarily preoccupied with the quality of the pig meat and the efficiency of its production. Only in Spain there were 2.4 million productive sows on 2011, 550 thousand productive sows in Catalonia; and 39 million of pigs in Spain and 17 million in Catalonia were slaughtered on 2011 (MAGRAMA, 2012).

Although all the different swine production stages have their importance and all of them are related, sow production cycle can be considered the first limiting step in pig production since it will determine the swine production flow.

It is of great interest to observe how productivity has evolved in the European countries during the last 30 years to satisfy the increasing pork demand. Focusing on breeding herds, it can be seen that the average number of piglets born alive per farrowing, has increased from 9.5 – 10.3 in 1981 up to 11 – 14 piglets in 2011 (Figure 1.1). Such increase has been exponentially, especially from early 1990s, and it presents considerable variability among European countries. However, increase in litter size has been together with a decrease in piglet's birth weight (Quiniou *et al.*, 2002). Accordingly, the average number of piglets weaned per productive sow per year has increased from 8.3 – 9.0 in 1981 up to 9.5 – 12.2 piglets in 2011 (Figure 1.2). Surprisingly, when the average pre-weaning mortality is compared between 1981 and 2011, it results that it has persisted invariably at a high ratio (12.6% in 1981 and 13.3% in 2011). All the improvements achieved in number of piglets weaned are due to increase in sows' prolificacy. From a commercial point of view, reduction in pre-weaning mortality should be an opportunity to improve performance and benefits.

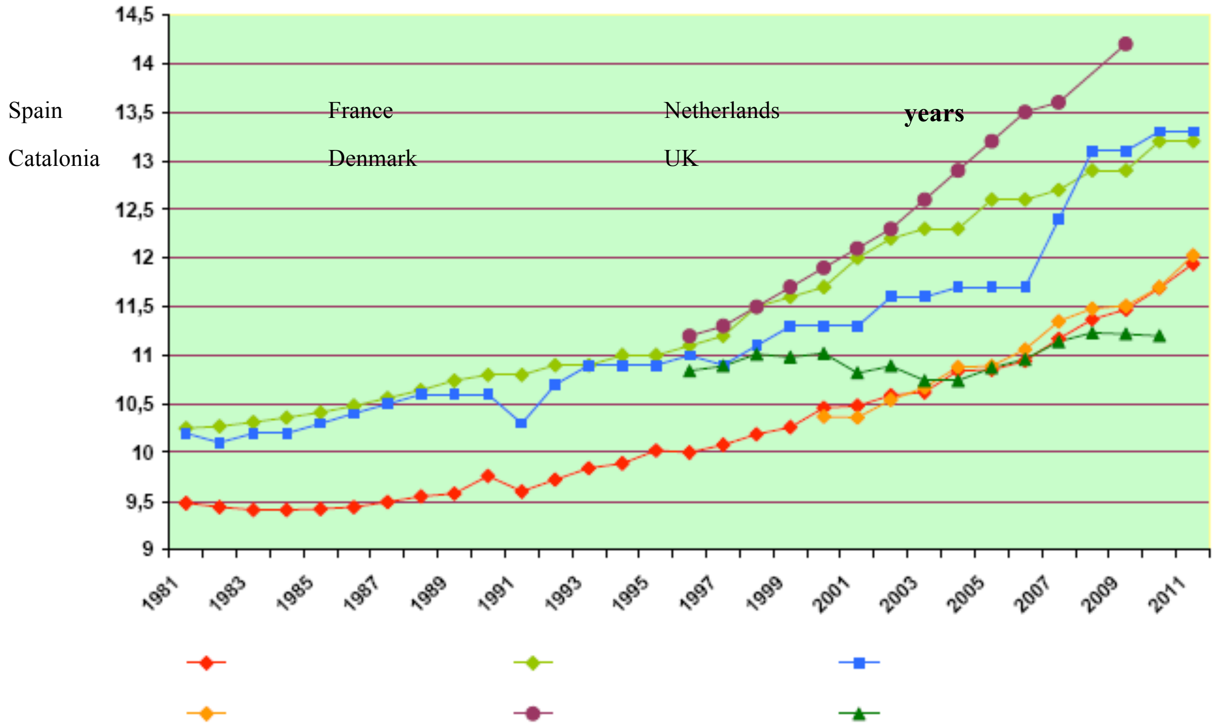

Figure 1.1: evolution of the average number of piglets born alive per farrowing (LB) in Catalonia, Spain, France, Netherlands, Denmark, and UK from year 1981 to 2011 (Observatori del Porcí, 2012).

Lawlor (2004) stated that a 25% increase in piglet survival would have an economic impact on production of 60€ per sow per year in systems with a baseline pre-weaning mortality above 15%; and would have an economic impact on production of 10€ per sow per year in systems with a baseline pre-weaning mortality below 10%. Compared to average piglet mortality below 5% observed during the fattening phase, producers should focus on improving efficiency and welfare during lactation phase to increase their productivity. This situation should also be contemplated as an opportunity for researchers and producers to collaborate studying welfare and management measures to reduce pre-weaning mortality.

Although pre-weaning mortality can be due to infectious and non-infectious causes, management of the farrowing house is the most important aspect in enhancing pre-weaning survival rates (Bandrick *et al.*, 2011). From a scientific point of view, piglet mortality is due to factors related to farm (e.g. modernity of facilities, all-in all-out management, site, colostrum supplementation and cross-fostering system, creep feeding, etc.), to sows (e.g. ease of farrowing, maternal behaviour, etc.), and to piglets (e.g. weight and vigour at birth, etc.)

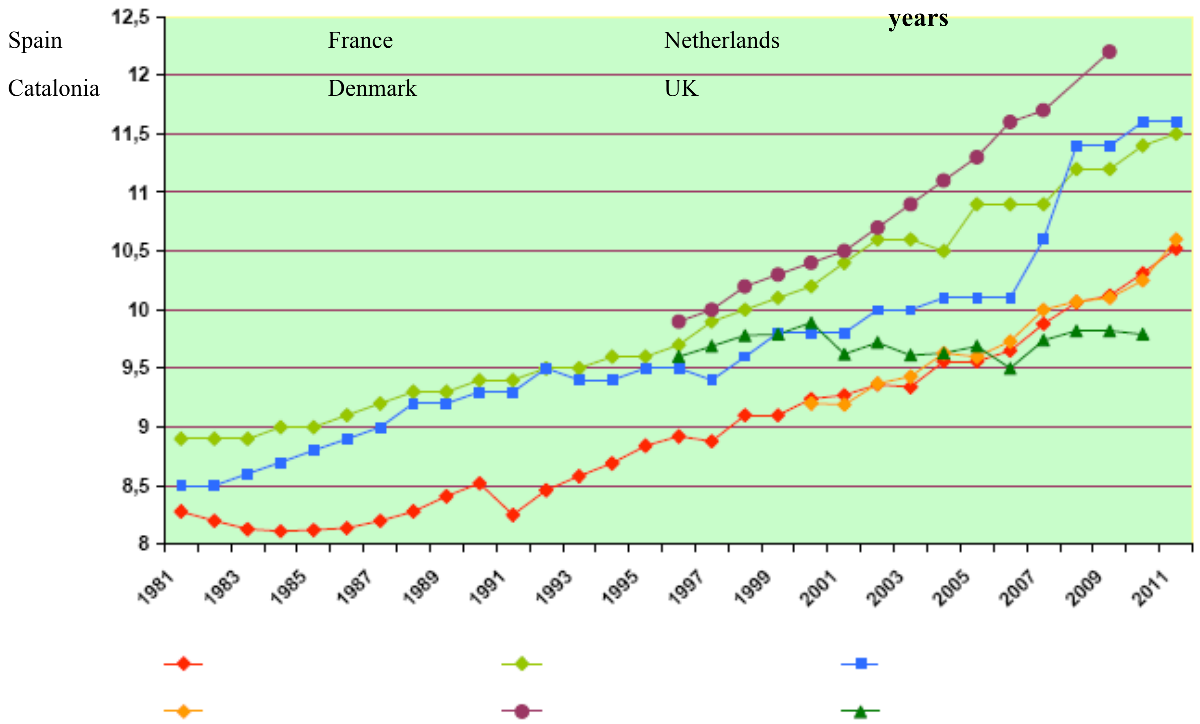

Figure 1.2: evolution of the average number of piglets weaned per farrowing (WF) in Catalonia, Spain, France, Netherlands, Denmark, and UK from year 1981 to 2011 (Observatori del porcí, 2012).

In addition to mortality, piglet's growth performance during lactation is also an important factor for piglet's long-term growth. Increased weaning weight at 20 days of age reduces time to reach final market weight (Cabrera *et al.*, 2010). Besides, differences observed between the lightest and the heaviest piglets at weaning increases during fattening (Quiniou *et al.*, 2002).

In conclusion, improvements in piglet's pre-weaning performance would have a considerable economic impact on the final production chain. On one hand, reduction of pre-weaning mortality would suppose both a welfare improvement and an increase in economic profitability of productive sows; on the other hand, improved weaning weight would enhance efficiency of the fattening period. Through a better analysis of the effects of the individual factors affecting piglet's pre-weaning performance and their possible interactions, general guidelines for breeding herd's assessment could be obtained. From that information, further personalised assessment to farms could become more accurate and effective.

"Hi poden haver els qui no tenen saber i el creen. Jo no sóc d'aquests. Però escoltar molt, triar el millor i seguir-ho, mirar molt i memoritzar-ho, és el grau següent a la saviesa."

Confuci

Chapter 2:

Literature Review

2.1. Pre-weaning mortality

As a polytocous species, such as mice or rabbit, pig has adopted an evolutionary strategy to produce a large number of relatively undeveloped offspring. Such strategy allows the sow to modify maternal investment in accordance with rearing conditions and to produce the optimal number of viable weaned offspring. Thus, some piglet mortality at an early stage can be considered normal for the reproductive biology of the pig (Edwards, 2002), in fact, mortality for wild boar kept in captivity is reported to be around 40% (Andersen *et al.*, 2005). Agriculture has exploited this natural ability to produce a large number of offspring in order to increase the efficiency of pig production (Baxter and Edwards, 2012).

Piglet pre-weaning mortality (considered in this thesis a synonym of postnatal mortality or the proportion of piglets born alive which are not weaned) is a generalized problem among commercial intensive production sow herds in EU (Figure 2.1). European average pre-weaning mortality from the presented countries would result in 12.3%, which approximately accounts for 39 million live-born piglets that die per annum, additionally, number of stillbirths (prenatal mortality) account for a further 8% of total born piglets. It has been pointed out that and increase of 0.5% in pre-weaning mortality reduces output by 10 kg/sow/year (Baxter and Edwards, 2012). As has been noted, pre-weaning piglet mortality represents both a welfare and economic concern.

To address pre-weaning mortality, first is important to differentiate between prenatal and postnatal piglet mortality. Foetal losses (mummies foetuses and stillborn) can vary from 5 to 15%. Pathogenic agents are responsible of around a third part of stillbirths (pre-partum stillbirths or mummies; stillbirths type I). The remaining stillbirths (intra-partum stillbirths; stillbirths type II) are associated with many factors such as parity and body condition of the sow, gestation length, stress around farrowing, dystocia, farrowing length, later birth order, litter size, etc. (Borges *et al.*, 2005; Casellas *et al.*, 2004; Le Cozler *et al.*, 2002; Leenhouwers *et al.*, 1999). A true intra-partum stillborn piglet is a piglet that did not get to breath and that also has the periople still present on the hooves, for that reason, dead piglets having lungs that do not float in water are considered stillbirth (Baxter *et al.*, 2009; Borges *et al.*, 2005; Le Cozler *et al.*, 2002). Improvement in litter size in the recent past years due to the introduction of hyperprolific sows in commercial herds comes together with increased stillbirth rate (Le Cozler *et al.*, 2002). It has been proved that stillbirth risk is higher for litters having more than 12 piglets (Borges *et al.*, 2005). Indeed, heritability of placental efficiency (measured as the ratio of foetal to placental weight) has been higher to that observed for uterine capacity or litter size, leading to allow smaller placentae to maintain relatively larger foetuses (Vallet *et al.*, 2002). Besides, higher odds of stillborns have been observed for distressed sows (Le Cozler *et al.*, 2002), and for sows with prolonged farrowing and with high birth intervals between piglets, especially for old sows with higher parity since they have poorer muscle tone (Borges *et al.*, 2005; Le Cozler *et al.*, 2002; Leenhouwers *et al.*, 1999). However, supervision of farrowing, including assistance to the piglets and to the sow, provides evidence that assistance to farrowing could save piglets which are usually classified as being born dead or stillbirth (Holyoake *et al.*, 1995; Le Cozler *et al.*, 2002; White *et al.*, 1996). Le Colzer *et al.* (2002) suggested that the birthing process may be an important cause of mortality since piglets undoubtedly suffer during that process. Furthermore, damage of the umbilical cord, mostly originated by stretching of the cord during expulsion of the piglet, is usually the final cause of intra-partum stillbirth (Borges *et al.*, 2005).

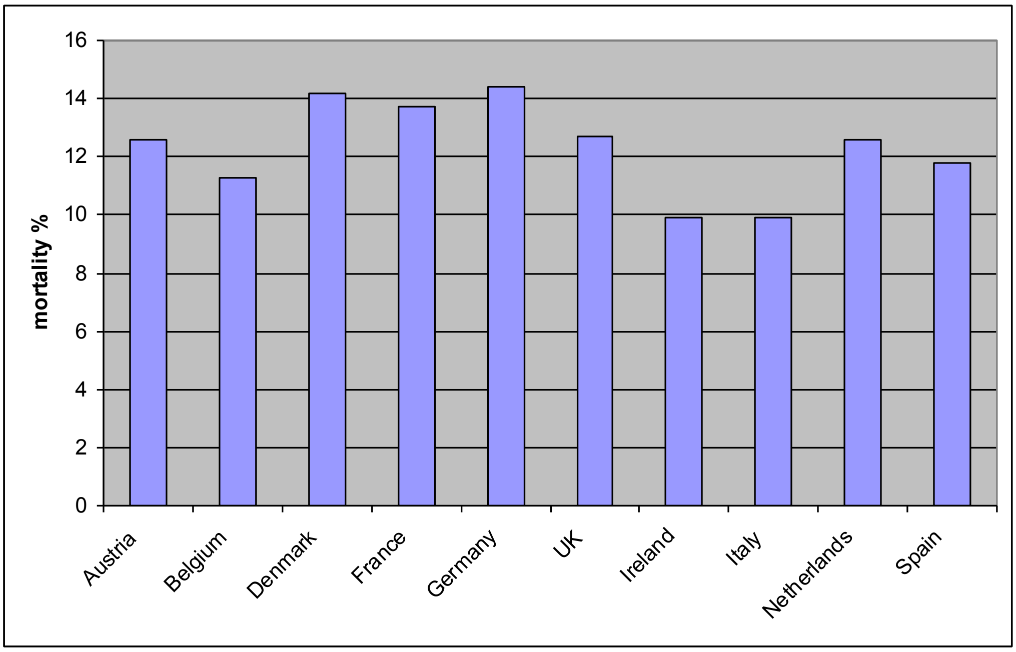

Figure 2.1 Piglet pre-weaning mortality rate in some European countries (Interpig, 2011)

2.1.1. When and how do piglets die?

The second step should be the identification of the causes of mortality, focusing the attention in postnatal pre-weaning mortality. Although there is an agreement about the most important causes of dead for piglets during lactation, we can not disregard some amount of uncertainty about the reliability of farm diagnosis of cause of mortality, being the most common mistakes the incorrect diagnosis of stillbirths and overestimation of crushing (Edwards, 2002). Nevertheless, there is a major consensus of suggesting crushing as the major ultimate cause of dead with chilling and starvation as underlying causes (Alonso-Spilsbury *et al.*, 2007; Edwards, 2002; Herpin *et al.*, 2002).

There are other minor non-infectious causes of dead such as congenital, low viability, or savaging by the sow. Indeed, piglet pre-weaning mortality, especially at early stages, it is considered the outcome of complex interactions between the piglet, the sow and its environment, being crushing the final act in a complex chain of events (Figure 2.2) (Alonso-Spilsbury *et al.*, 2007; Edwards, 2002). In table 2.1 are represented different studies of the last 5 years in which different causes of pre-weaning dead are described. The average pre-weaning mortality from the table is 14.0% (12.2%, excluding the highest value) which is slightly above the mean value of the EU pre-weaning mortality previously presented in the text (12.3%). It is hard to obtain from the bibliography papers recording the different causes of dead during lactation. Nonetheless, according to what has already been said, crushing is the major cause of dead reported for the authors (45.8% of the total pre-weaning mortality).

Despite table 2.1 includes studies with sows and gilts or with sows in farrowing pens and in crates, the data presented underlies some interesting facts. On one hand, there is a wide range from the minimum and the maximum value for the overall postnatal mortality (from 7.9% to 19.1% or 26.6%). On the other hand, differences in the classification of mortality causes and the elevated number of deaths classified as "others", manifest the difficulty of diagnosis and identification of the triggering cause of the dead in field condition.

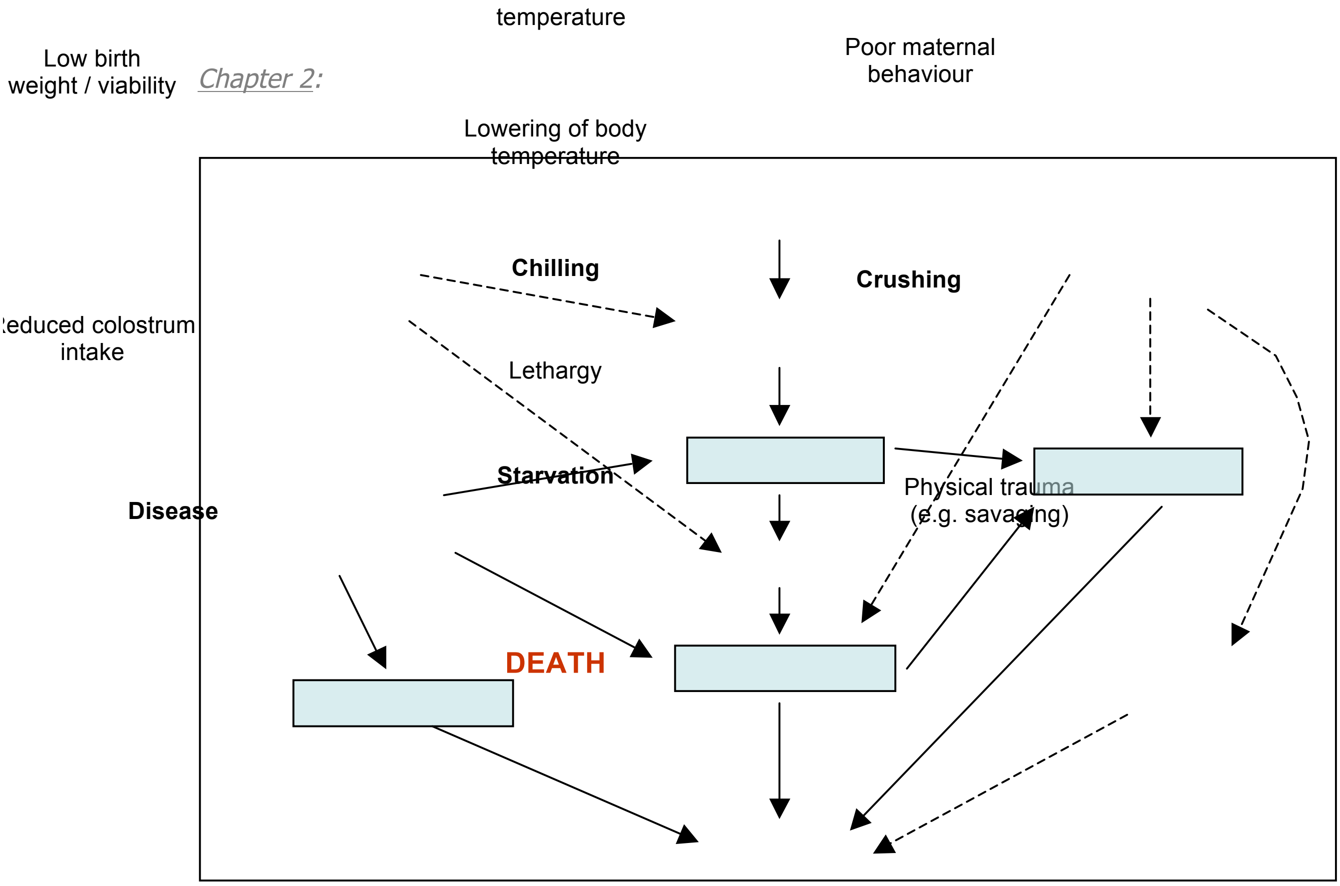

Figure 2.2 Interactions between the piglet, the sow and the environment pre-disposing pre-weaning mortality (Edwards, 2002)

Piglets, born with an average weight of 1.5 kg, have to acquire colostrum from the sow, with an average body weight (BW) of approximately 200 kg, such combination of circumstances makes easy to understand why is crushing the major cause of dead. Farrowing crates were designed to prevent piglet crushing by restricting sow movements and to provide a zone of retreat for the piglets (Andersen *et al.*, 2005; Pedersen *et al.*, 2011a; Wischner *et al.*, 2010); crates were especially designed for preventing posterior crushing (beneath the sow's hind quarters) however, they are not as effective preventing ventral crushing when lying down from sitting position (beneath the udder and rib cage). Any circumstance impairing piglet vigour or any handicap in the environment will make the piglet more prone to be crushed by the sow (Baxter *et al.*, 2008). Equally important, because of the epitheliocorial nature of the placenta in pigs, preventing the transfer of immunoglobulins across the placenta, piglets had low immunocompetence at birth, becoming more susceptible to pathogens leading to death during lactation (Rooke and Bland, 2002). As a result, it is really hard to establish single attributions for piglet mortality, but inadequate colostrum intake might be the main factor triggering early dead in piglets (Casellas *et al.*, 2004; Edwards, 2002; Le Dividich *et al.*, 2005; Quesnel *et al.*, 2012).

Table 2.1 Studies that determined overall pre-weaning mortality differentiating different causes of dead. Incidences of the different causes of dead are referred to the overall pre-weaning mortality.

References	n	Postnatal mortality	Crushing	Starvation or low viability	Dead with no milk in the stomach	Dead with milk in the stomach	Other
Baxter *et al.* (2008)	Sows: 10 Piglets: 129	11.9%	62.5%	18.8%	-	-	18.7%
Baxter *et al.* (2009)[1]	Sows: 38 Piglets: 485	14.3%	57.5%	13.7%	-	-	28.8%
Baxter *et al.* (2011)[1]	Sows: 65 (gilts) Piglets: 757	10.4%	64.5%	14.6%	-	-	20.9%
Baxter *et al.* (2012b)[1]	Sows: 36 Piglets: 478	13.4%	57.8%	14.1%	-	-	28.1%
Panzardi *et al.* (2013)	Sows: 56 Piglets: 648	8.7%	26.4%	20.8%	-	-	52.8%
Pedersen *et al.* (2011a)[2]	Sows: 87 (gilts) Piglets: 1233	19.1%	31.8%	22.5%	-	-	45.7%
Vasdal *et al.* (2011)[1]	Sows: 67 Piglets: 872	7.9%	25.3%	-	49.4%	25.3%	-
Wientjes *et al.* (2012)[1]	137 sow cycles	26.6%	40.2%	18.5%	-	-	41.3%

[1]Sows allocated in loose-housing systems during farrowing (individual pens or paddocks, whether in indoor or outdoor systems)
[2]Compared sows in crates or pens during farrowing, but did only presented mean values (type of housing only influenced the amount of deaths caused by disease, being the penned sows the ones with more mortality due to disease)

Almost 80% of the total piglet pre-weaning mortality occurs during the first week of lactation, with the 50% being concentrated in the first two days of life (Hellbrügge *et al.*, 2008; Rootwelt *et al.*, 2012; Svendsen, 1992), when piglets are more vulnerable.

One singularity of piglet mortality is that it appears to be sex-biased, with males being at greater susceptibility to causal mortality factors mainly associated with energetic demands, Baxter *et al.* (2012b) and Roehe and Kalm, (2000) estimated that odds of pre-weaning mortality in males is 1.7 and 1.5 times higher than in females, respectively. Although it has been described that male piglets are born with higher BW than females (Alonso-Spilsbury *et al.*, 2007; Baxter *et al.*, 2012b; Quesnel *et al.*, 2012), higher survival rate for female piglets have been observed during lactation (Alonso-Spilsbury *et al.*, 2007; Baxter *et al.*, 2012; Roehe and Kalm, 2000). In their study, Baxter *et al.* (2012) suggested that females would be investing energy resources towards specific physiological systems (e.g. thermoregulation and immuno-competence), whereas males would be investing energy resources towards body size and body composition (processes linked with reproductive fitness in adulthood), consequently predisposing male piglets to chilling, becoming more prone to starvation, crushing, and even to disease, thus, reducing their short-term survival.

In conclusion, high variability among farms for piglet pre-weaning mortality and the dilemma identifying the real cause of dead, evidence that it is possible to act and reduce mortality in the farrowing house. Indeed, the main goal for each farm should be the identification of the factor that directly or indirectly acts causing most of the piglet mortality. Multifactorial and high variability nature of mortality should encourage producers, professionals, and veterinarians to improve the knowledge on mortality aetiology and dynamics, and should stimulate to take the correct decisions in the farm.

2.1.2. Factors affecting birth to weaning performance and mortality in the piglets

Adaptation to the extra-uterine environment by the newborn piglet is a problematic process; piglets with small size, have limited body reserves, reduced physiological maturity and are immunologically underdeveloped at birth (Herpin *et al.*, 1993). They have to overcome respiratory, immunological, digestive, and nutritional challenges to survive (Herpin *et al.*, 2002), and also have to cope with a decrease in ambient temperature of 15 – 20 ºC and compete with their siblings for suckling. Non-infectious aetiological factors that intervene in piglet survival are due to interactions between the piglet and its environment, and piglet survival success depends, at a great extend, on factors such as birth BW, vitality, thermoregulation capacity and also on maternal factors in addition to the danger from environmental hazards (Alonso-Spilsbury *et al.*, 2007). Although we are trying to present the most important factors affecting piglet performance and mortality from birth to weaning separately, the different factors influence piglet viability concomitantly. Indeed, they reflect physiological and physical characteristics of the newborn piglet, and are highly influenced by both dam and environmental conditions.

2.1.2.1. Body weight at birth

2.1.2.1.1. Impact of body weight at birth on mortality and performance

Piglet birth weight is the most important factor determining early piglet survival and influencing its pre-weaning performance, since lower piglet birth weight is associated with both an increased risk of mortality (Alonso-Spilsbury *et al.*, 2007; Vasdal *et al.*, 2011) and a reduced weight gain during lactation (Milligan *et al.*, 2002ab; Panzardi *et al.*, 2013; Quiniou *et al.*, 2002). Panzardi *et al.*, 2013 observed that piglets weighing less than 1.3 kg of BW, although representing around 25% of piglets born alive, contributed to 55% and 42% of mortality up to 3 and 7 days post-partum, respectively; and Quiniou *et al.* (2002) found that piglets born weighing less than 1.0 kg of BW had little probabilities of being alive at weaning.

Piglets born with higher BW seem to be physiologically more mature at birth, thus more prepared to cope with extra-uterine environment. Indeed, different studies showed that piglets born with higher BW had higher rectal temperature 1 h or 2 h after birth (Baxter *et al.*, 2008; Casellas *et al.*, 2004; Herpin *et al.*, 2002). Higher incidence of crushing have also been observed for piglets with light birth weight (Pedersen *et al.*, 2011a), suggesting that small piglets with increased hunger may spend more time close to the udder hence with more risk of mortality due to crushing (Weary *et al.*, 1996). Piglets with low birth weight have a reduced ability to reach the udder and to compete for a teat, therefore, having lower colostrum intake (Bikker *et al.*, 2010; Tuchscherer *et al.*, 2000; Vasdal *et al.*, 2012) and resulting in a low energy and IgG intake, thus leading to more chances of dying by starvation (Pedersen *et al.*, 2011a).

Not only piglet BW at birth influences piglet performance, but also BW variation within litter shows some controversial effect in the literature. On one hand, an increase in pre-weaning mortality with increased variation of birth weight within litter has been described (Akdag *et al.*, 2009; Deen and Bilkei, 2004; Roehe and Kalm, 2000). On the other hand, the increase in mortality with variability in weight have been attributed to a greater number of piglets with low BW rather to the variability in weight itself, suggesting that higher mortality of low BW piglets is more related to litter size rather than to the birth weight of their litter mates (Milligan *et al.*, 2002a; Quesenel *et al.*, 2012).

Furthermore, there is a marked large variation between litters for piglet weight gain during the first days after birth (Alonso-Spilsbury *et al.*, 2007) which suggests that must be additional piglet characteristics or indicators, different to the birth weight, also responsible for piglet survival and viability (Baxter *et al.*, 2008; Casellas *et al.*, 2004).

2.1.2.1.2. Factors affecting body weight at birth

The main objective of feeding sows during the last third of gestation is to maximize foetus development and to prepare mammary gland for colostrum accumulation and later milk production (Hurley, 2001); perturbations in the amount and/or equilibrium among energy and nutrients supply through placenta can compromise foetus growth (Alonso-Spilsbury *et al.*, 2007). However, there are other factors that might influence piglet BW at birth. For example, selection for sows with increased litter size has resulted in a reduction in piglets BW, mainly due to a decreased uterine space for foetus development. Quiniou *et al.* (2002) observed that between sows with 9 and 17 total born piglets (which represents an 88% increase in litter size) there was only a 50% increase in total litter BW. Fetal location of the foetuses may also affect BW, Kim *et al.* (2009) observed a decrease in weight for foetuses location from the anterior region of the uterine horn towards the cervix at the last third of gestation. A major cause for intrauterine growth reduction is placental insufficiency; a small placenta results in decreased growth rates of foetus, affecting birth weight and subsequent piglet's chance of growth and development because of it provides insufficient levels of monosaccharides (glucose and fructose) to the foetus (Baxter *et al.*, 2008). First parity sows are susceptible to have piglets with lower birth weight, since they have not reached maturity and might have smaller placenta. In large litters, the degree of variation in birth weight within litter is explained by difference in placental transfer of nutrients to individual foetuses (Alonso-Spilsbury *et al.*, 2007).

In conclusion, birth BW is crucial for piglet’s future survival since it is usually a close reflection of piglet’s physiological matureness, and it critically determines piglet’s odds of success when competing for a teat. Nevertheless, there are other factors that also determine piglet’s survival and growth. On the other hand, piglet’s birth BW is basically determined for the uterine capacity or placenta efficiency, in other words, for dam’s characteristics (e.g. breed, prolificacy, age, etc.). As a result, producers can basically deal with alterations and deviations of piglets birth BW (e.g. piglets born with low BW, high variability in litter BW, etc.) through management; since there is little leeway for action to modify birth BW.

2.1.2.2. Neonatal Vitality

2.1.2.2.1. Impact of neonatal vitality on mortality and performance

Vitality, vigour, or even measures of behaviour are often used in the literature to refer to newborn piglet strength. All vitality evaluations and determinations performed so far are recorded immediately after birth of the animals, and they mainly consist in physiological parameters such as interval from birth to onset of respiration, muscle tone, heart rate, etc., or they are based on behavioural observations such as rooting behaviour; whereas other piglet’s behaviours, such as time to reach the udder or time to first suckle, can be used as a measure of vitality or can also be used to relate them with a vitality score obtained from the previously mentioned physiological parameters. In the present literature review we define vitality as piglet strength.

By any means, vitality seems to influence the performance of piglet’s early behaviour, thus it considerably determines piglet’s final survival. Piglets with more vitality have shorter interval of time from birth to reach the udder and to first suckle (Casellas *et al.*, 2004; Herpin *et al.*, 1996); besides, higher vitality has been associated to an improved early postnatal survival rate (Baxter *et al.*, 2008) and up to 10 days after birth (Vasdal *et al.*, 2011). Moreover, piglets showing more vitality have increased rectal temperature after birth (Casellas *et al.*, 2004).

2.1.2.2.2. Factors affecting neonatal vitality

Vitality has mainly been considered, and also studied, as an indirect measure of the degree of intra-partum asphyxia suffered by piglets at birth. First studies of newborn piglets' vitality showed a relationship between low vitality scores and cordal blood pCO_2 and pH (Randall, 1971; Zaleski and Hacker, 1993) indicating that intra-partum asphyxia influences piglet's vitality. Intra-partum asphyxia is also positively associated with birth order, thus, piglet vitality can be influenced by birth order as well (Herpin *et al.*, 1996). Besides, damage to the foetal central nervous system, triggered either by intra-partum hypoxia, congenital causes or maternal stress (among other factors), can reduce piglet vitality (Herpin *et al.*, 1996). Contractions during delivery, especially in oxitocin-induced farrowing, can compromise neonatal vitality in particular when they are of great frequency and intensity (Mota-Rojas *et al.*, 2005). Therefore, any factor influencing sow's delivery will also affect piglet vitality (e.g. sow body condition, parity, stress, etc.). Cold stress at birth can also reduce vitality (Herpin *et al.*, 2002). Finally, intra-uterine environment can also influence vitality since placenta areola density is positively related with piglet vitality (Baxter *et al.*, 2008). Obviously, any congenital malformation or physical abnormality (e.g. splay-leg) that will difficult piglet's movements will, therefore, reduce piglet's vitality.

Additionally to being representative of asphyxia during parturition, vitality is considered a crucial characteristic for piglets that it seems to be independent from birth weight and is determinant for piglets' capacity to obtain colostrum and preserve body temperature (Baxter *et al.*, 2008). Yet, vitality has not been clearly correlated with piglet growth or survival at weaning.

In conclusion, vitality is a piglet's characteristic mainly related to suckling behaviour, that can be impaired principally for delivery-related complications resulting in intra-partum hypoxia. Additional to birth BW, vitality is a determinant factor for piglet's growth and survival. Besides, an easier and more feasible measure of piglets' vitality, without requiring to be recorded during the first minutes of life, should be of interest for a better implantation of vitality determination as a management tool in commercial farms.

2.1.2.3. Thermoregulation

2.1.2.3.1. Impact of thermoregulation on mortality and performance

As has been previously described, the decrease in environmental temperature experienced by the newborn piglet is probably the most immediate hazard that the animal has to face after abandoning the intra-uterine environment. Pigs are born with high surface/volume ratio due to its small size, no fur and with very little adipose tissue to act as energy source (no brown fat). Furthermore, newborn piglets are wet with placental fluid (Herpin *et al.*, 2002). The ability of the newborn piglet to cope with the sudden 15 – 20 ºC decrease in ambient temperature (which easily results in a body temperature drop by about 2 ºC within the first 20 min of life) is decisive for its survival. In fact, when evaluating thermoregulatory ability, rectal temperature measured 2 h after birth is considered a good pointer for piglet success. Piglets that die during the postnatal period are usually characterized for being unable to sustain an optimum rectal temperature (approximately 37.9 – 38.3 ºC) during the first 24 h of life (Baxter *et al.*, 2008; Vasdal *et al.*, 2011). Concurrently, a proper thermoregulation capacity will benefit colostrum intake by the piglet (Herpin *et al.*, 1996), and excessive heat loss during the first day will make piglets less viable thus, more predisposed to be crushed by the sow, more prone to starvation, or more susceptible of dying by disease (Pedersen *et al.*, 2011a).

2.1.2.3.2. Factors affecting thermoregulation

As it can be inferred, piglet size at birth is probably thermoregulation biggest enemy, from it can be concluded that the capacity of thermoregulation is positively correlated to the birth weight (Casellas *et al.*, 2004). Actually, Heim *et al.* (2012) pointed out that below a birth weight of around 1.1 kg, piglets from modern European breeds have their thermogenic capacity impaired. Piglet is a cold sensitive neonate and heat loss through convection and radiation together with conduction are piglet's main thermodynamic processes leading to chilling. Nevertheless, newborn piglets have different metabolic and behavioural strategies to overcome hypothermia. As reviewed by Herpin *et al.* (2002), cardiovascular thermoregulatory adjustments efficiency increases rapidly after birth, favouring redistribution of cardiac output towards skeletal muscle, thus potentiating shivering efficiency. Shivering thermogenesis capacity (repetitive contractions of muscle fibres to produce heat) plays a key role in preserving homeothermy. To maintain body core temperature, piglet has low energy substrate, basically from glycogen and fat (e.g. 12 times lower in a newborn piglet than in a newborn infant), underlying the importance of early colostrum intake as energy source. On the other hand, during the initial phase of body cooling, piglet is able to raise its metabolic rate, basically through thyroid hormones modulation (Hampl *et al.*, 2006; Silva, 2006).

Equally important, behavioural strategies are crucial to maintain the delicate balance between heat production and heat loss. Indeed, huddling with the littermates and staying in the warm areas of the pen benefits heat influx from warmer objects (Kammersgaard *et al.*, 2011). In addition, piglets spending more time by the udder during the first and the second hour after birth show increased rectal temperature 2 h after birth in comparison to piglets being alone on the floor (Kammersgaard *et al.*, 2011). Large litters seem to have a negative correlation with rectal temperature at 2 h of life (Heim *et al.*, 2012).

Asphyxia during farrowing is another factor that can act influencing piglet's ability to thermoregulate, for it can alter piglet's metabolism (Herpin *et al.*, 2002). Besides, poor intrauterine environment may result in lower heat production capability (Baxter *et al.*, 2008). Prenatal maternal endocrine alterations can also have an impact on offspring metabolic ability to cope with a cold challenge (Finsten *et al.*, 1998).

The farrowing house usually has a temperature 10 – 12 ºC lower than the piglet's lower limit of the thermoneutral zone at 2 h of life (close to 34 ºC) (Herpin *et al.*, 2002), evidently a proper management of the environment properties, floor heating, drying of the piglets, etc., at the time of birth could be the most efficient ways to reach an optimal piglet thermoregulatory capacity (Pedersen *et al.*, 2011; Vasdal *et al.*, 2011).

In conclusion, thermoregulation is, after the onset of respiration, probably the most important physiological/metabolic capacity that the piglet has to develop after birth. Thermoregulation in the neonate piglet is sustained by different metabolic events, and is determined by different piglet characteristics together with early energy intake from colostrums'. Moreover, environmental characteristics of the farrowing facilities and management around farrowing will strongly influence piglet thermoregulation capacity, thus, influencing piglet future growth and survival.

2.1.2.4. Dam traits

2.1.2.4.1. Behaviour and well-being

Some maternal factors affecting directly or indirectly piglet mortality and growth have been already introduced while discussing the three main factors affecting pre-weaning mortality. Is easy to understand that some maternal traits as body condition, parity, physiological or endocrinal status, intra-uterine environment or placental quality, etc., are going to have consequences on final foetal development and piglet's early viability.

In lactation phase, nursing behaviour is probably the most representative example of sow-piglet relation, relying in a complex communication system. Besides, essential suckling behaviour in domestic pig does not differ from wild boar (Horrell, 1997). The onset of lactation (appearance of synchronous and cyclical nursing in piglets) is established once the continuous colostrum let-down has been progressively replaced by a cyclical milk let-down (Torrey and Widowski, 2007). Due to sows lack a milk cistern, milk is only available for short periods of time during the day, simultaneously at all the teats. Thus, piglets suckle simultaneously in nursing bouts every 30 – 70 minutes, over 20 times a day, though milk ejection is not achieved in all the sequences (Fraser, 1980). Fraser (1980) described 5 phases for the regular nursing bouts, starting once most of the piglets of the litter have assembled at the udder. First, piglets display themselves one to each functional teat (phase I), that process might last from few seconds to several minutes. Following from this, piglets start massaging the udder for about 1 minute (phase II). Then, the animals start suckling with slow movements for 20 seconds (phase III), from they immediately switch to suckling with rapid mouth movements for 10 – 20 seconds (phase IV). Is during phase IV while milk is available, and in 15 seconds time a piglet can gulp down up to 50 g of milk. Finally, piglets resume suckling, but they can keep noising the udder for few seconds to several minutes (phase V). Sow maternal behaviour is obviously crucial since sows have to lie presenting the teats to the piglets. Moreover, sow's grunts seems to be important in gathering the piglets at the udder prior to the beginning of a suckling bout, and it has also been observed that sow's grunting rate responds to piglets' rhythmic mechanical stimulation of the udder (Fraser, 1980). Likewise, since sow maternal behaviour patterns are of great similitude with undomesticated sow (Spinka *et al.*, 2000), and though the importance of maternal behaviour is likely to be reduced in domestic confined sows, good mothering style, specifically postural movements and pre-lying behaviours (e.g. grunting, presenting the teats when lying, looking at the piglets, sniffing, or rooting away the piglets), are still an important precondition for high sow productivity. Indeed, inappropriate mothering style influences piglets' behaviour, resulting in reduced milk intake, impaired growth, and also increasing the odds of being crushed (Andersen *et al.*, 2005; Cui *et al.*, 2011; Wischner *et al.*, 2010).

The reduction or inability to perform the mentioned maternal behaviours also impairs sows welfare (Baxter *et al.*, 2012a). Wischner *et al.* (2010) reported 'sniffing', 'looking around', and 'nosing' as essential parts of the pre-lying behaviour in crated sows during farrowing. They observed that sows crushing no piglets during lactation performed the mentioned conducts more often and with longer duration before lying down than sows that did crush piglets. In primiparous sows, Wischner *et al.* (2009) observed that sows that did crush piglets performed rolling behaviour (postural changes between lying on one side to lying on the other side) more often and in longer bouts than primiparous sows that did not crushed piglets during lactation.

Sow's responsiveness to piglet distress squeal might reduce number of trapped piglets crushed (Wechsler and Haggin, 1997), notwithstanding, sow's reaction to the screams of trapped piglets is very variable (Harris and Gonyou, 1998; Illmann *et al.*, 2008) for crushing by the sow can be considered as failure to, or lack of, willingness to protect the offspring and also a failure to establish common maternal bonds (Andersen *et al.*, 2005; Chen *et al.*, 2008). Another abnormal maternal behaviour directly affecting piglet mortality is sow's piglet-directed aggression around farrowing, also known as savaging. Savaging is more likely to occur in gilts than in sows, though sows that savage as gilts have more odds to savage in their subsequent farrowing (Harris *et al.*, 2003).

2.1.2.4.2. Milk production and lactational failure

Despite all the described factors influencing piglet early viability and chances to reach a teat and suckle, piglet survival and growth depends mainly first on colostrum and later on milk intake. Sow capacity to produce milk can vary among animals, particularly during the first days of lactation. It is suggested that insufficient milk production or lactation failure in sows might account for between 6 and 17% of pre-weaning mortality (Alonso-Spilsbury *et al.*, 2007). From and endocrinological point of view, milk production is a rather complex process. For all mammalian species, mammary gland development starts in the foetus (Svennersten-Sjaunja and Olsson, 2005). In gilts, the quantitative development of the mammary gland occurs in phases from birth until the end of pregnancy, being the last third of pregnancy the most critical for the development of milk-secreting tissue (Sorensen *et al.*, 2002), becoming the major determinant of lactational performance (Hurley, 2001). Indeed, the extent of mammary growth and the number of milk-producing cells in the mammary gland are determinant of subsequent milk production. Additionally, pre-partum mammary growth and milk production are mainly controlled by prolactin and growth hormone during lactogenesis (Svennersten-Sjaunja and Olsson, 2005). In addition to what has already been said, mammary gland still has the capacity to double its number of mammary cells during lactation. Opposite to pre-partum mammary growth, post-partum mammary growth is stimulated by suckling and milk removal, and is affected by nursing frequency, stage of lactation, litter size, litter weight, and gland location (Hurley, 2001; King, 2000).

Together with the sow's genetic potential, piglet's intensity to stimulate or massage the udder and piglet's capacity to empty the mammary gland are the main responsible for total milk yield (Hurley, 2001). Besides, teats intensely suckled in the first lactation will have better development and will produce more milk in the second lactation (Farmer *et al.*, 2012). There is also a synergistic relationship between piglet vitality and milk yield (Laws *et al.*., 2009). Furthermore, litter size and amount of nursing bouts are positively related with milk yield (Auldist *et al.*, 1998; Pedersen *et al.*, 2011b; Thodberg and Sorensen, 2006).

Despite the fact that sows have a genetically defined potential for milk production, it has been observed that providing sows with high energy diets during gestation may be detrimental for mammary gland development. Meanwhile, high protein intake during gestation might enhance subsequent milk production (Farmer and Sorensen, 2001). Moreover, milk fatty acid profile can be improved through fat supplementation of maternal diet during gestation (Laws *et al.*, 2009).

Reduction in milk yield or lactation failure may occur in hot conditions or heat stress. Assuming sow's good health, such reduction of milk yield it is suggested to be related with a decrease of voluntary feed intake during lactation, mediated by the increase of leptin concentration, which would result in a reduction of nutrients available for lactogenesis. Concurrently, heat stress would also increase the proportion of blood flow irrigating skin capillaries to dissipate body heat, consequently reducing blood flow and nutrient supply to mammary gland, therefore increasing mammary gland inefficiency (Renaudeau *et al.*, 2003). Following from this, Silva *et al.* (2009b) observed and increase in daily milk production during summer when sows were kept in farrowing pens with cooled floors (system using running water at 17 ºC under the dam's crate).

Post-partum dysgalactia syndrome is a multifactorial process with a considerable prevalence among herds, causing lactation failure during the first days after farrowing. Late transferring of sows to farrowing facilities, *ad libitum* feeding during the first days of lactation, and dystocia are factors that have been observed to increase the odds for post-partum dysgalactia sydrome (Papadopoulos *et al.*, 2010); factors that can be minimized with specific management and feeding practices. Finally, Gerjets *et al.* (2011) found an increased risk of suffering coliform mastitis with a higher number of total born piglets, and also found higher incidence of mastitis in gilts compared to sows.

In conclusion, given the current restricted crate allocation for sows during farrowing and lactation, producers can basically influence sow's maternal behaviour procuring a quiet and restful atmosphere/environment. Because a distressed dam will be more prone to farrowing problems, and it will perform more postural movements increasing both, the odds of crushing piglets and the number of nursing bouts interruptions.

On the other hand, although milk production capacity in sows is genetically determined, producers can slightly influence in mammary gland development and in milk composition through sows' nutrition during gestation. Management of the piglets to maximize litter capacity to increase nursing frequency or enhance the completeness of gland emptying, and capacity to overcome high environmental temperatures during the hot seasons, are probably the main methods for helping to improve milk yield during lactation.

2.2. Management during lactation

To deal with the pre-weaning mortality problem, there are some management priorities and procedures, concerning sows and piglets, commonly established in the farrowing house. Producers attempt to satisfy the main needs of dams and piglets to achieve an optimum performance.

2.2.1. Management of the lactating sow

Both wild *Sus scrofa* and domestic sows, under proper conditions, would show motivation to seek isolation and nesting behaviour prior to farrowing; and would not return with the other members of the herd before 1 or 2 weeks after farrowing, this may lead sows to become aggressive particularly around farrowing time (Arey, 1997). Confining sows to conventional farrowing crates prevents the performance of sow's maternal behaviour resulting in stress for the sow (Ringgenberg *et al.*, 2012), which should be even of greater magnitude for group housed sows during gestation than those kept in stalls (Baxter *et al.*, 2012a). Consequently, sow's management at farrowing facilities before farrowing should consider sow's behavioural restrictions. Within the intensive production limitations, sows are moved to farrowing facilities aiming for a minimum adaptation time prior to deliver (4 to 7 days). Since farrowing is easily disturbed by many factors within and around the sows (e.g. breed, age, number of piglets born, body condition, housing, stress, etc.) (Oliviero *et al.*, 2010), it is important to provide animals with an environment as much quite and non-disturbed as possible, especially around farrowing.

Besides, sows also have to cope with birth of the piglets and milk production. Through genetic selection and improving environment conditions, productivity of sows has increased worldwide, mainly by increasing litter size. Furthermore, selection on increased litter size comes together with selection on production efficiency (gain during finishing) and quality of the carcass (increasing lean and reducing fat) (Knol *et al.*, 2010). Therefore, during the last decades sow's genetic selection has resulted in an increase in litter size together with a clear reduction of the amount of sow's body fat reserves (Eissen *et al.*, 2000). On the other hand, lactation is the most nutritional demanding physiological phase for sows, with metabolism oriented towards mobilization of body reserves to provide energy and nutrients for milk production (Mosnier *et al.*, 2009), with the particularity that lower parity sows, specifically primiparous sows, have higher energy and protein requirements for body growth (Eissen *et al.*, 2000; Yoder *et al.*, 2012); in fact, during lactation, feed intake is not high enough to sustain milk production and mobilization from body reserves must occur. It has been observed that improved average daily feed intake (ADFI) during lactation reduces BW loss, improves litter weaning weight, and also improves both weaning to first service interval and percentage of sows returning to oestrus (Sulabo *et al.*, 2010a; Yoder *et al.*, 2012). Bergsma *et al.* (2009) also stated the need for more efficient sows during lactation (sows with enhanced milk output given the feed intake and mobilization from body stores). Therefore, the main objectives of sow's management during lactation are to maximize number and quality of piglets weaned and to preserve and optimize sows productive live. Maximizing sow's total feed intake in a properly pattern is the most critical point to fulfil those objectives.

A correct pattern of ingestion which may produce the maximum feed intake during lactation is attained monitoring feed consumption through the whole lactation period by getting to equilibrium between labour possibilities and technological facilities. One of the most successful procedures is the Stotfold feeding scale presented in table 2.2, with lactating sows being fed following a close "controlled" *ad libitum* pattern. On farrowing day (expected based on the mating date and/or determined through the observation of farrowing symptoms), sows are not offered feed or just a small amount of it (1 – 2 kg) for the following 24 h. Thereafter, the amount of feed offered is increased daily until *ad libitum* is reached after 1 week of lactation. Once the *ad libitum* is reached, the amount of feed that the dam will be able to ingest might vary based upon age or number of piglets reared. The full application of the Stotfold feeding scale is highly labour consuming, especially if gestation feed is offered during the 3 or 4 days after farrowing, and easier labour systems are often adapted in farms.

In any case, feed intake restriction around farrowing and during the first days of lactation it is usually recommended to reduce occurrence of post-partum agalactia and also because of voluntary feed intake may be reduced due to gastrointestinal tract it is not yet adapted to high daily feed intake (Eissen *et al.*, 2000); greater feed intake during the first days of lactation is associated with greater occurrence of feed intake drops, especially with primiparous sows; however higher whole lactation feed intake is reached as earlier the peak daily feed intake (highest ADFI) is attained (Koketsu *et al.*, 1996a). Day of peak feed intake and ADFI may be affected for farm-to-farm variations in feeding management, equipment, genotype, and housing. Further, elevated ambient temperatures (e.g. summer conditions) reduces feed intake while ADFI may slightly increase with parity (Koketsu *et al.*, 1996a). Koketsu *et al.* (1996a) recommended that producers should manage their sows to optimize the proportion of sows with feed intake increased gradually or rapidly after farrowing with no drop in feed intake during lactation, aiming for a peak feed intake at day 10 after farrowing.

Table 2.2 The Stotfold feeding scale for lactating gilts and sows considering litters with different number of piglets, published by the Meat and Livestock Commission (1995)

Day	Gilt: < 10 piglets Sow: < 9 piglets	Gilt: 10 piglets Sow: 9 piglets	Gilt: 11 piglets Sow: 10 piglets	Gilt: 12 piglets Sow: 11 piglets	Gilt: 13 piglets Sow: 12 piglets
1	2.5	2.5	2.5	2.5	2.5
2	3.0	3.0	3.0	3.0	3.0
3	3.5	3.5	3.5	3.5	3.5
4	4.0	4.0	4.0	4.0	4.0
5	4.5	4.5	4.5	4.5	4.5
6	5.0	5.0	5.0	5.0	5.0
7	5.5	5.5	5.5	5.5	5.5
8	6.0	6.0	6.0	6.0	6.0
9	6.5	6.5	6.5	6.5	6.5
10	7.0	7.0	7.0	7.0	7.0
11	7.0	7.5	8.0	8.5	9.0
12	7.0	7.5	8.0	8.5	9.0
13	7.5	8.0	8.5	9.0	9.5
14	7.5	8.0	8.5	9.0	9.5
15	8.0	8.5	9.0	9.5	10.0
16	8.0	8.5	9.0	9.5	10.0
17	8.5	9.0	9.5	10.0	10.5
18	8.5	9.0	9.5	10.0	10.5
19	9.0	9.5	10.0	10.5	11.0
20	9.0	9.5	10.0	10.5	11.0
21	9.5	10.0	10.5	11.0	11.5
22	9.5	10.0	10.5	11.0	11.5
23	9.5	10.0	10.5	11.0	11.5
24	9.5	10.0	10.5	11.0	11.5
25	9.5	10.0	10.5	11.0	11.5
26	9.5	10.0	10.5	11.0	11.5
27	9.5	10.0	10.5	11.0	11.5

By comparison, less research on water consumption relationship with sow or litter performance during lactation has been done. Nonetheless, water is the major component of milk. Daily water consumption of lactating sows varies in literature from 17.2 to 27.5 l/day. Kruse *et al.* (2011) described an increasing pattern, similar to feed intake, for water intake at the beginning of lactation reaching a plateau at day 16.

They also positively correlated water intake with litter weaning weight and negatively correlated it with body weight loss.

Despite each phase is usually analyzed or treated independently, all phases of the reproductive cycle of the sow are related, deviations of the normal body condition in one phase can have significant effects on performance in another one (Maes *et al.*, 2004), for low energy intake throughout lactation may result in an excessive body fat mobilization and also protein loss during lactation decreasing later reproduction and production performance of the sow (Clowes *et al.*, 2003; Eissen *et al.*, 2003; Koketsu *et al.*, 1996b). Furthermore, lactation feed intake can be influenced through gestation feeding management; hence, high fibre inclusion level on gestation diets may increase feed intake during lactation (Quesnel *et al.*, 2009), whereas overfeeding during gestation may reduce feed intake during lactation (Eissen *et al.*, 2000; Koketsu *et al.*, 1996a) though it has not been widely studied for group housing sows during gestation.

2.2.2. Management of the newborn piglet

Characterized by their high surface to body mass ratio, limited reserves and poor immunity status, neonate piglets are very vulnerable at birth. Moreover, with high prolific sows, piglets have to compete with numerous and variable littermates for a teat to suckle. Together with other factors, these confluence of peculiarities lead to a high pre-weaning mortality, especially during the first 72 h of life (Alonso-Spilsbury *et al.*, 2007). Several management routines are performed during de first 2 days post-partum to enhance piglet viability. On farrowing day, and within the first hours after birth, management is focused on helping piglets to minimise heat loss and to maximize colostrum intake.

2.2.2.1. Colostration

Colostrum is secreted by the mammary gland starting shortly before parturition and for a time interval of approximately 12 – 24 h in most sows (Quesnel *et al.*, 2012). Piglets may suckle colostrum freely since the physiological cyclical pattern of suckling and milk ejection is not established until 24 – 48 hours after farrowing (de Passille and Rushen, 1989). Colostrum is a source of very digestible nutrients and various forms of bioactive compounds such as immunoglobulins, hydrolytic enzymes, hormones, and growth factors (Rooke and Bland, 2002; Wu *et al.*, 2010). Besides, colostrum is the first and only food that is ingested by piglets after birth, it is crucial in providing energy for thermoregulation and body growth (Figure 2.3) (Devillers *et al.*, 2011; Herpin *et al.*, 2005; Le Dividich *et al.*, 2005). In addition, passive immunity supply in species with epitheliochorial placenta mainly occurs from immunoglobulin G (IgG) in colostrum, providing newborn animals with passive humoral immune protection. Newborn piglet absorption of IgG befalls before gut closure (Bland *et al.*, 2003; Quesnel *et al.*, 2012), which takes place at approximately 24 h of age (Rooke and Bland, 2002).

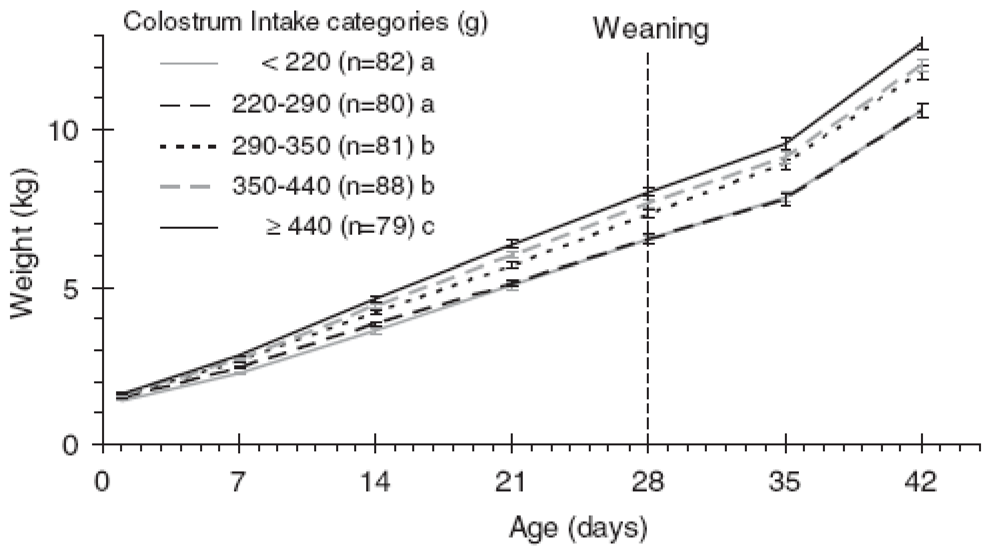

Figure 2.3 Growth of piglets according to colostrum intake between birth and 24 h after birth for piglets still alive at 42 days of age. Data presented are least square means ± s.e. Different letters at the right side of the legend indicate significant differences ($P \leq 0.05$) between colostrum intake categories on days 21, 28, 35 and 42. (Devillers *et al.*, 2011)

However, colostrum yield is limited since it is somehow independent of litter size, and it only seems to be moderately influenced by litter weight and piglet live weight variability at birth (Devillers *et al.*, 2007). Moreover, colostrum yield and IgG concentrations were shown to be highly variable from sow to sow, even within sows from the same unit (Devillers *et al.*, 2011; Quesenel, 2011). In addition, the amount of colostrum ingested during the first 24 h after birth is also highly variable between littermates and averages 250 – 300 g/kg of birth weight (ranging from 0 to 700 g/kg) for sow reared piglets (Quesnel *et al.*, 2012); newborn piglets from the same litter (whose number of live born piglets may easily exceed number of functional teats) compete for mammary glands, preferably the anterior and the middle ones, for the posterior mammary glands can produce less beneficial proteins than anterior ones (Wu *et al.*, 2010). Additional to the early aggressive competence for a teat (De Passillé *et al.*, 1988), piglets from the same litter indirectly compete for milk intake during lactation. Higher stimulation of the udder increases milk production in the same lactation through an increase in plasma levels of prolactin, gastrin and glucagon, increasing the nutrient supply to the udder. Moreover, piglets more effective at draining, massaging, and stimulating the teat will favour local blood flow together with hormonal and nutrient investment, thus, increasing teat's milk production (Algers, 1993).

Most of the management routines that have been studied consist in practices performed around piglet's birth, including supervising the farrowing, and are oriented to cope with the two main challenges stated above: thermoregulation and colostrum intake by the piglet. Drying piglets at birth has been proved to be a useful practice to apply 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; 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 for loose housed sows. Practices to ensure colostrum intake by the piglets have also been tested. Andersen *et al.* (2007), after comparing the records of an entire year from 39 Norwegian farms, observed that helping piglets to obtain colostrum by placing them at the udder 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. Improvements on survival during the first day, reduction in number of stillbirth and increased weaning weight have been obtained with more complex protocols that included drying the newborn piglets but also an oral administration of 12 ml of bovine colostrum and oxygen administration through an oral mask (White *et al.*, 1996), good supervision when farrowing is induced have also improved pre-weaning survival (Holyoake *et al.*, 1995). On the other hand, removing larger piglets in a litter from the dam for a set period to allow the smaller piglets adequately access to the udder (split nursing), is a different way to try to enhance colostrum intake of low birth weight piglets often practiced in sow herds. Yet, this practice does not seem to have a real impact on litter performance, Donovan *et al.* (2000) only observed a decrease in variation for piglet's average daily gain (ADG) in large litters (> 9 pigs born alive) with no effect on IgG plasma concentration and mortality rate when performing split nursing of the heaviest 50% of the piglets in the litter for 2 h; and Thorup (2006) did not obtain a drop in low birth weight piglets' mortality through split nursing neither.

In commercial herds, the importance of a proper colostrum intake by piglets is completely assumed. For this reason, producers intend for management practices to enhance piglet's colostrum intake. However, management protocols studied so far in the bibliography are too complex and laborious, or need to be performed too close to piglet's birth, to be reasonable and profitable under commercial conditions, that is oral administration of colostrum (usually with manually milked sow colostrum obtained in the same herd) to low viable piglets is the effort mostly performed in sow herds to ensure a proper colostrum intake by the piglets during the first day of life (www.3tres3.com). In contrast, there are very few experiences in the bibliography focusing on the study of the productive impact of oral colostrum supplementation of piglets, either on the amount of colostrum that needs to be administered or the number of times that needs to be administered during the day; however, it has been well described the optimum colostrum ingestion required for sow reared piglets (Devillers *et al.*, 2011; Quesnel *et al.*, 2012). Such circumstance makes piglet colostrum supplementation a wide extended practice in pig production based in commercial empiricism but with a poor scientific background.

2.2.2.2. Cross-fostering

In addition to colostrum supplementation, cross-fostering is an important and common management practice performed in commercial farms. There are many reasons to perform cross-fostering: foster the surplus piglets when a sow has more live born piglets than functional teats, foster small piglets to create litters with similar birth weights and/or to create litters with low weight variation, death of a sow at farrowing, when a gilt or sow attacks their offspring, etc. Concurrently, cross-fostering can be performed at a minimum extent, fixing litters only by number of piglets according to number of functional teats, transferring as minimum number of animals as possible. On the contrary, cross-fostering can be performed at a greater extent, adjusting litters by BW of the piglets, transferring animals based on parity of the dams (piglets from gilts transferred to middle-age sows), etc., involving the transfer of a high number of piglets and, in turn, entailing most of the litters in the herd.

Cross-fostering should be performed once piglets have had the possibility to ingest the maximum amount of colostrum from their genetic dams, but before teat order has been established (Heim *et al.*, 2012). As previously stated, colostrum decreases after 12 h post-partum, after the initial phase of continuous colostrum ejection a cyclical milk let-down instauration progressively occurs, thereafter, and within the first week after birth, a stable teat order among littermates is established (de Passille *et al.*, 1988). Technical recommendations and farm routine procedures aim to perform cross-fostering between 12 and 24 h after farrowing. Moreover, during the first day after farrowing, sows accept alien offspring without litter suckling patterns being disrupted, without impairing piglet's and sow's welfare, or without originating sow's aggressions towards adopted piglets (Robert and Martineau, 2001).

In the literature, cross-fostering has been well studied though obtaining results of diverse nature. Heim *et al.* (2012) observed that survival and growth was not impaired in fostered piglets and also that litters composed exclusively of adopted piglets had no prejudice on behaviour, survival or growth. Bierhals *et al.* (2011) found that piglets nursed by primiparous sows had lower BW during lactation than piglets nursed by parity 5 sows. Akdag *et al.* (2009) and Milligan *et al.* (2002a) associated birth weight variation with low survival rate although other studies did not relate increased birth weight variation with low survival (Bierhals *et al.*, 2011; Milligan *et al.*, 2001). Deen and Bilkei (2004) found that mortality of low birth weight piglets increased when they were cross-fostered with high birth weight piglets, and also stated that low birth weight piglets have higher chances to survive in small litters irrespective of the birth weight of their littermates. On the other hand, repeated cross-fostering through lactation reduces weight gain of both adopted and resident piglets and increases sow's aggressions towards alien piglets (Robert and Martineau, 2001).

It is of common practice in different farms, mainly favoured by the herd size and/or batch management strategy, to induce farrowings, especially in multiparous sows, to be able to concentrate and to optimize tasks; in those conditions cross-fostering become easier to perform. In any case, advantages and disadvantages of farrowing induction is outside of the scope of this literature review and it has been recently documented (Kirkden *et al.*, 2013). On the other hand, cross-fostering might have implications on transferring pathogens from one litter to another; moreover, it can also be critical for the success of immune transfer (humoral immunity and cell-mediated immunity) from the biological dam to newborn piglets. However, long-term impact of cross-fostering on piglet health and immunity has not been well examined (Bandrick *et al.*, 2011).

Nevertheless, more conclusive experiences are needed to clearly understand the effect of cross-fostering on piglet performance, especially when cross-fostering to reduce litter weight variation. Besides, it has not been studied the effect of cross-fostering in combination with other husbandry practices to enhance piglet performance, such as colostrum supplementation.

2.2.2.3. Creep feeding

Once producers have focused all the efforts to enhance newborn piglet's early viability and future performance by ensuring piglet optimum colostrum intake and equalizing and/or homogenizing litters, all the efforts are oriented to maximize piglet's weight at the end of lactation and to ease piglet's transition from milk consumption during the suckling period to a solid feed diet after weaning. For that purpose, after the first week or ten days of lactation, piglets are frequently given a highly palatable and easily digestible diet (creep feeding). Piglet's creep feed intake usually is not very high and it is inversely related to sow's milk production; consequently, creep feed offered during lactation period do not have high impact on sow performance and does not greatly affect piglets growth at weaning (Bruininx *et al.*, 2004; Sulabo *et al.*, 2010a). It has been observed that only low proportion of piglets consume feed intake during lactation (Sulabo *et al.*, 2010b) and also that creep feed intake is variable between and within litters (Bruininx *et al.*, 2002; Wattanakul *et al.*, 2005). Nevertheless, creep feeding has been proven to benefit post-weaning performance of piglets that consumed creep feed during lactation through shortening the onset of feed consumption (Bruininx *et al.*, 2002) and increasing feed intake and BW gain during the first days after weaning (Bruininx *et al.*, 2004; Pluske *et al.*, 2007; Sulabo *et al.*, 2010a; 2010b). Longer duration of creep feeding during lactation increase the proportion of piglets eating creep feed (Sulabo *et al.*, 2010b); nonetheless, lactation length seems to influence creep feed intake, Callesen *et al.* (2007a) observed a creep feed consumption increase between 137 and 266% when weaning piglets at 33 days of age rather than at 27. Following from this, Callesen *et al.* (2007b) found that creep feed may benefit post-weaning growth of piglets after longer lactations. Still, there are some lack of knowledge on whether the more vigorous or the smaller piglets are the ones who consume creep feed during lactation, and on the motivation that leads piglets to consume creep feed and how can consumption be enhanced through management (Wattanakul *et al.*, 2005).

Additionally to the management practices mentioned above (calostration, cross-fostring and creep-feeding), weaning age is also an important factor determining further performance of the animals. Lactations of 21 days increase wean-to-finish ADG and survival compared to shorter ones (Main *et al.*, 2004), and lactations of 33 days improve piglet's growth after weaning in comparison to 27 day-long lactations (Callesen *et al.*, 2007b); for longer lactations increase weight and physiological maturity at weaning (Main *et al.*, 2004). However, with the current multisite pig production system and its specific pig-flow, little decision capacity is left concerning weaning age.

Moreover, there are some other important husbandry practices, routinely performed in farrowing facilities and on subsequent stages towards either piglets or sows (e.g. castration, iron administration, vaccination, ear clipping, tail docking, etc.), that are not discussed in this literature review, but that have an impact on piglets and sows welfare and performance, and they should be considered when planning or suggesting a protocol for management routines in the farrowing house. In addition, environmental factors, such as facilities' design, also play and important role in the success of management performed around farrowing or during lactation. Besides, because of the existence of a vast design types and commercial options for farrowing crates, creep area, feeders, drinkers, farrowing room, ventilation system, etc., any management decision should be done considering farm characteristics.

2.2.2.4. Human-animal interaction

Intensive husbandry and housing practices have also affected the nature and amount of human contact that the animals receive. Routine interactions between stockpeople and their animals can result in farm animals becoming highly fearful of humans and, through stress, their productivity and welfare might be impaired (Hemsworth, 2003). Attitude and behaviour of the stockpeople to sows and pigs when handling and interacting with them may have implications on both the productivity and stress physiology of the animals (Gonyou *et al.*, 1986; Hemsworth and Coleman, 2010; Hemsworth *et al.*, 1989). Besides, it has also been observed that handling pigs early in life may influence their subsequent behavioural responses to humans (Hemsworth *et al.*, 1992). Lactation is a very demanding phase for human handling of sows and especially of new born piglets. Implications of good practices from trained employees and positive affective experiences in animals arising from human interactions may have powerful influences. Its influences might not only have an effect on the productivity and welfare of the animal but also on how the animal responds to aversive routine practices (Hemsworth and Coleman, 2010). The effects of negative emotional states, such as fear, on the welfare of animals are well known (Gonyou *et al.*, 1986; Hemsworth *et al.*, 1981, 1987, 1989). However, there is some limited data indicating the impact of positive emotional responses in the presence of humans on subsequent experiences in farm animals when in the presence of humans.

It is of great importance that producers consider the stockpeople skills and the impact of their management procedures and their attitudes towards their animals during routine husbandry practices.

***

As we stated at the introduction of the present thesis, management performed in the farrowing house plays the most important part in ensuring pre-weaning survival. This section has tried to draw a picture of the main management practices that are usually performed on sows and piglets during lactation to satisfy their metabolic requirements and overcome their physiological limitations at birth. However, there is no unique way to apply these management practices, and other factors, such as stockpeople attitude and skills or farm environment, may also play and influencing role. Moreover, the management required for sows and piglets in the farrowing house will be influenced by the management received during gestation period and, in turn, will influence future management of both piglets and sows.

2.3. Production cycle of the sow and piglets

In practice, most commercial gilts are introduced to the production cycle after being inseminated at the 2nd or later observed oestrus following puberty, with an average BW of 130 – 140 kg (Tummaruk *et al.*, 2007). For most European breeds, prepubertal gilts attain puberty, on average, at 210 days of age (expressing the first oestrus between 183 and 225 days of age). Physiological age, more than chronologic age, appears to hold the greatest relationship to the puberty age, being the BW and backfat thickness (BF) the factors explaining most of the variation in age at puberty (Knox *et al.*, 2007). A mating program with a proper "mating objective" (number of sows to be inseminated per batch) is essential to guarantee an optimum farrowing rate, a key factor to improve herd reproductive productivity and profitability (Kaneko *et al.*, 2013).

Assuming a standard lactation period of 21 days, sows' production cycle accounts by a minimum of 140 days, including gestation, lactation and the interval between weaning and mating. Sows' gestation is, on average, 114 days long. Although 80% of the time of the year the sow is pregnant, gestation has frequently been a forgotten stage within the reproductive cycle by most farmers and nutritionists (Cerisuelo, 2007). Gestation is the only production stage, in swine production, where the feeding regime is restricted (Figure 2.4).

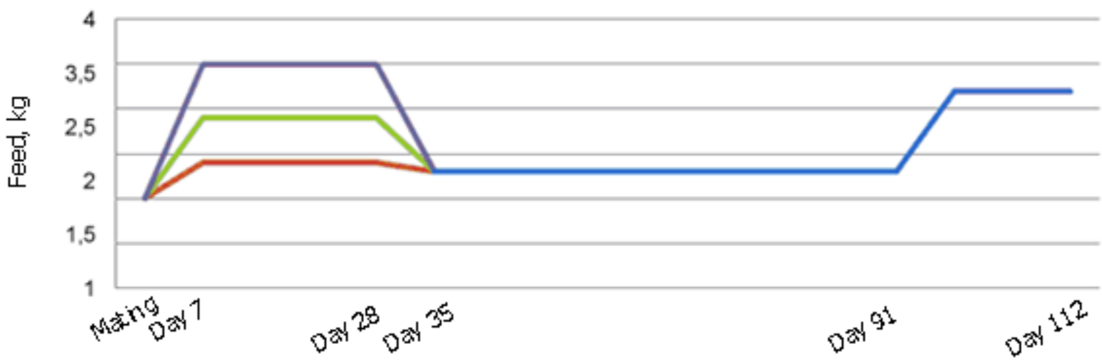

Figure 2.4. An example of a feeding pattern usually suggested for breeding sows throughout gestation. For this example, a commercial gestation diet with an energetic concentration of 12.1 MJ ME/kg of feed was considered (Wennberg *et al.*, 2012).

Two main objectives, yet not the only ones, should be considered during gestation:

- Recovery of sow's body reserves lost during the preceding lactation to better prepare sows for the following farrowing and lactation, and also to guarantee the optimum growth of young sows.
- Minimize embryo mortality and maximize foetus growth and mammary gland development, especially during the last third of pregnancy.

With the mandatory allocation of gestation sows in groups from 4 weeks after service until a week before parturition, individual control of both sows' feed consumption and body condition variation have become a major concern for pig producers during the last decade. From groups of 6 – 8 sows with trickle feeding to large dynamic groups (40 or more sows) with an electronic sow feeding system, numerous grouping strategies and feeding systems have been developed and tested for a better accomplishment of the main objectives on gestation phase, preserving the welfare status of the animals with no clear cut advantage to any sow gestation housing system (Spoolder *et al.*, 2009). Several reviews have been recently published about the advantages and the shortcomings of different systems of group housing for gestating sows (McGlone *et al.*, 2004; Spoolder *et al.*, 2009). Although traditionally it has been demonstrated than overfeeding during gestation has a negative impact on farrowing, lactation and even future reproductive performance (Eissen *et al.*, 2000), some evidences have pointed out that *ad libitum* feeding pattern in group housed sows during gestation does not seem to affect sow's short term farrowing performance, feed intake during lactation or subsequent reproductive performance (van der Peet-Schwering *et al.*, 2004).

With the introduction of group housing during gestation, concerns on productivity, labour requirement, and management were raised among producers and specialists. Therefore, early research was focused mainly on group housed sow's reproductive performance (farrowing rate, litter size in the ongoing pregnancy, and piglets birth BW) and welfare in comparision to stall allocated sows during gestation. Reviews on comparing housing systems have stated that productivity of stalled sows was equal to sows housed in groups during pregnancy in terms of physiology or productivity, with no real differences noted between housing systems for labour input (den Hartog *et al.*, 1993; McGlone *et al.*, 2004). A more recent review (Spoolder *et al.*, 2009) showed that the main risk for an optimum farrowing rate in different group housing systems is the early introduction of pregnant sows to group housing (group housing of sows from 4 days after insemination). Risk that can actually be considered minimized with the introduction of gestating sows to group housing from 3 weeks after insemination.

Approximately 1 week before farrowing, sows are moved to farrowing facilities. In European farms, sows have to adapt from group housing during gestation to individual farrowing crates, situation that has raised concerns for the welfare of these animals. Thus, the influence of group housing during gestation on sow's welfare while they are in the farrowing crate has been widely studied. Welfare of sows when introduced to farrowing crates is adversely affected by loose housing during gestation, and group housed gestating sows also experience greater restlessness at parturition and into early lactation (Boyle *et al.*, 2000), probably due to inability to show maternal behaviour near farrowing (Baxter *et al.*, 2012a; Marchant and Broom, 1993). On the contrary, stall allocated sows during gestation are likely more adapted to behavioural restriction (Boyle *et al.*, 2000). Conversely, loose housing gestation may help to improve dam's fitness favouring a faster delivery performance (Hemsworth, 1982; Oliviero *et al.*, 2008, 2010), for lower incidence of intra-partum asphyxia should be expected. Schenck *et al.* (2008) observed that more exercise during gestation improved gilts offspring survival. However, few experiments to date have been done on the effect of group housing of sows during gestation on offspring physiology and performance. As mentioned above, group housing of sows during pregnancy does not affect offspring birth weigh, still, social stress and elevated maternal cortisol concentrations during gestation can alter offspring hypothalamic-pituitary-adrenal axis (HPA) and behaviour, thus negatively affecting piglet's performance (0009-Kranendonk *et al.*, 2007; 0341-Otten *et al.*, 2010). Indeed, while stall allocated sows may experience greater welfare challenges at later stage of gestation, group housed sows are more susceptible to welfare impairment due to social stress (Karlen *et al.*, 2007).

Lactation is probably, together with post-weaning period, the pig production phase with more technical and expensive facilities, and more management and health care requirements. Producers have to deal with animals with different physiological and environmental condition needs: sows and newborn piglets. On one hand, sows, with a thermoneutral zone ranging from 18 to 20 ºC (Silva *et al.*, 2009a), have to face a great energetic demand through milk production, and the main objective during lactation, after ensuring a proper environment for farrowing development, is to maximize sows feed intake after farrowing. On the other hand, newborn piglets, with a lower critical temperature of 25 – 30 ºC when grouped in a litter (Herpin *et al.*, 2002), have to adapt to extrauterine life conditions, and the main objective for piglets during lactation is to maximize its colostrum and milk intake and to reduce pre-weaning mortality. Weaning takes place 21 or 28 days after farrowing. After weaning, sows start again their production cycle and piglets are transferred to nursing facilities.

Technical parameters for pig production cycle obtained from Spanish farms during the year 2011 are presented in table 2.3. Weaned piglets enter the nursing phase with approximately 5 to 8 kg of BW, depending on the weaning age, until transferred to a commercial fattening facility, when piglets are about two month old at least 4 – 5 weeks after weaning, with approximately 18 – 20 kg of BW. Pigs are allocated in the fattening facilities through growing and finishing phase until they reach the slaughter BW at approximately 5.5 or 6.0 months of age weighing 105 kg of BW. Pigs are fed *ad libitum* throughout all their production cycle, starting with the nursing phase just after weaning, the most challenging point due to the fact that when piglets are separated from their mothers they have to adapt to both a new building facilities and change feeding from milk to solid diet.

Observing the data for the different production stages in table 2.3, despite the obvious differences in length of each phase and the subsequent increase in pigs BW and feed intake, the most outstanding information relays in mortality rate values. Nursing and fattening phases have a similar low mortality rate accounting by 3 and 4% with most of the management efforts during these periods oriented to improve animals' feed conversion ratio and to avoid the onset of sanitary problems. In farrowing and lactation phase, mortality rate averages 17 – 18% of the total born piglets, and 11 – 12% of the live born piglets in Spanish farms (BDporc, 2012). Higher mortality during lactation compared to nursing and fattening phase (about 12% compared to 3 – 4%) might be expected due to lower age and more immaturity of the newborn piglet though the differences are remarkable; especially considering that transition to nursery phase is a very stressful and challenging step for piglets.

Based on mortality rate, lactation period may be considered the most critical step in pig production cycle requiring a high demand of attention by producers. Furthermore, the condition in which sows arrives to the lactation period (in terms of physiological stress and body condition), will influence the ease of farrowing and piglet viability in addition to farrowing environment and management.

As it has been shown, swine production is clearly divided in different stages or phases, divided according to the type of animal (sows or pigs), the age of the animals or their physiological state, and, at the same time, these stages are also physically differentiated in different facilities. Among them, from a biological point of view, production cycle of the sow is probably more complex than the production cycle of the pig, where producers have to deal with sows of different ages through different physiological states (e.g. mating, gestation, farrowing and lactation) ending in the lactation period were lactating sows and newborn piglets share the same environment.

Table 2.3 Average values for technical productive parameters obtained during the year 2011 from some Spanish swine commercial farms. Information compiled and published by Observatori del Porcí, 2012).

year 2011	Spain
Lactation	
Number of sows	583,416
Piglets weaned per sow per year	26.12
Total born piglets	12.97
Stillbirth	1.03
Number of piglets weaned per litter	10.5
Mortality rate (from total born piglets)	17.43
Piglet age at weaning, days	23
Weaning to oestrus interval	6.12
Farrowings per year per sow	2.48
Nursing	
Number of piglets	9,250,000
initial BW, kg	6.0
final BW, kg	18.0
Feed conversion ratio	1.69
Feed intake per pig, kg	19.96
Mortality rate	3.2
Length, days	41.6
Growing and finishing phase	
Number of piglets	12,475,503
initial BW, kg	18.3
final BW, kg	105.0
Feed conversion ratio	2.66
Feed intake per pig, kg	229.17
Mortality rate	3.7
Length, days	131.5

As it has been previously stated, to optimize the productivity at the end of the lactation period producers have to differentiate between sows and piglets that will require different management strategies and priorities which, in turn, will vary throughout lactation. On one hand, sow management is focused on maximizing its milk production basically through maximizing energy intake during lactation, with the particularity that management performed during gestation will also influence the success in lactation performance. On the other hand, piglet management is strictly directed to help the animals overcome its neonatal immatureness and to ease its adaptation to the hostile extra-uterine environmental conditions, and then, management is directed to reduce piglet losses and to maximize piglet's body weight at weaning.

* * *

As we have seen during lactation, particularly during early lactation, swine producers have to overcome different hazards coming from either the sows or the piglets, which will jeopardize what it can be considered producers main objective at this phase: maximum colostrum and milk consumption by the piglets. Knowledge on the dynamics and main factors that affect pre-weaning mortality might be useful and might have implications at two different levels:

1) Updated information on aetiology of pre-weaning mortality will provide improved and more accurate guidelines for breeding selection programs. Such information, may contribute to lead the pig industry to re-think and to re-adjust the way pork meat is currently produced, assuming the mentality that has been slowly adopted in the EU (e.g. legislation on the minimum standards for the protection of the pigs). That re-orientation of pig production is evident in sow production, especially during gestation phase, with the introduction of group housing; and presumably it will soon attempt to legislate the farrowing and lactation process to add more welfare improvements in the pork production chain.
2) From a producers point of view, the fact of being aware of the different factors that can be affecting piglet mortality, particularly being aware of the ones that are most relevant and prevalent in their farms, will suppose an extremely valuable information to continue improving farm's productivity, mainly through enhanced hierarchy for management routines and procedures, resulting in an optimisation of stockpeople work and in an improvement in farm productivity and herd welfare.

"i puc lliurar-me al dubte i a la incertesa, al meu estat original, que és la ignorància"

Assaigs (Michel de Montaigne)

Chapter 3:

Objectives

The literature review has highlighted the importance of piglet pre-weaning mortality in the pork production chain. Equally important, it has revealed the complexity of the interactions between the piglet, the sow and the environment that usually underlie per-weaning mortality, and the most important factors influencing piglet mortality and growth. In addition, it has also been manifested that there is a leeway to act reducing pre-weaning mortality through improvements in management and welfare around farrowing. In this broad context, there are some aspects that have been emphasized in the literature review and that need further enlightenment: 1) the concerns on sow's welfare and productivity when placed in the conventional farrowing crates, particularly when moving from group housing systems during gestation, 2) the need for more conclusive scientific evidence on routine management practices, such as colostrum orally supplied to low viable piglets, or cross-fostering strategies and its final impact on piglets performance, and 3) the need for more accurate knowledge on piglets factors influencing its viability in addition to birth body weight.

From the pork industry there is a strong interest on piglet pre-weaning mortality and growth and its economical impact on productivity. In fact, in commercial conditions (Table 2.3) mean piglet's losses during lactation are higher of 15% meanwhile mortality is much lower (less than 10%) along the nursing, growing and finishing phases. Additionally, during the last decade it has been an increasing demand for improved animal welfare in livestock production systems from society, making pork industry to become more interested in improving welfare in commercial herds. Concurrently, from a scientific point of view, management of piglets around farrowing is of great interest to researchers due to the lack of scientific experiences performed with orally supplementation of piglets, and due to the controversial effects of cross-fostering observed so far on piglets' performance. Besides, further study of physiological alterations due to welfare impairment could benefit producers through practical recommendations.

From this mutual interest, three Catalan Agricultural Cooperatives (Cooperativa d'Artesa, Cooperativa d'Ivars and Cooperativa Plana de Vic) started a collaboration in 2008 with researchers from the *Servei de Nutrició i Benestar Animal (SNiBA)* of the *Universitat Autònoma de Barcelona (UAB)*, obtaining, in 2009, public founding from the *Dirección General de Programas y Transferencia de Conocimiento* of the *Ministerio de Ciencia e Innovación* to develop a project of "fundamental research oriented to knowledge transfer to industry" (*TRACE*). The whole project has lasted almost five years and during this time some other private companies joined the project: Sat La Vall farm (Soses, Lleida) from the group Vall Companys; and a breeding herd from Cooperativa Lar (Itaipulândia, Brazil). Those two farms have been very helpful since both have enough herd size (6.500 and 7.000 sows, respectively) to carry out proper experimental designs using the sow as experimental unit.

On this context, the present work has been developed to attain the **main objective** of the project: "to identify the main aspects that may help to reduce on-farm piglet pre-weaning mortality and to establish a management hierarchy identifying the most effective tasks around farrowing".

To achieve the main objective of the project, three specific objectives were formulated:

1. To study the impact of group housing during gestation on the welfare of gilts after being allocated in conventional farrowing crate and its effect on the offspring pre-weaning performance.
2. To study piglet behavioural traits not related to birth weight and their influence on their pre-weaning growth and survival.
3. To study the real impact of colostrum supplementation and different cross-fostering strategies on piglet pre-weaning growth and mortality.

To reach the objectives four experiments were planned and conducted in commercial herds.

"It is better to be lucky. But I would rather be exact. Then when luck comes you are ready"

The old man and the sea (Ernest Hemingway)

Chapter 4:

Effect of gestation management system on gilt and piglet performance

4.1. Introduction and objectives

According to EU Directive 2001/88/CE, group housing of pregnant sows from 4 weeks after mating until 1 week before farrowing is mandatory from January 1, 2013. It has been presented in the literature review that gestation management and housing system have implications for sows' welfare (Anil *et al.*, 2005; Karlen *et al.*, 2007; Marchant and Broom, 1994). Many studies have looked at the possible effects of loose housing during gestation on sow welfare at and after farrowing. Inability to show maternal behaviour near farrowing leads to more active and restless sows when loose-housed during pregnancy compared to those kept in stalls (Baxter *et al.*, 2012a; Marchant and Broom, 1993). Indeed, cortisol levels are higher when loose housed sows are moved to farrowing crates compared to those moved to farrowing pens (Oliviero *et al.*, 2008). Kranendonk *et al.* (2007) observed that offspring can be negatively affected not only by elevated maternal cortisol concentration during gestation but also by a low social rank of their mother during gestation.

A proper control of gestating sows nutrition and body condition in group housing systems is also a concerning issue. As reviewed by Spoolder *et al.* (2009), underfeeding in group housing systems with floor feeding may especially be a problem in the submissive and/or slow-eating sows. Increasing feeding levels in pen housed gilts improves their body condition and decreases cortisol levels in gestation (Amdi *et al.*, 2013). However, few studies on overfed sows during gestation in group housing systems have been done. van der Peet-Schwering *et al.* (2004) found that *ad libitum* fed sows during gestation in a group housing system did not differ in their reproductive performance from restricted fed sows over three reproduction cycles, but more information is required to optimize the transition of gilts and sows from gestation pens to farrowing stalls.

We hypothesized that transition from pen housing with overfeeding to farrowing stalls in gilts should not negatively impact gilt reproductive performance. Thus, the objective of these experiments was to measure the effect of a group housing gestation with an overfeeding management system on gilts adaptation to farrowing stalls and on piglets performance and physiological development compared to gilts housed in stalls during gestation. Finally, despite the banning of gestating stalls in the EU, its comparison with group housing systems could help to identify risk factors and to evaluate group housing influence on the occurrence of farrowing.

4.2. Material and methods

4.2.1. Experimental design and treatments

Two experiments were conducted on a 6,000-sow commercial farm in Lleida, Spain, after being approved by the Institutional Animal Care and Use Committee of the *Universitat Autònoma de Barcelona* (UAB). Gilts (Large white x Landrace) were stall housed from service to 28 day after service. Following confirmation of pregnancy by ultrasound, gilts were moved to the gestation room and randomly allocated to one of the 2 gestation housing systems:

Gilts loose-housed in pens with slightly overfeeding (PEN): Gilts in group pens were housed in 4 pens of 9 gilts each (36 gilts total). All females in a particular pen were not necessarily included in the experiment. Animals were included in the study depending on farrowing date. Pens were concrete floored (6.4 m x 7.5 m; 4.8 m^2/gilt) including a slatted dunging area (7.5 m x 1.1 m) and an automatic feeding system (Evofeed® feeder Erra Tecni-Ram S.L., Spain.) with one feeder per pen. The feeder detected the presence of an animal by a laser detector as soon as the animal introduced its head into the feeder and it delivered a small amount of feed every 30 seconds. Once the sow removed the head from the feeder, it stopped feed delivery. Farmers were able to set the number of sows in the group, along with the kg of feed per sow and per day. In the present experiment the system was set for 9 gilts with an average ingestion of 2.5 kg of feed per sow per day, aiming to slightly overfeed the animals. While eating, gilts were not protected or isolated from their pen mates.

Gilts housed in stalls with regular management (STALL): Gilts were housed in individual concrete floored steel stalls (2.0 m x 0.6 m; 1.2 m^2/gilt) including a 0.5 m^2 slatted dunging area. Feed was provided twice a day with automatic feeders following a standardized feeding pattern. Gilts were fed 2.1 kg/day per gilt until day 90 of pregnancy and 2.8 kg/day per gilt afterwards, resulting in a mean fed amount of 2.2 kg/day per gilt. Feeders were volume regulated and were calibrated for the particular feed used in the trial.

The two systems shared environmental conditions. Temperature was not regulated except for a forced ventilation system set to 20 ºC. All animals in gestation room were fed a commercial diet based on wheat, sunflower meal, wheat bran and rice bran (133 g of Crude Protein, 5.4 g Lys and 12.2 MJ ME per kg as fed) to meet or exceed their nutritional requirements (NRC, 1998). Human grade water was available *ad libitum* during all gestation by nipple drinker. On day 109 of gestation all gilts were moved to a climate-controlled (25 ºC) farrowing room. A total of 6 farrowing rooms with 14 individual farrowing pens each were used. Gilts from the 2 treatments were evenly distributed within each room. Farrowing pens (4.37 m^2) were distributed in 2 rows with a central alley and had plastic slat flooring and a farrowing stall (1.20 m^2) in the centre. Each pen was provided with a creep area for piglets (0.42 m^2) on one side of the pen. Following the usual feeding routine of the farm, when farrowing symptoms were observed the feeder was emptied and gilt was not offered any feed for the following 24 h. The amount of feed offered daily was increased daily until *ad libitum* was reached after 1 week of lactation. Gilts were fed twice a day a dry feed based on wheat, barley, soy bean meal and wheat bran (15 g of Crude Protein, 8.2 g Lys and 13.4 MJ ME per kg as fed) that met or exceeded nutritional requirements (NRC, 1998). Feed leftovers were removed from the feeder and weighed to record ingestion. Gilts and piglets had *ad libitum* access to human grade water in separated nipple drinkers. Procedures performed on piglets included administering a 1 ml iron supplement subcutaneously (Ferrovial, MEVET, Lleida, Spain), tail docking and putting an identification tag in the right ear on the 3rd day post-partum. Weaning was done at 23 ± 2 days of age. During all the experiment the animals were daily checked twice for health or eating problems.

4.2.1.1. Experiment 1

A total of 27 gilts were included in the PEN group and 24 gilts in the STALL group. Back fat thickness was measured on the P2 spot (last rib 65 mm from the dorsal middle line) on both sides of the body using a Renco Lean Meater ultrasound system (Renco Corporation®, North Minneapolis, MN, USA) after they entered into the farrowing room and at day 20 after farrowing. The numbers of piglets born alive, stillborn and mummified were recorded after the farrowing was completed (expulsion of the placenta). Each farrowing event was individually monitored and the birthing time for each piglet was recorded. Assistance was provided to gilts showing contraction efforts 45 min after the last piglet had been born, and gilts that needed assistance during delivery were registered. Piglets were ear notched after birth (339 piglets for PEN group and 331 piglets for STALL group) for individual identification. Piglets were weighed on day 0, 1 (18 to 24 h after birth), 2 (42 to 48 h after birth) and 20 (end of the experimental trial). Piglets were cross-fostered within treatment groups based on their BW on day 2 so that litters had and 12.0 ± 0.08 piglets/litter. Litter pre-weaning mortality and gilts' total feed intake were recorded by checking daily the litters and gilts' feeders during the first 18 days of lactation.

The behaviour of 10 PEN and 8 STALL gilts was continuously videotaped in two rooms with 2 Network IP7142 cameras (Vivotek® San Jose, CA, USA) 2 days before and 2 days after farrowing. Gilt's number of movements (number of times that gilt changed from one posture to another) and time spent in each posture were registered. Postures were described as: lying in sternal, ventral or lateral recumbence; sitting partly erect on stretched front legs with caudal end of body contacting the floor; or standing on extended legs with only hooves in contact with the floor (modified from Wischner *et al.*, 2009).

To assess piglet distribution in the farrowing pens during the first day of lactation, piglets from 13 litters (5 litters from PEN gilts and 8 from STALL gilts) were videotaped with 8 Network IP7142 cameras (Vivotek®, San Jose, CA, USA) during the first 20 h post-partum. Cameras were programmed for a scan-sampling (30 seconds recordings every 10 min) starting after the delivery of the last part of placenta and the first clear image of each recording was used. Position of the sow was recorded as, lying with the udder exposed to the creep area or exposed to the other side of the pen. Piglet distribution was described by the following areas: mammary gland area including any piglet standing, suckling, massaging the udder, lying, or sleeping next to or in contact with the udder; creep area including any piglet standing, lying, or sleeping on the creep area; and other areas including any piglet being in an area of the farrowing pen not previously described.

4.2.1.2. Experiment 2

A total of 10 gilts were included in the PEN group and 9 gilts in the STALL group. The variables recorded for sows during lactation in Exp. 2 were the same as described for Exp. 1. Gilts were individually monitored during farrowing as described for Exp. 1. Shortly after birth, piglets from the individually monitored sows were ear notched for individual identification (117 piglets for PEN group and 102 for STALL groups) and their rectal temperature (RT) was recorded 1, 24 and 48 h (RT1, RT24 and RT48) after birth

(MSR thermometer, Measure Technology Co. Ltd; Taipei, Taiwan, with a display resolution of 0.01 ºC and an ± 0.1 ºC accuracy). Piglets were weighed on day 0, 1, 2 and 17 (end of the experimental trial). Cross-fostering was performed at 48 h of age obtaining litters with 12.4 ± 0.18 piglets/litter. Mortality was registered as described in Exp. 1. Then, all piglets that died within the first 48 h of life were weighed and classified as culled, crushed with colostrum or milk in the stomach, crushed without colostrum or milk in the stomach, or starved to death. All piglets that died after the first 48 h of life were classified as crushed, starved to death, dead following diarrhoea and dead from other causes. A piglet was classified as crushed when internal or external traumas were visible.

Saliva samples to measure cortisol were collected from 12 gilts from the PEN group and from 19 gilts from the STALL group 24 h after entering the farrowing rooms and again during the last week of lactation. Saliva samples were collected between 1000 and 1200 h using cotton swabs (Salivette®, Stardedt, Nümbrecht, Germany). Gilts were allowed to chew on the Salivette® for approximately 30 seconds. Samples were centrifuged at 3000 x *g* for 15 min at 5 ºC and stored frozen at -22 ºC until analyzed. Cortisol was measured in salivary samples with a luminescence immunoassay kit (DRG Instruments, Marburg, Germany). A 3 ml blood sample from 2 piglets of each monitored gilt was obtained when the umbilical cord was severed (20 piglets for PEN group and 18 for STALL group). Blood was centrifuged at 2000 x *g* for 10 min at 18 ºC within 30 min and the serum was stored frozen at -22 ºC for thyroid-stimulating hormone (TSH) and thyroid hormone (TH) T4 analysis. TSH was measured in serum samples with a third generation TSH Immulite® kit (Siemmens, Deerfield, USA) and T4 was measured in serum samples with a total T4 Immulite® kit (Siemmens, Deerfield, USA).

4.2.2. Statistical analysis

All statistical analyses were carried out using SAS 9.2 (SAS Inst. Inc., Cary, NC). All data were explored to determine distribution using Univariate procedure of SAS. In all cases gilt or litter was the experimental unit, except for TSH and T4 analysis where the piglet was the experimental unit. The alpha level of significance was set at 0.05. Data from sows and mortality were analyzed merging the two experiments and including "Exp." in the model as random effect. Data from piglets was analyzed separately because of the different measuring moments or days. Obviously, data measured exclusively in one of the two experiments was analyzed independently. Differences between treatments for BF, BF loss during lactation, duration of farrowing, mortality, number of piglets weaned and sows' total feed intake were analysed with general linear models using the GLIMMIX procedure of SAS. The model included the treatment as a fixed effect for all variables and the assistance at farrowing was included as a fixed effect for the duration of farrowing. Number of piglets per sow after cross-fostering was introduced as covariate for the number of weaned piglets. Total number of piglets born alive, stillborn and mummified were analysed by generalized linear models using GENMOD procedure of SAS following a negative binomial distribution and with treatment as the main effect. Sow cortisol concentration in saliva and piglet serum concentration of TSH and T4, BW, BW gain and RT parameters were analysed by general linear mixed models using MIXED procedure of SAS. The model included treatment as fixed effect and farrowing room as random effect. For BW and RT, initial BW was introduced as a covariate and sow as random effect nested to treatment. The interaction between treatment and initial BW was also included in the model.

The percentage of piglets in each area of the pen were analysed by generalized linear mixed models using the GLIMMIX procedure of SAS. The model included treatment and posture of the gilt (udder exposed towards the creep area or udder exposed towards the opposite side of the pen) as fixed effects and the interaction between them was also included. Behavioural traits for gilts were analysed by repeated measures using the MIXED procedure of SAS. The model included treatment and day of sampling as fixed effects and the interaction between treatment and day of sampling were also included.

4.3. Results

Gilts performance and litter mortality results obtained after merging the data from the 2 experiments are presented in table 4.1. When entering the farrowing rooms, gilts from the PEN group had higher BF than gilts from the STALL group ($P < 0.001$). Although PEN gilts lost more BF than STALL gilts ($P < 0.001$) during lactation, PEN gilts still had more BF than STALL gilts at weaning ($P < 0.001$). There was a tendency for PEN gilts to have shorter total farrowing time (interval between the birth of the first and the last piglet) than STALL gilts ($P = 0.067$) and also a tendency for lesser time between the birth of the first and tenth piglet ($P = 0.054$). No differences were observed between treatments for farrowing performance traits (piglets born alive, stillborn and mummified). STALL gilts tended to have higher total feed intake during lactation than PEN gilts (P = 0.052). Piglet mortality during the first 2 days of lactation (before cross-fostering) did not differ between groups (P = 0.674), but from cross-fostering (at 48 h post-partum) to the end of lactation, mortality was higher in PEN than in STALL litters (P = 0.001). However, overall pre-weaning mortality did not differ between groups (P = 0.346). At the end of lactation, STALL gilts weaned more piglets than PEN gilts (11.9 vs. 11.1 ± 0.02; P < 0.001).

Table 4.1 Effect of gestation management system on gilt's back fat, farrowing duration, reproductive performance, total feed intake during lactation and litter mortality (Exp. 1 and Exp. 2)

Variable	PEN	STALL	SEM	*P*-value
n	37	33	-	-
Initial BF[1], mm	19.4	15.0	0.78	<0.001
Final BF[2], mm	15.7	13.1	0.64	<0.001
BF loss[3], mm	3.7	1.9	0.39	<0.001
First 10 piglets[4], min	118	134	15.9	0.054
Farrowing duration[5], min	167	189	19.1	0.067
Lactation total feed intake, kg	109	113	6.0	0.052
Litter size				
Born alive	13.3	13.8	0.04	0.337
Stillbirth	0.78	0.77	0.244	0.567
Mummified foetuses	0.78	0.77	0.276	0.974
Mortality, %				
first 48 h of life	11.5	8.7	0.38	0.674
from day 2 to weaning	6.5	1.9	0.40	0.005
Total mortality	18.9	11.8	0.07	0.346

[1]Back fat thickness measured when entering the farrowing facilities; [2]Back fat thickness measured at the end of the experiment (day 20 after farrowing); [3]Initial BF – Final BF; [4]Time between the birth of the first and tenth piglet; [5]Time between the birth of the first and the last piglet.

Results from piglet productive performance in Exp. 1 are presented in table 4.2. There were no differences between experimental groups for piglet BW after birth (day 0), at day 1 and at day 2, but piglets born from STALL gilts tended to grow faster than PEN piglets during the first 24 h of life (*P* = 0.059). However, at the end of lactation period, there were no differences between groups for piglet performance, and piglets from both groups did not differ in BW (*P* = 0.397) or ADG (*P* = 0.185) at day 20. Behavioural data (Table 4.3) shows that gilts from both experimental groups spent most of the day lying, but lying time was reduced when farrowing approached (on average 22 – 23 h and 19 – 20 h of day on day 2 and day 1 before parturition respectively). On day 1 before parturition, the number of movements per day increased in both groups, and on day 1 and day 2 after parturition gilts from both groups showed a number of movements per day similar to day 2 before parturition. There was no effect of treatment in the number of movements during day 2 before parturition and day 1 after parturition (*P* = 0.154 and *P* = 0.291, respectively). However, PEN gilts tended for more movements during day 1 before parturition and day 2 after parturition (*P* = 0.083 and *P* = 0.090 respectively). During day 1 before parturition gilts from PEN group tended to spend more time in sitting or standing position (*P* = 0.057) than gilts in STALL group. Concerning piglet distribution in the farrowing pen, there was a higher percentage of piglets in close contact to the udder during the first 20 h of life in STALL gilts than in PEN gilts (64.7 ± 1.02% vs. 53.1 ± 1.19%; *P* = 0.031).

Table 4.2 Effect of gestation management system on piglet's performance during lactation (Exp. 1)[1]

Item	PEN	STALL	SE	*P*-value
n	27	24		
BW, kg				
after farrowing (day 0)	1.30	1.28	0.012	0.485
day 1	1.37	1.39	0.013	0.475
day 2	1.39	1.44	0.028	0.207
day 20	5.50	5.60	0.002	0.397
BW gain the first 24 h post-partum, kg	0.042	0.059	0.0033	0.059
ADG from day 2 to 20 of life, kg/day	0.220	0.227	0.0021	0.185

[1]All data presented as LSmeans.

Table 4.3 Effect of gestation management system on the activity of gilts during the 2 days before and after parturition, recorded for a 24 h period each day (Exp. 1)

Item	PEN	STALL	SE	*P*-value
n	10	8		
No. of movements				
Day 2 before parturition	68	49	5.5	0.154
Day 1 before parturition	206	154	13.5	0.083
Day 1 after parturition	53	38	5.9	0.291
Day 2 after parturition	52	47	4.6	0.090
Min sitting or standing[1]				
Day 2 before parturition	102 (7.1 %)	72 (5.0 %)	10.1	0.451
Day 1 before parturition	280 (19.4 %)	230 (16.0 %)	28.1	0.057
Day 1 after parturition	91 (6.3 %)	78 (5.4 %)	13.3	0.646
Day 2 after parturition	94 (6.5 %)	77 (5.3 %)	19.6	0.644

[1]Minutes spent by gilts in sitting or standing position of a total of 1,440 min recorded (percentage of the total time recorded).

Results from piglet productive parameters and RT in Exp. 2 are presented in table 4.4. Piglets born from STALL gilts had higher RT1 (*P* = 0.007), RT24 (*P* = 0.026) and RT48 (*P* = 0.007) than piglets born from PEN sows. Piglets born from PEN gilts had higher BW on day 0 than piglets born from STALL gilts (*P* = 0.019). However, piglet BW on day 1 and BW gain from day 0 to day 1 did not differ between groups (*P* = 0.222 and *P* = 0.189, respectively). Piglets born from STALL gilts had higher BW on day 2 (*P* = 0.008), higher BW on day 17 (*P* = 0.028) and an increased ADG at the end of the trial (*P* = 0.025) than PEN piglets. During the first 48 h post-partum, the number of piglets culled, crushed without colostrum or milk in the stomach, crushed with colostrum or milk in the stomach, or starved to death did not differ between experimental groups (*P* = 0.118, *P* = 0.206, *P* = 0.392, *P* = 0.100, respectively). After cross-fostering and until day 17 of lactation, the number of piglets found crushed, starved to dead, dead with diarrhoea symptoms, or dead by an unknown reason did not differ between groups (*P* = 0.206, *P* = 0.100, *P* = 0.471, *P* = 0.164, respectively).

Table 4.4 Effect of gestation management system on piglet's rectal temperature and growth performance during lactation (Exp. 2)[1]

Item	**PEN**	**STALL**	**SE**	***P*-value**
n	10	9	-	-
Rectal temperature, ºC				
60 min after birth	37.0	38.1	0.27	0.007
24 h after birth	38.3	38.6	0.03	0.026
48 h after birth	39.0	39.2	0.03	0.007
BW, kg				
after farrowing (day 0)	1.43	1.23	0.019	0.019
day 1	1.33	1.37	0.021	0.222
day 2	1.39	1.47	0.022	0.008
day 17	3.74	4.37	0.079	0.028
BW gain the first 24 h post-partum, kg	-0.001	0.044	0.0004	0.189
ADG from day 2 to 17 of life, kg/day	0.140	0.178	0.004	0.025

[1]All data presented as LSmeans.

Cortisol levels obtained from saliva samples collected 24 h after entering the farrowing room tended to be higher in PEN gilts than in STALL gilts (10.21 ± 1.050 nM/l vs. 8.17 ± 0.668 nM/l; P = 0.070), whereas no difference between PEN and STALL gilts was observed in the last week of lactation for cortisol levels (5.80 ± 0.658 nM/l vs. 6.35 ± 0.656 nM/l; P = 0.639). Piglets born from STALL gilts tended to have higher levels of serum T4 than piglets born from PEN gilts (7.91 ± 0.480 □g/dl vs. 6.75 ± 0.393 □g/dl; P = 0.078). However, no differences were found between STALL and PEN piglets in TSH levels in serum (0.035 ± 0.0056 □gU/ml vs. 0.038 ± 0.0057 □gU/ml; P = 0.814).

4.4. Discussion

As we expected, in our study PEN gilts entered the farrowing facilities in higher body condition than STALL gilts. Sows that eat more than their physiological needs will gain more weight and more BF than required (Spoolder *et al.*, 2009). During lactation, PEN gilts lost more BF compared to STALL gilts and showed a tendency for a lower feed intake during lactation. Eissen *et al.* (2000), van der Peet-Schwering *et al.* (2004), and Yang *et al.* (1989) found that sows with higher BW and BF at the end of gestation lost more BW and BF during lactation with no reduction in feed intake. However, Amdi *et al.* (2013) showed that a higher ingestion during gestation induced a higher body condition at farrowing and a reduction in lactation feed intake.

Reproductive performance did not differ between groups. McGlone *et al.* (2004) in their meta-analysis of 35 scientific papers found no differences between pen and stall gestation housing systems in reproductive performance (total number of piglets born, piglets born alive and stillborn piglets). van der Peet-Schwering *et al.* (2004) also failed to find differences in reproductive performance between stall housed and group housed sows. However, Jansen *et al.* (2007) reported that stall housed sows tended to have larger litter size. According to Spoolder *et al.* (2009), higher weight and BF gains during gestation does not seem to affect short term reproductive performance; however Amdi *et al.* (2013) showed a lower number of piglets born alive in gilts fed more than recommended. Amdi *et al.* (2013) also found that piglets born from overfed gilts were heavier as we observed in Exp. 2 (but not in Exp. 1) where PEN piglets had higher BW on day 0 than STALL piglets. There was also a trend for faster delivery in PEN gilts for both the first 10 piglets born and the total farrowing time. Hemsworth (1982) and Oliviero *et al.* (2010) observed that allocating sows in groups during gestation and allowing them to move freely before farrowing might help shortening farrowing time.

In both experiments piglets from the STALL group showed a better growth during the first 24 h of life and, in Exp. 2, such differences were also observed at day 2 and at the end of the lactation period. These differences may be related to the differences observed for RT after birth and also on the following days. Differences in RT shortly after birth indicate a greater thermoregulatory capacity in STALL piglets than in PEN piglets. Cold stress at birth reduces the vigour of the piglet, leading to a less active nursing behaviour and reducing colostrum intake (Alonso-Spilsbury *et al.*, 2007; Baxter *et al.*, 2008; Herpin *et al.*, 2002), which provides newborn piglets with energy and immunoglobulins, therefore playing an essential role in piglet survival (Quesnel, 2011). The higher thermoregulatory capacity showed by STALL piglets may improve their suckling ability enhancing piglet's growth during the first days of life, and also enhancing its survival from day 2 to weaning as observed in the study. The lack of difference between groups for the cause of death, especially for deaths due to starvation and the increased mobilization of BF during lactation by PEN gilts may suggest that milk yield might not be impaired. Alonso-Spilsbury *et al.* (2007) pointed out that piglets suffering from asphyxia had lower rectal temperatures 1 h after birth. In our study, however, it is unlikely that asphyxia was causing the differences in RT 1 h after birth, because PEN gilts had faster deliveries than STALL gilts, whereas STALL piglets showed a higher RT 1 h after birth.

In Exp. 1, gilts showed an increase in activity 1 day before farrowing compared to the other days of the study. These results agree with those observed by Mainau *et al.* (2009). Concerning treatments, PEN gilts tended to spend more time standing up or sitting up and also tended to change position more often than STALL gilts on day 1 before farrowing. Other authors have reported that sows that have been housed in pens during gestation are more active and restless when they are moved to farrowing stalls as a consequence of adapting their behaviour to the new environment (Beattie *et al.*, 1995; Boyle *et al.*, 2000; Harris and Gonyou, 1998; Marchant and Broom, 1993). Lawrence *et al.* (1994) suggested that close confinement at farrowing of previously loose-housed gilts could induce psychological stress by interfering with the expression of maternal behaviour. However, Biensen *et al.* (1996) related sow detrimental maternal behaviours to prolonged time interval between piglet births. We did not find a similar effect for PEN gilts in the present study. The expected better muscular condition of PEN gilts may counteract the negative effect of crating interfering with the maternal behaviour on parturition length. Nevertheless, the higher saliva cortisol showed by PEN gilts 24 h after entering the farrowing stall may indicate a higher stress level, idea supported by the higher activity level described above. The lack of behavioural and physiological differences between groups at the end of lactation suggests that PEN gilts are able to adapt to the new situation during lactation.

Piglets born from PEN gilts tended to have lower concentration of T4 than STALL piglets. Thyroid hormones, T3 and T4, are known to increase metabolic rate and thermogenesis in homeothermic species (Hampl *et al.*, 2006; Litten *et al.*, 2008; Silva, 2006). Berthon *et al.* (1993) found that piglets with lower plasma level of T4 during the first 6 h of life also showed a greater drop in RT after birth. As described by Finsten *et al.* (1998) TH are released by the thyroid gland in response to stimulation by TSH from the hypophisis which is in turn stimulated by the hypothalamic tripeptide thyrotropin-releasing hormone (TRH) secreted by the HPA axis. Maternal prenatal stress has been observed to affect behavioural and physiological aspects of the offspring by altering the HPA (Kaiser and Sachser, 2001; Kranendonk *et al.*, 2007; McCormick *et al.*, 1995).

Increase in feed intake during gestation has been shown to decrease cortisol levels in gilts (Amdi *et al.*, 2013), however, moving PEN gilts to farrowing stalls still increased cortisol levels more than for STALL housed gilts. Thus, PEN gilt's higher prenatal stress may be impairing piglet early thermoregulation. Darwish and Ashmawy (2011) found that ewes that were stressed at lambing delivered lambs with lower T4 levels and lower RT compared with non-stressed ewes. Berthon *et al.* (1993) also found that thyroid function during the late intra-uterine period has large effect on thermoregulatory capacity after birth.

In summary, group housed gilts slightly overfed during gestation did not have worse farrowing performance than stall housed gilts. However, the greater stress suffered for gilts that have been housed in pens during pregnancy when moved to farrowing crates compared to gilts that have been housed in stalls may have impaired the thyroid function of piglets before birth and may have reduced their thermoregulatory capacity. Pen housing systems may need longer adaptation periods for gilts when moved to farrowing facilities or may work better combined with pen farrowing systems instead of farrowing crates.

"Hi ha més d'una saviesa en aquest món, i totes li són igual de necessàries; no és pas dolent que s'alternin"

Memòries d'Adrià (Margarite Yourcenar)

Chapter 5:

Piglet behaviour as a measure of vitality and its influence on piglet survival and growth during lactation

5.1. Introduction and objectives

As it has been previously introduced in the literature review, the management strategies that are usually performed after farrowing are mainly based on piglet BW at birth. However, many animals do not properly respond to those actions. Body weight may be the main but not the only predictor of the viability (defined here as survival with adequate growth) of piglets. Piglet behaviour or vitality (defined here as physical strength, or vigor) may also be useful in order to determine individual piglet viability.

Several authors have studied physiological variables such as heart rate or muscle tone of the newborn piglets and their relation with piglet viability (Casellas *et al.*, 2004; Randall, 1971; Zaleski and Hacker, 1993). Other authors have related piglet neonatal vitality with its survival during lactation (Baxter *et al.*, 2008; Herpin *et al.*, 1996). All the studies mentioned above reflect directly or indirectly the physical strength or vigor of the newborn piglet. However, all the parameters were obtained during piglets' first minutes after birth, which may not be feasible in a commercial setting.

Therefore, the objective of the present study was to propose a novel practical vitality scoring method, which can be used once farrowing ends, and to relate it with piglet survival and growth during lactation. Such vitality score, combined with birth BW, could become a practical tool in order to help farmers to improve management decisions with their piglets.

5.2. Material and methods

5.2.1. Animals, housing and management

All experimental procedures involving animals were conducted on a commercial farm in Catalonia, Spain, after being approved by the Institutional Animal Care and Use Committee of the *Universitat Autònoma de Barcelona* (UAB).

A total of 287 piglets born from 21 randomly selected sows (Large White x Landrace) between second and sixth parity were used in this experiment. Sows were kept in individual stalls (1.2 m^2) during gestation and fed a commercial gestation diet according to (NRC, 1998) requirements. At day 109 of gestation sows were moved to climate-controlled farrowing rooms (22 ºC) and placed in individual farrowing crates

(1.20 m^2) which were located in the centre of farrowing pens (4.37 m^2). Pens were fully slatted with plastic slats and with steel slats under the farrowing crate located over a manure pit. Each pen was provided with one heating plate set at 30 ºC for piglets (0.42 m^2) placed on the floor on one side.

On farrowing day sows were not offered feed. During lactation period, following farm's usual feeding routine, sows were fed twice a day increasing the daily amount of feed offered according to litter size and sow's body condition until *ad libitum* was reached after 1 week of lactation. Sows and piglets had *ad libitum* access to water. Farm's usual procedures performed on the piglets included a 1 ml iron supplement given subcutaneously (Ferrovial, MEVET, Lleida, Spain), tail docking, and a farm identification tag clipped in the right ear at day 3 post-partum. Weaning took place at 23 ± 2 days of age.

5.2.2. Experiment development

Sow's BF was measured on P2 spot (on the last rib 65 mm down the dorsal middle line) on both sides using an ultrasound system Renco Lean Meater (Renco Corporation®, North Minneapolis, MN, USA) when entering the farrowing room and at the end of experimental period (day 17 post-partum). Sow's productive parameters were also recorded: total piglets born, number of piglets born alive, stillbirth, and mummified. Number of piglets that died during lactation period was registered differentiating between before and after cross-fostering.

Within 3 h after the end of the farrowing, piglets were individually evaluated for 4 parameters depending on an observational evaluation (Table 5.1) to determine the vitality score: movement capacity (M), udder stimulation (U), number of completed circles around the enclosure (N) and screaming (S). The end of the farrowing was considered after placental expulsion. All the sows that needed intervention during farrowing were excluded from the experiment, and piglets were not removed from the dam after birth. Each piglet was given a score for each of the four parameters during a 30 seconds test, according to the definitions in table 5.1. For the observations, piglets were separated from the litter and introduced in to a 55 cm diameter x 60 cm height solid plastic enclosure, open at the bottom and at the top. The enclosure was located in the isle, over solid floor, in front of the crate. If a litter was in a sleeping period, we waited and did the test once they were awake.

Table 5.1 Description of the behavioural parameters evaluated to establish the vitality of the piglets

Movement capacity (M)
0: Unable to keep a voluntary position
1: Able to keep a voluntary position but unable to move (unable to turn its body axis more than 90º from its initial orientation)
2: Moving "slowly" (able to turn its body axis more than 90º from its initial orientation within 30 seconds)
3: Moving "fast" (able to turn its body axis more than 90º from its initial orientation within 15 seconds)
Udder stimulation (U)
0: Shows no head movements emulating udder stimulation movements or searching behaviour within 30 seconds
1: Shows head movements emulating udder stimulation movements or searching behaviour within 30 seconds
Number of completed circles around the enclosure (N)
0: Not able to turn its body axis 360º from its initial orientation nor able to walk along the limits of the bucket
1: Able to turn its body axis 360º from its initial orientation or walk along the limits of the bucket once within 30 seconds
2: Able to turn its body axis 360º from its initial orientation or walk along the limits of the bucket at least twice within 30 seconds
Screaming (S)
0: The piglet does not scream during the manipulation/observation time
1: The piglet does scream during the manipulation/observation time

Vitality test parameters were mainly based on previous observation of piglets and also literature. Parameter M was developed as a practical simplification of the test developed by Randall (1971) based on an Apgar (1953) and modified later by Zaleski and Hacker (1993), Herpin *et al.* (1996), Casellas *et al.* (2004), Baxter *et al.* (2008), Orozco-Gregorio *et al.* (2008), and González-Lozano *et al.* (2010). Parameter N was developed based on the importance of birth-to-suckling interval or time to reach the udder as a vitality index (Bate and Hacker, 1982; Baxter *et al.*, 2008; González-Lozano *et al.*, 2010; Hacker *et al.*, 1979; Orozco-Gregorio *et al.*, 2008; Tuchscherer *et al.*, 2000). Parameter U was developed as an indirect assessment of piglet's capacity for suckling and stimulating a teat. Different authors have used the number of teats suckled during the first 2 h of suckling (Hacker *et al.*, 1979), the capacity for taking the first colostrum (Tuchscherer *et al.*, 2000) or latency to suckle (Baxter *et al.*, 2008) as vitality measures. Finally, parameter S was based on the fact that piglet's distress calls or screams could induce posture changes in the sows preventing piglet from crushing (Wechsler and Hegglin, 1997).

After the vitality test was performed, piglet's RT was measured with a digital thermometer (MSR, Measure Technology Co. Ltd; Taipei, Taiwan, with a display resolution of 0.01 ºC and an ± 0.1 ºC accuracy), and they were weighed, and ear-tagged for individual identification purposes. On day 1, 2, and 3 post-partum, piglets were weighed and RT was measured. Piglets were weighed again at the end of the experiment (day 17 post-partum). Twenty-four hours after birth, litters were fixed at 12 or 13 piglets per litter. Cross-fostering was limited to necessary changes to minimize possible effects on piglets.

5.2.3. Statistical analysis

To investigate the piglet vitality measures that may influence the dependent variables piglet BW gain at weaning and survival, a multivariate model was developed for each dependent variable. Statistical analyses were performed using SAS program version 9.2 (SAS Inst. Inc., Cary, NC). Univariate analysis was performed to check variables for normality and to identify outlier candidates. A bivariate analysis using Pearson correlation, Spearman rank correlation, and chi-square test was carried out to study collinearity, especially among vitality parameters (M, U, N, and S) and other explanatory variables. Any collinearity problem was solved not considering the covariate with the lower correlation to dependent variables (piglet BW gain at weaning and piglet survival) in the multivariate analysis.

For the multivariate regression analysis, the effect of vitality parameters, litter average weight, total piglets born, number of piglets born alive, stillbirth and mummified piglets, sow's parity number, piglet's RT and birth weight (independent variables) on piglet BW gain at weaning and piglet survival (dependent variables) were analyzed by general and generalized linear models using REG, GLM, and GLIMMIX procedure of SAS. All potential predictive variables were introduced as fixed effects and removed based on significance in order to avoid over parameterization. Litter was initially considered as a random variable but was removed from the model due to lack of significance. Once a final multivariate model was obtained for each dependent variable, the model was fitted also including the sum of the significant vitality parameters and not the single parameters. It would allow for a more practical approach with a single criterion of classification for piglets. Alpha level for determination of significance was 0.05.

5.3. Results

Sows had an average BF when entering the farrowing room of 15.8 ± 3.99 mm, and an average BF at the end of lactation period of 13.0 ± 3.34 mm. Average number of piglets born alive per litter was 13.6 ± 2.34, the average of stillborn and mummified piglets per litter was 0.76 ± 1.300 and 0.67 ± 1.017 respectively. Piglets were born with an average birth weight of 1389 ± 333.4 g, and an average RT measured within 3 h after the end of parturition was 38.0 ± 0.86 ºC (Table 5.2). Descriptive statistics for all the measures recorded from piglets during the experimental period are shown in the table 5.2.

Table 5.3 shows the distribution of scores obtained for the piglets for each vitality parameter evaluated (M, U, N, and S). At the end of the experiment, sows weaned 11.7 ± 1.31 piglets per litter. Mortality calculated as piglets per litter after cross-fostering was 9.2 ± 2.21%. Mortality calculated as number of piglets born alive was 10.7 ± 2.25%.

Table 5.2 Rectal temperature and growth of piglets throughout the experiment

Item	n	Mean	Min.	Max.	CV, %	SD
Rectal temperature (RT), °C						
After farrowing[1]	287	38.0	32.5	39.8	2.27	0.86
24 h post-birth	283	38.3	34.9	39.8	1.97	0.75
48 h post-birth	264	38.9	34.0	40.3	1.46	0.57
72 h post-birth	264	39.2	38.1	40.7	0.98	0.38
RT gain after 24 h	284	0.3	-2.2	5.1	281.91	0.84
RT gain after 48 h	264	0.8	-1.7	4.9	93.43	0.79
RT gain after 72 h	264	1.1	-0.7	5.1	57.32	0.66
Body weight, g						
After farrowing[1]	287	1389	532	2382	24.0	333.4
24 h post-birth	283	1458	516	2453	24.1	351.9
48 h post-birth	268	1632	678	2732	20.7	337.8
72h post-birth	265	1800	887	2847	19.8	355.6
At weaning (day 17)	247	4802	1244	7067	21.7	1041.3
Body weight gain (BW gain), g						
BW gain after 24 h	283	61.6	-259.0	355.0	127.96	78.88
BW gain after 48 h	267	208	-205	572	56.4	117.2
BW gain after 72 h	264	3721	-332	729	41.4	153.8
BW gain at weaning (day 17)	246	3375	252	5319	26.3	889.0
ADG at weaning (day 17)	246	198.6	14.8	312.9	26.33	52.29

[1] Taken approximately 3 h after the completion of farrowing

In the bivariate analysis, parameter M of vitality was strongly related with parameters U and N (χ^2 = 46.65 and χ^2 = 35.96 respectively, P < 0.001). This parameter also showed the lowest correlation to the dependent variables, thus, it was removed from the model in order to avoid collineality problems. There was no correlation between U and N parameters (χ^2 = 1.96, P = 0.375) and neither U nor N were correlated with BW after farrowing (r = 0.089, P = 0.133; and r = -0.018, P = 0.758 respectively), or RT after farrowing (r = 0.0118, P = 0.842 and r = -0.0929, P =

0.116 respectively). No correlation among parameter S of vitality and other explanatory variables was found in the bivariate analysis (*P* > 0.10). Thus, three independent variables, U, N, and S were included in the multivariate analysis. Piglet's BW gain at weaning was correlated with BW after farrowing and BW gain at 48 h of life (r = 0.392, *P* < 0.001, and r = 0.328, *P* < 0.001 respectively). The first was kept for the multivariate analysis based on its better r (and biological meaning) in order to avoid collinearity problems. Piglet's RT within 3h after end of parturition was correlated with RT 72 h after birth and BW after farrowing (r = 0.279, *P* < 0.001; and r = 0.399, *P* < 0.001 respectively). Thus, RT was removed from the multivariate analysis because it had a worse r to dependent variables than RT 72 h after birth.

Table 5.3 Piglets scoring frequency distribution for the different vitality parameters

	Frequency	Percentage
Movement capacity		
0	15	5.2%
1	62	21.6%
2	81	28.2%
3	129	44.9%
Udder stimulation		
0	15	5.2%
1	272	94.8%
Number of completed circles around the enclosure		
0	47	16.4%
1	240	83.6%
Screaming		
0	232	80.8%
1	55	19.2%

The final multivariate models for BW gain and survival at weaning including parameters measured from the piglet, information obtained from the sow, and both U and N are described below. Parameter U had the highest correlation with BW gain at weaning and piglet survival (r = 0.111, *P* = 0.084; and r = 0.110, *P* = 0.063

respectively). Parameter S of vitality was neither correlated with BW gain nor with survival and it was not considered for the final multivariate models.

The final multivariate BW gain model included piglet BW after farrowing as the most influential piglet factor (F 1, 230 = 54.6; $P < 0.001$). The sow factors of number born alive and parity number were influential (F 8, 230 = 5.73; $P < 0.001$ and F 3, 230 = 3.2; $P = 0.024$ respectively), in addition to average litter weight (F 2, 230 = 4.32; $P = 0.015$). The model showed a better fit including the sum of the U and N vitality parameters instead of both U and N separately. Sum of U and N was an influential parameter for piglet BW gain at weaning (F 1, 230 = 5.25; $P = 0.023$). The overall significance for the model was $P < 0.001$ with a coefficient of variation (CV) = 21.94 and $R^2 = 0.35$.

The final multivariate survival model included only piglet factors. Piglet BW after farrowing and RT at 72 h of life were influential with F 1, 259 = 5.97 ($P = 0.015$) and F 1, 259 = 2.99 ($P = 0.085$) respectively. The model including the sum of the U and N vitality parameters showed better fit than the one including both separately. Sum of U and N was an influential parameter of piglet's survival (F 1, 259 = 4.98; $P = 0.026$). The Wald test of significance for the model was $P = 0.027$.

5.4. Discussion

Most of the attempts to find an objective index in order to predict newborn piglet's viability (Randall, 1971; Zaleski and Hacker, 1993) have been defined in experimental conditions but are difficult to apply to commercial conditions. Aiming to develop an objective index easy to perform in commercial conditions, we evaluated piglet's vitality with 4 parameters (M, U, N, and S) and we related these parameters to survival and growth of newborn piglet. The 4 parameters were initially considered independent. However, M was dismissed because it showed a strong relation with U and N. The observed correlation may result from the fact that characteristics of piglet movement (M) may also be measured during measurement of U and N.

Parameter S was independent from the rest of the vitality measures. However, the results showed that screaming during the test did not increase piglet chance to survive nor influenced its growth. Our results agree with Illmann *et al.* (2008) who found that sows only reacted in 50% of trappings to the screams of their piglets. Held *et al.* (2006, 2007) also failed to show a relationship between responsiveness in a Piglet

Scream Test and piglet mortality in outdoor sows. On the other hand, Wechsler and Hegglin (1997) found that sows with higher responsiveness to playbacks of piglet distress calls had fewer trapped piglets crushed and Andersen *et al.* (2005) observed that sows that did not crush any piglet during lactation showed a more protective mothering style. Differences in sow's responses to a squealing piglet may be much more influential on survival than piglet screaming capacity. Moreover, in our experiment we only recorded the presence of screaming while performing the test, not its type or intensity. We may not have been measuring the right type of vocalization for survival (Von Borell *et al.*, 2009). Further studies on the effect of different type of stress calls and its frequency or intensity on survival would be of interest.

Parameter U showed the best correlation to piglet's BW gain and survival. This result indicates that our hypothesis of using U in order to evaluate the udder stimulation capacity of the piglet and thus, its milk intake capability may be plausible. Piglet ability to move forward (N) and to stimulate the udder (U) might be positively associated with piglet capacity to reach the udder, maintain suckling, and thus promote sow's milk production and piglet's survival and growth. In our final multivariate survival and growth models, combination of U and N parameter as one unique parameter UN was an even better option which simplifies its on-farm application.

As we expected, piglet's BW after farrowing was the most influential variable for both BW gain and survival. Our results are in agreement with Baxter *et al.* (2008), Casellas *et al.* (2004), Pedersen *et al.* (2011a), and Tuchscherer *et al.* (2000) who found that birth weight was one of the most important covariates for postnatal survival. As we observed in our study, many authors have also observed a positive relationship between birth weight and growth (Castren *et al.*, 1991; Fix *et al.*, 2010; Litten *et al.*, 2003). Furthermore, litter average weight after cross-fostering was also an influencing factor in the multivariate growth model. It may be related to the observation made by Milligan *et al.* (2001) that sows with a low within-litter birth weight variation had lower within-litter weaning weight variation, showing the importance of allocating piglets between litters to achieve similar weight. Piglet RT at 72 h of life was also an influencing factor in the multivariate survival model. In concordance, Baxter *et al.* (2008) observed higher RT 24 h after birth in surviving piglets.

Sows are also important subjects for neonatal piglet studies because piglet growth depends in great measure on sow's characteristics and milk production. Our multivariate growth model included 2 sow parameters that could influence milk production: number of piglets born alive and parity number. Hoshino and Koketsu (2009) indicated that sows with increased number of mummified and stillbirth piglets had low milk yields. On the other hand, Eissen *et al.* (2000) pointed that milk production decreases after fourth parity. Piglets born alive and parity number are usually recorded in the farm and are easy to obtain while evaluating the piglets. In fact, these two parameters are usually considered when cross-fostering is used.

This study has identified 2 behavioural traits (udder stimulation and number of completed circles around the enclosure) easy to assess after birth and not correlated to birth BW that reflect vitality of the piglet and may help to predict piglet's viability as a complementary/alternative to parameters proposed so far in the literature. These behavioural traits may be also useful to quickly identify weak piglets and piglets at a high risk of death and to establish palliative measures. Further studies should be performed in order to better understand how assessing piglet's vitality might influence the way the standard management techniques are performed in the farm, stock people requirements for evaluation and palliative measures, and its final benefits in number of piglets weaned.

"per aquest absurd lligam, tot quant havien estat o fet repercutia en mi"

Cavalls cap a la fosca (Baltasar Porcel)

Chapter 6:

Effect on piglet's growth and mortality of different management techniques to enhance piglet colostrum intake

6.1. Introduction and objectives

It has been presented in the literature review that piglet growth and survival are strongly influenced by piglet birth weight and vitality, and also that passive transfer of immunity via colostrum intake is crucial during the first 24 h of life due to the ephitheliocorial nature of the placenta in pigs. With the ongoing selection for larger litter size sows, the number of small and immature piglets at birth have increased in commercial farms (Vasdal and Andersen, 2012), resulting in more piglets at risk of low colostrum intake during the first hours of life. Different authors have focused on different management techniques to increase colostrum intake by drying and/or warming up the piglets (Christison *et al.*, 1997). Drying and placing the piglets close to the udder (Vasdal *et al.*, 2011), administering some colostrum replacement (Holyoake *et al.*, 1995), provisioning piglets with extra oxygen (White *et al.*, 1996) or performing split nursing (Donovan *et al.*, 2000), are among the most successful techniques.

Intestinal macromolecular transmission in piglets (Svendsen *et al.*, 2005) and the effect of different source of IgG fed to artificially reared piglets (Gomez *et al.*, 1998) have also been studied. However, no experiences focused on the effect on survival and growth of oral supplementation of piglets during the first hours of life has been done so far under commercial conditions.

From a preliminary study (Muns *et al.*, 2010) we observed improved BW gain and RT at first day of life, and promising improvement of pre-weaning survival (although not significant) of piglets orally supplemented with sow's colostrum under commercial conditions. Therefore, the objective of the present study was to compare the efficiency of different management techniques oriented to enhance colostrum intake by the piglets, usually performed during the first hours of life in commercial farms, and to assess their impact on piglet growth and survival. Because of the confounding effect of different management strategies usually performed simultaneously or consecutively in commercial farms, only a minimum cross-fostering intervention was allowed by equilibrating litters only by number. Results of the study should contribute to assess the impact of the management techniques on piglet growth and survival and become a useful information for farmers when considering the balance between the amount of extra work required and its final impact on piglet performance.

6.2. Material and methods

The study was conducted after being approved by the Institutional Animal Care and Use Committee of the *Universitat Autònoma de Barcelona* (UAB). The experiment was carried out on a 6,000-sow farm in Lleida, Spain.

6.2.1. Animals, housing and management

Sows were kept in individual stalls (1.2 m^2) during gestation and fed a commercial gestation diet. On day 109 of gestation sows were moved to a climate-controlled (25 ºC) farrowing room. Farrowing pens (4.37 m^2) had plastic slat flooring and a farrowing stall (1.20 m^2) in the center. Each pen was provided with a creep area (0.42 m^2) in one side of the stall. Following the usual feeding routine of the farm, when farrowing symptoms were observed, feeder was emptied and sow was not offered any feed for the following 24 h. The amount of feed offered daily was increased daily until *ad libitum* was reached after 1 week of lactation. Sows were fed twice a day a commercial lactation diet according to NRC (1998) requirements. Sows and piglets had *ad libitum* access to human grade water in separated nipple drinkers. Farm's usual management performed around farrowing consisted in drying paper addition at the back of the dam and one heating lamp on the creep-area. Farm's usual procedure on piglets included a 1 ml iron supplement given subcutaneously (Ferrovial, MEVET, Lleida, Spain), tail docking, and a farm identification tag clipped in the right ear at day 3 post-partum. Weaning took place at 23 ± 2 days of age. During all the experiment the animals were daily checked for health or eating problems.

6.2.2. Experiment development

During a period of 4 weeks, a total of 1885 piglets from 139 sows (Large White x Landrace) were used in the experiment. Two parity groups were differentiated: 39 primiparous sows and their litters (a total of 507 piglets) and 100 multiparous sows (2^{nd} to 7^{th} parity) and their litters (a total of 1375 piglets). Once the farrowing was completed (expulsion of the placenta) piglets were weighted, individually identified with an ear tag and classified as small piglets (SP) or big piglets (BP) according to their BW at birth: SP, piglets born weighing 1.30 kg or less; and BP, piglets born weighing more than 1.30 kg of BW. Body weight classification was fixed based on Milligan *et al.*

(2002b) who defined 3 BW categories for piglets: 1.7, 1.2 and 1.0 kg and is consistent with Bierhals *et al.* (2012) who defined an 'intermediate' piglet when being born weighing 1.4 – 1.6 kg of BW. The number of piglets born alive, stillborn, and mummified were recorded after the farrowing was completed. Within 4 h after the farrowing was completed, litters were allocated to one of the 4 treatment groups and immediately performed: a control group with no extra management to piglets (CON); split nursing of the BP piglets of the litter for 2 h allowing SP piglets free access to teats (SPLIT); orally supplementation with 15 ml of sow colostrum to the SP piglets of the litter (COL); and orally supplementation with one pulse (3 ml) of a condensed energetic product Calostrene® (Laboratorio JAER S.A., Sant Vicenç dels Horts, Barcelona, Catalonia, Spain) to the SP of the litter (EN). Split nursing for SPLIT group is defined as removal of the larger piglets (BP piglets) in a litter for a period of 2 h, during the 2 hours-time BP piglets were caged inside their respective farrowing pen provided with an extra heating lamp to keep body temperature. Sow colostrum for COL group was manually obtained from multiparous sows not included in the experiment ranging from 2^{nd} to 5^{th} parity, pooled and used de very same day. Based on its posology recommendation (3 ml of product every 8 h), the energetic product used in the EN group was administered only once, due to its composition (short-chain and middle-chain fatty acids, and vitamins as additives) the energetic product was used as a source of energy without IgG in opposition to colostum in group COL.

On day 1 (18 to 24 h after birth) all the initial piglets were weighed again and then the animals were cross-fostered within the same treatment and within the same parity group obtaining litters fixed at 12.1 ± 0.08 and 12.0 ± 0.03 piglets for primiparous and multiparous sows respectively. Aiming to study the impact of only oral supplementation on litter performance, cross-fostering was performed at a minimum level ensuring as minimum number of animal movements as possible and with all the litters containing 4 or 5 SP piglets (4.9 ± 0.38 and 4.4 ± 0.14 SP piglets per litter, for primiparous and multiparous sows respectively). Piglets were weighed again at day 18 post-partum.

Litter pre-weaning mortality was recorded through lactation. Back fat thickness from sows was measured on the P2 spot (last rib 65 mm down the dorsal middle line) on both sides of the body using a Renco Lean Meater ultrasound system (Renco Corporation®, North Minneapolis, MN, USA) 2 days before farrowing and again on day 18 post-farrowing.

6.2.3. Statistical analyses

All statistical analyses were carried out using SAS 9.2 (SAS Inst. Inc., Cary, NC). All data was explored to determine distribution using Univariate procedure of SAS. All variables were analyzed using litters as experimental units. The alpha level of significance was set at 0.05.

Differences among groups for the SP and BP piglet's BW variables were analyzed by general linear mixed models using GLIMMIX procedure of SAS. The different models included oral supplementation option and parity group (primiparous and multiparous) as fixed effects, and the interaction between oral supplementation option and parity group; week of the experiment and piglet gender were introduced as fixed effects and removed from the model based on its significance. Initial BW (day 0) was introduced as covariate for BW at day 1 and BW at day 18 analyses. Differences among treatments for sow's variables (primiparous and multiparous) were also analyzed using GLIMMIX procedure of SAS. All the models included oral supplementation as fixed effect and week of the experiment was also included as fixed effect when significant, and for CV for litter BW at day 18, the CV for litter BW at day 1 was introduced as covariate.

6.3. Results

Back fat measures 2 days before farrowing did not differ among treatment groups neither for primiparous (overall average of 18.2 ± 0.61 mm) nor for multiparous sows (overall average of 16.8 ± 0.50 mm). Moreover, no differences for final BF were also found among groups for primiparous (overall average of 14.6 ± 0.51 mm) or multiparous sows (overall average of 14.3 ± 0.47 mm). Total life born piglets, stillbirth, and mummified piglets per litter were 13.3 ± 0.82, 1.24 ± 0.426, and 0.35 ± 0.212 for primiparous sows and 14.0 ± 0.59, 1.27 ± 0.495, and 0.43 ± 0.166 for multiparous sows.

Body weight results for all the piglets (including SP and BP piglets) are presented in table 6.1. Piglets born from primiparous sows had lower BW at both day 0 and day 18 than piglets born from multiparous sows (1.29 vs. 1.39 ± 0.031 kg, and 5.55 vs. 5.74 ± 0.084 kg; P = 0.002 and P = 0.025, respectively). Total BW gained from day 1 to day 18 was also lower for piglets born from primiparous sows compared to piglets born from multiparous sows (3.96 vs. 4.24 ± 0.078 kg; $P < 0.001$). Coefficient of variation for litter BW did not differ among treatments after cross-fostering (day 1) or at day 18 ($P = 0.769$ and $P = 0.824$, respectively). However, at day 1 litters from gilts had lower CV of BW than litters from multiparous sows (17.8 vs. 19.7 ± 0.97 %; $P = 0.046$); that difference between gilts and multiparous' litters was persistent at day 18 (18.6 vs. 22.0 ± 1.32%; $P = 0.010$).

Body weight and BW gain during lactation (from day 1 to day 18) for SP are presented in table 6.2. Gilt's SP had higher BW at day 1 than sows' SP ($P = 0.020$). Oral supplementation with COL enhanced SP BW at day 1 in gilts compared to CON, SPLIT, and EN SP piglets also born from primiparous sows ($P = 0.020$, $P = 0.022$, and $P = 0.046$, respectively). Within multiparous sows, no differences among treatment groups were observed for SP BW at day 1. At the end of the experiment no differences among groups and no differences between parity groups were observed for BW at day 18 or BW gain until day 18. In table 6.3 are presented the growth results during lactation from BP. Piglets born from multiparous sows were heavier at birth than BP born from primiparous sows ($P < 0.001$) and BP from multiparous sows also had both higher BW at day 18 and more BW gain from day 1 to day 18 than BP from primiparous sows ($P = 0.004$ and $P < 0.001$, respectively).

Total mortality rate at the end of lactation did not differ among groups for multiparous sows ($P = 0.600$) with an overall mean of 11.6 ± 2.15%; no differences were also observed among groups for SP mortality rate (percentage of total SP present in the litter that died before weaning) ($P = 0.985$) with an overall mean of 20.7 ± 4.94%. Primiparous sows' total mortality rate was 5.4 ± 2.96%, lower than multiparous sows' mortality (P < 0.001), whereas no differences were observed for total mortality rate among groups for primiparous sows ($P = 0.794$). Primiparous sows' SP mortality rate was 12.8 ± 4.97%, also lower than multiparous sows ($P = 0.001$). Moreover, within primiparous sows, CON group and EN group had lower SP mortality rate than SPLIT and COL groups (6.8 ± 3.52% and 6.0 ± 4.27% vs. 23.9 ± 5.56% and 14.6 ± 6.54%, respectively; $P < 0.001$ for all cases), while between CON and EN group and between SPLIT and COL there were no differences ($P = 0.784$ and $P = 0.363$, respectively).

Table 6.1 Effect of oral supplementation and dam's parity (gilts or multiparous sows) on body weight and growth performance for all the piglets included in the experiment.

	CON[1]		SPLIT[2]		COL[3]		EN[4]			*P-value*		
	Gilts	Sows	Gilts	Sows	Gilts	Sows	Gilts	Sows	SEM	Treat.	Parity	Treat.*Parity
All piglets	n=143/11*	n=345/25	n=120/9	n=364/26	n=120/9	n=344/25	n=127/10	n=322/24				
BW d 0, kg	1.283	1.440	1.299	1.361	1.278	1.404	1.312	1.345	0.0696	0.837	0.002	0.410
BW d 1, kg	1.511	1.506	1.504	1.495	1.538	1.506	1.507	1.508	0.0181	0.244	0.155	0.428
BW d 18, kg	5.609	5.682	5.546	5.772	5.536	5.809	5.528	5.708	0.1487	0.973	0.025	0.840
BW gain at d 18, kg	4.098	4.176	3.926	4.257	3.998	4.321	3.970	4.200	0.1391	0.989	<0.001	0.861
CV of litter BW d 1	16.6	19.6	17.1	19.6	18.7	20.2	18.6	19.5	1.84	0.769	0.046	0.847
CV of litter BW d 18	19.3	21.3	16.1	21.8	17.5	22.7	18.8	22.8	1.87	0.824	0.010	0.625

[1]Control group with no extra management to piglets; [2]Split nursing of the bigger piglets of the litter for 2 h allowing SP piglets free access to teats; [3]Orally supplementation with 15 ml of sow colostrum to the SP piglets of the litter; [4]Orally supplementation with 2 ml of and energetic product to the SP of the litter. *Total number of piglets / total number of litters

Table 6.2 Effect of oral supplementation and dam's parity (gilts or multiparous sows) on body weight and growth performance for piglets born weighing 1.30 kg or less (SP).

	CON[1]		SPLIT[2]		COL[3]		EN[4]			*P-value*		
	Gilts	Sows	Gilts	Sows	Gilts	Sows	Gilts	Sows	SEM	Treat	Parity	Treat*Parity
Piglets born weighing <1.30 kg	n=55/11*	n=105/25	n=40/9	n=117/26	n=47/9	n=115/25	n=47/10	n=100/24				
BW day 0, kg	1.13	1.13	1.14	1.11	1.12	1.11	1.11	1.10	0.036	0.712	0.490	0.789
BW day 1, kg	1.15	1.14	1.15	1.14	1.20	1.15	1.16	1.15	0.020	0.105	0.020	0.181
BW day 18, kg	4.83	4.89	4.85	4.91	4.75	4.93	4.78	4.83	0.167	0.948	0.367	0.967
BW gain at day 18, kg	3.68	3.75	3.67	3.77	3.55	3.79	3.62	3.62	0.162	0.885	0.391	0.796

[1]Control group with no extra management to piglets; [2]Split nursing of the bigger piglets of the litter for 2 h allowing SP piglets free access to teats; [3]Orally supplementation with 15 ml of sow colostrum to the SP piglets of the litter; [4]Orally supplementation with 2 ml of and energetic product to the SP of the litter. *Total number of SP piglets / total number of litters

Table 6.3 Effect of oral supplementation and dam's parity (gilts or multiparous sows) on body weight and growth performance for piglets born weighing more than 1.30 kg (BP).

	CON[1]		SPLIT[2]		COL[3]		EN[4]			*P-value*		
	Gilts	Sows	Gilts	Sows	Gilts	Sows	Gilts	Sows	SEM	Treat.	Parity	Treat.*Parity
Piglets born weighing >1.30 kg	n=88/11*	n=240/25	n=80/9	n=247/26	n=73/9	n=229/25	n=80/10	n=222/24				
BW day 0, kg	1.54	1.63	1.48	1.59	1.50	1.61	1.53	1.57	0.042	0.321	<0.001	0.645
BW day 1, kg	1.68	1.69	1.67	1.67	1.71	1.68	1.69	1.69	0.013	0.252	0.695	0.700
BW day 18, kg	5.99	6.15	5.84	6.22	5.91	6.27	5.91	6.15	0.173	0.964	0.004	0.815
BW gain at day 18, kg	4.31	4.46	4.17	4.55	4.16	4.60	4.20	4.46	0.164	0.878	<0.001	0.753

[1]Control group with no extra management to piglets; [2]Split nursing of the bigger piglets of the litter for 2 h allowing SP piglets free access to teats; [3]Orally supplementation with 15 ml of sow colostrum to the SP piglets of the litter; [4]Orally supplementation with 2 ml of and energetic product to the SP of the litter. *Total number of BP piglets / total number of litters

6.4. Discussion

As expected, gilt's offspring were born with lower BW than sow's offspring, which is consistent with results observed by Milligan *et al.* (2002a). Moreover, gilt's offspring also had lower BW and BW gain at day 18 compared to sow's offspring; Milligan *et al.* (2002b) also observed that litters from middle-aged sows had higher mean weaning weights. Such differences might partly be attributed to the previous differences observed at day 0, for birth BW it is known to have an important influence on weaning BW (Casellas *et al.*, 2004; Muns *et al.*, 2013a; Pedersen *et al.*, 2011a). Carney-Hinkle *et al.* (2013) suggested that progeny from first parity sows could have a reduced health status decreasing its growth capacity. Litters from gilts also had lower total and SP mortality rate than litters from multiparous sows. Our results do not coincide with Knol *et al.* (2002) who found no influence on pre-weaning survival through an increase in parity. In contrast, Roehe and Kalm (2000) found that pre-weaning mortality increased with parity of the dam, although they related the influence of parity on mortality with litter size and individual BW. In our study litters were fixed at the same number of piglets per litter. Once cross-fostering was completed (day 1), gilts had lower CV for litter BW than multiparous sows. Lower mean birth weight of gilt's offspring could indirectly be explaining the lower variability observed in gilts' litters for piglets BW. Such difference could be explained by the lower number of piglets with high BW found in gilt's litters. However, the magnitude of the difference observed for CV for litter BW between gilts and sows at day 18 compared to the difference observed at day 1, suggest that sows incremented CV for litter BW during lactation at a greater extent than gilts. Such effect could be due to the evolution of SP and BP piglets' BW during lactation. It has been stated that inherent variation in teat productivity can introduce variation in weight gain (Milligan *et al.*, 2001). At day 1, SP from sows had lower BW than SP from gilts while BP from sows had higher BW than BP from gilts; nonetheless, at day 18, SP did not differ between sows and gilts while BP from sows had higher BW. That difference in piglets' BW evolution might be explaining the increased CV for litter BW difference between sows and gilts at day 18.

At day 1, within primiparous sows, SP supplemented with 15 ml of colostrum had higher BW than the other groups. Piglet's dependence on early energy intake through colostrum to overcome neonatal hypothermia and to be able to compete for a teat and keep suckling are well known (Herpin *et al.*, 2005; Le Dividich *et al.*, 2005;

Tuchscherer *et al.*, 2000). Still, colostrum intake during the first 24 h of life is highly variable among piglets and will determine piglet's future growth (Quesnel *et al.*, 2012). However, no treatment effect on litter total mortality was observed at the end of lactation for primiparous sows, yet differences were observed among treatment groups for SP mortality rate. Dewey *et al.* (2008) orally administered 12 – 20 ml of colostrum to chilled piglets, and also performed split nursing for 1 hour-time in litters with more than 12 piglets among other attentions in a 'maximal care' treatment obtaining increased piglet's BW at day 16, especially in low birth weight piglets, and also reducing its mortality. In another study, Holyoake *et al.* (1995) observed lower mortality of low birth weight piglets after providing them with colostrum supplementation, and after split-nursing litters with more than 12 piglets, among other cares in a 'good supervision' protocol. Notwithstanding, due to their experimental design, it is impossible to assess the individual impact on piglet and litter performance of colostrum supplementation or split-nursing of the litter from the experiments already mentioned. Nevertheless, our results observed in primiparous sows' offspring growth are consistent with our previous experience (Muns *et al.*, 2010) from which we observed improvements in low birth weight piglets growth at first day of life when supplemented with 10 ml of colostrum. On the contrary, our mortality results differ from the promising results observed in Muns *et al.* (2010) for piglets supplemented with colostrum. While in the present experiment total mortality was similar among treatments for gilts, SP mortality was reduced in CON and EN group compared to SPLIT and COL. Because of dealing with a field experiment under commercial conditions, such random differences lead us to hypothesize that might not be associated to a treatment effect but to other environmental or management factor/s unexpectedly occurred during the experiment that could have introduced variability. Notwithstanding, it could have been useful to record mortality differentiating between the first week of life and the rest of the lactation together with the cause of death. One of colostrum's most important advantages is that it provides newborn piglets with passive immunity (Rooke and Bland, 2002). Assuming that immune status at weaning is directly influenced by the extent of passive immunity through colostrum intake (Quesnel *et al.*, 2012), animals with enhanced humoral immune protection should have less chances of suffer from inflammatory affections and/or diseases, thus, could have been of interest to observe the impact of colostrum supplementation on mortality rate and cause of death before and after the first week of lactation. Nevertheless, in the present study, we aimed for a minimum cross-fostering management to try to observe the real impact of oral supplementation on piglets with low birth weight, conversely in Muns *et al.* (2010) we cross-fostered piglets fixing litters by number and piglet size, from which we think cross-fostering management might be important on influencing the possible benefits of colostrum supplementation throughout lactation.

The lack of effectiveness of SPLIT and EN treatment in both primiparous and multiparous sows litters probably relay in the same nature of the treatments. Donovan *et al.* (2000) only observed a decrease in ADG variation of pigs from birth to weaning with no effects on mortality or final BW, after performing split-nursing during the first day of life. Low birth weight piglets are more prone to hypothermia at birth for they might have its vigour reduced, thus compromising its suckling capacity (Herpin *et al.*, 2002), for many of those animals removing competence from their bigger siblings for a limited time might not be enough to ensure proper suckling. On the other hand, there was probably a wrong design for the EN treatment since the beginning. A 3 ml oral dose of the product was indicated for an 8 h period, so only one dose of the product did not suppose an influential amount of energy for the animals.

Despite the findings observed for litters from primiparous sows, no effect was observed on litters from multiparous sows. For gilts, that are presumed to have lower colostral immunoglobulins concentrations than higher parity sows due to its lower antigenic exposure (Farmer and Quesnel, 2009), the oral supplementation focused on low birth piglets with colostrum obtained from middle age sows might provide them not only with early extra energy input but with valuable immunological protection that will result in a cut advantage helping to reduce mortality. That circumstance may explain the bigger impact of colostrum supplementation on piglets from primiparous sows than piglets from multiparous sows.

Summing up, colostrum supplementation of low birth weight piglets enhanced colostrum intake during the first day of life, improving weight gain in piglets born from gilts. However, benefits of colostrum supplementation early in life were not maintained until the end of lactation. Our results also suggest the need for different management protocols for primiparous and multiparous sows' litters. Further studies on the impact of cross-fostering protocol combined with colostrum supplementation on piglet growth and survival from different parity dams are of great interest, and will provide further information on management prioritization on piglets.

Results presented in the present study address to colostrum supplementation to piglets, a management aspect in the farrowing house (with conventional farrowing crates) not considered so far in the scientific literature. Although the experiment was performed in stall allocated sows during gestation, our results should be of interest also for breeding herds with group housed sows during gestation. Besides, according to recent studies evidencing the welfare impairment in farrowing pens for sows group housed during gestation (Boyle *et al.*, 2000) together with the possible negative effect of maternal stress during gestation on offspring behaviour and HPA axis (Kranendonk *et al.*, 2007; Otten *et al.*, 2010), our results should emphasise the importance of piglet's colostrum supplementation study.

"les circumstàncies mai no es repeteixen. No pas exactament"

Cròniques volum I (Bob Dylan)

Chapter 7:

Effect of cross-fostering and oral supplementation with colostrum on performance of newborn piglets

7.1. Introduction and objectives

Results obtained in chapter 6 raised the hypothesis that other management practices performed on piglets, such as cross-fostering, could be determinant to preserve the benefits observed early in life of colostrum supplementation until weaning.

Due to large variability in birth weight and to reduce pre-weaning mortality rate, cross-fostering is an important management practice usually adopted in commercial farms. Different authors have studied the benefits of cross-fostering on growth performance and survival rate of piglets (Bierhals *et al.*, 2012; Deen and Bilkei, 2004; Heim *et al.*, 2012). Theoretically, combination of colostrum supplementation and cross-fostering strategies should enhance piglet growth and survival. Those management strategies require skills on identifying viable and non-viable piglets and on choosing the most appropriate nursing sow for small piglets.

The objective of this contribution is to study the effect of both, supplementing colostrum to lighter piglets and the cross-fostering strategy, on piglet survival and performance. Such information should help producers to optimize piglet's management strategies early after farrowing.

7.2. Material and methods

The experiment was conducted after being approved by the Institutional Animal Care and Use Committee of the *Universitat Autònoma de Barcelona* (UAB). The experiment was carried out on a 7,000-sow farm in Medianeira, Paraná (Brasil).

7.2.1. Animals, housing and management

Sows were kept in individual stalls (1.31 m^2) during gestation and fed a commercial gestation diet according to NRC (1998) requirements. On day 109 of gestation all gilts were moved to a climate-controlled (25 ºC) farrowing room. A total of 6 farrowing rooms with 30 individual farrowing pens each were used. Sows from the different treatments were evenly distributed within each room. Farrowing pens (3.28 m^2) were distributed in 3 rows with a central alley and 2 alleys on the sides and had plastic slat flooring and a farrowing crate (1.31 m^2) in the center. Attached to the front of each pen, next to the sow's feeder, it was a shelter box (0.49 m^2 x 0.55 m) provided with a heating lamp. The researcher had access to the sow from the front and the rear of the pen and had easy access to the creep box through the top of it. Following the usual feeding routine of the farm, when farrowing symptoms were observed, feeder was emptied and sow was not offered any feed for the following 24 h. The amount of feed offered daily was increased daily until *ad libitum* was reached after 1 week of lactation. Sows were fed twice a day a dry feed diet based on corn and soy bean meal (20.2% of Crude Protein, 8.0% Gross Energy, and 14.7 MJ ME per kg as fed) that met or exceeded nutritional requirements (NRC, 1998). Sows and piglets had *ad libitum* access to water in separated nipple drinkers. Farm's usual management performed around farrowing consisted in drying paper addition at the back of the dam and one heating lamp on the creep area. Farm's usual procedure on the piglets included a 1 ml iron supplement given subcutaneously (Gleptoferril®, PEARSON, São Paulo, Brasil), tail docking, and a farm identification tag clipped in the right ear at day 3 post-partum. Weaning took place at 23 ± 2 days of age. During all the experiment the animals were daily checked twice for health or eating problems.

Herd's routine vaccination program included gilts and sows vaccination against enterotoxigenic *Escherichia coli*, clostridial enteric disease, Glässer's disease, porcine parvovirus infection, leptospirosis, and swine erysipelas with commercial inactivated vaccines. During the experiment no pathologic symptoms outcome was observed in the farm.

7.2.2. Experiment development

A total of 503 piglets from 46 multiparous sows (Large White x Landrace), ranging from 2nd to 6th parity, were used in the experiment. The effects of piglet's oral supplementation and cross-fostering on piglet survival and growth were evaluated as a 2 x 2 factorial treatment design. Within 4 h after the farrowing was completed (expulsion of the placenta), litters were allocated to 1 of the 2 oral supplemental options: no oral supplementation (CON) and orally supplementation with 15 ml of sow colostrum (COL). Oral supplementation was only applied to piglets of the litter born weighing 1.35 kg of BW or less (SP), leaving the piglets born weighing more than 1.35 kg of BW (BP) with no oral supplementation. Sow colostrum was manually obtained one week before its use from multiparous sows ranging from 2nd to 5th parity. The colostrum was pooled and stored frozen (-20 ºC). On day 1 (18 to 24 h after birth), litters were equalized to 11 or 12 piglets per litter. Two levels of cross-fostering were performed within litters of the same oral supplemental group: litter standardized with most of the piglets of the litter being SP, assuring sows with thin and functional nipples (LL); and litter standardized by number, aiming to as minimum movements of piglets as possible from one sow to another, and also ensuring that less than 50% of the piglets of the litter were SP (HL). The combination of the 2 management strategies described above resulted in a 2 x 2 factorial model: CON-LL, CON-HL, COL-LL, COL-HL. In addition to the 4 treatment groups, 57 BP piglets from 5 multiparous sows with litters composed only by BP piglets (BIG) were also monitored during all the experiment to use their information when comparing piglets' growth data. Back fat thickness from sows was measured on the P2 spot (last rib 65 mm down the dorsal middle line) on both sides of the body using a Renco Lean Meater ultrasound system (Renco Corporation®, North Minneapolis, MN, USA) 24 h after farrowing and on day 19 post-farrowing. The number of piglets born alive, stillborn, and mummified were recorded after the farrowing was completed.

On farrowing day (day 0) piglets RT was recorded with a digital thermometer (MSR, Measure Technology Co. Ltd; Taipei, Taiwan, with a display resolution of 0.01 ºC and ± 0.1 ºC accuracy) and piglets were ear notched for individual identification. On day 1 (18 to 24 h after birth) piglets RT was recorded again. Piglets were weighed on day 0, 1, 10, and 19. On day 1, cross-fostering was performed, as described above, to obtain the 4 treatment groups. Litter pre-weaning mortality was recorded by checking daily the litters.

On day 4 post-farrowing, a 2 ml blood sample was obtained from 79 SP piglets born from multiparous sows included in the experiment. To obtain a negative control group, blood samples were also obtained on day 4 post-partum from 8 extra SP piglets that were separated from their mothers at birth and bottle fed with milk replacement for 12 h before being returned to the dam. Samples were obtained by jugular venipuncutre, centrifuged at 2000 x *g* for 10 min and serum was stored frozen at -8 ºC until IgG was determined. IgG was measured in serum samples using the Pig IgG ELISA Quantitation Set® (Bethyl Laboratories, Inc. Montgomery, USA).

7.2.3. Statistical analyses

All statistical analyses were carried out using SAS 9.2 (SAS Inst. Inc., Cary, NC). All data was explored to determine distribution using Univariate procedure of SAS. All variables were analyzed using litter as experimental unit. The alpha level of significance was set at 0.05.

Piglet mortality at day 5 followed a Poisson distribution and piglet mortality at day 19 followed a Negative Binomial distribution, while mortality rate of SP piglets at day 19 followed a Poisson distribution after being submitted to an exponential transformation.

Differences among groups for piglets BW, litter average piglet BW, and CV for piglet BW within litter were analyzed by repeated measures using the GLIMMIX procedure of SAS. The model included oral supplementation option, cross-fostering level and day of weighing as fixed effects and the interaction between oral supplementation option, cross-fostering level, and day of weighing was also included. Farrowing room was also introduced in the model as fixed effect when significant. Differences among treatments for sow BF loss during experiment, piglet RT, BW gain and piglet's serological IgG concentration were analyzed by general linear mixed models using GLIMMIX procedure of SAS. All the models included oral supplemental and cross-fostering as fixed effects. Farrowing room for all variables and piglet gender for piglet variables were introduced as fixed effects and removed from the model based on its significance. For RT and BW data, BW at day 0 was introduced as covariate, and for RT at day 1, RT at day 0 was also introduced as covariate.

7.3. Results

Sows entered the farrowing rooms with an average BF of 18.4 ± 0.51 mm, and had an average BF at the end of the experiment of 16.8 ± 0.47 mm. Total life born piglets, stillbirth, and mummified piglets were 14.1 ± 0.29, 0.87 ± 0.136, and 0.35 ± 0.105, respectively. At day 1, after cross-fostering was performed, litters were fixed at 11.91 ± 0.097 piglets.

Performance results are presented first by litters which include SP piglets (table 7.1 and table 7.2) and later referring to piglets SP or BP separately (tables 7.3 and 7.4). Litter productive parameters for the different treatment groups are presented in table 7.1.

Table 7.1 Effect of oral supplementation (OS) and cross-fostering (CF) management on litter average body weigh and CV for piglet BW within litter for multiparous sows.

	Oral supplementation option (OS)							
	CON		COL			*P*-value		
	HL (n = 14)	LL (n = 6)	HL (n = 19)	LL (n = 7)	SEM	OS	CF	OS*CF
BF loss	1.81	1.42	1.31	2.30	0.968	0.696	0.537	0.161
Litter av. piglet BW day 1*, kg	1.55	1.18	1.52	1.21	0.125	0.962	0.011	0.087
Litter av. piglet BW day 10, kg	3.38[a]	2.71[b]	3.26[a]	2.54[b]	0.129	0.206	<0.001	<0.001
Litter av. piglet BW day 19, kg	5.64[a]	4.71[b]	5.52[a]	4.40[b]	0.125	0.079	<0.001	<0.001
Litter CV day 1**	23.5[a]	15.4[b]	20.8[ab]	16.9[b]	1.643	0.754	0.003	0.017
Litter CV day 10	25.0	19.7	21.3	24.3	1.696	0.938	0.676	0.222
Litter CV day 19	25.9[a]	22.5[ab]	21.4[b]	25.6[ab]	1.643	0.735	0.848	0.137

Values with different superscripts differ significantly ($P < 0.05$)
*Litter av. Piglet BW = Litter average piglet BW
**Litter CV = Litter CV for piglet BW within litter

Table 7.2 Effect of oral supplementation (OS) and cross-fostering (CF) management on litter mortality for multiparous sows represented by total number of piglets dead during lactation and percentage of piglets born weighing 1.35 kg or less that died before day 19 post-partum.

	Oral supplementation option (OS)							
	CON		COL			*P*-value		
	HL (n = 14)	LL (n = 6)	HL (n = 19)	LL (n = 7)	SEM	OS	CF	OS*CF
Num. Dead day 0-5	0.57	0.67	0.37	0.71	0.447	0.665	0.341	0.552
Num. Dead day 5-19	0.57[ab]	1.00[b]	0.11[a]	1.00[b]	0.361	0.290	0.007	0.365
Num. Dead day 0-19	1.14[ab]	1.67[a]	0.47[b]	1.71[a]	0.700	0.230	0.022	0.201
% Little Dead day 0-19	15.5	12.5	10.0	14.1	0.53	0.682	0.993	0.560

Values with different superscripts differ significantly ($P < 0.05$)

Table 7.3 Effect of oral supplementation (OS) and cross-fostering (CF) management on piglets' body weight and growth performance for piglets born weighing 1.35 kg of BW or less (SP).

	Oral supplementation option (OS)							
	CON		COL			*P*-value		
	HL (n=58/n=14)	LL (n=64/n=6)	HL (n=77/n=19)	LL (n=72/n=7)	SEM	OS	CF	OS*CF
Piglets born weighing < 1.35 kg	58/152*	64/72	77/211	72/81				
BW at day 1, kg	1.17	1.15	1.20	1.17	0.049	0.310	0.314	0.673
BW at day 10, kg	2.58	2.63	2.74	2.52	0.244	0.782	0.695	0.032
BW at day 19, kg	4.38	4.54	4.83	4.40	0.396	0.894	0.759	0.029
BW gain at day 10, kg	1.47^{ab}	1.51^{ab}	1.58^{a}	1.36^{b}	0.223	0.942	0.513	0.053
BW gain at day 19, kg	3.27^{b}	3.42^{ab}	3.66^{a}	3.24^{b}	0.401	0.591	0.551	0.040
BW gain day from day 10 to 19, kg	1.80	2.00	2.05	1.82	0.269	0.943	0.976	0.057

Values with different superscripts differ significantly ($P < 0.05$)

*Number of SP piglets/ total number of piglets present in the treatment group

As expected, at day 1 post-partum sows with cross-fostering performed to HL level had higher litter average piglet BW than sows with LL as cross-fostering level (1.53 vs. 1.19 ± 0.118 kg, $P = 0.011$). At day 10 and 19 post-partum difference between HL and LL sows on litter average piglet BW was maintained (3.31 vs. 2.61 ± 0.084 kg, $P < 0.001$ for day 10; and 5.57 vs. 4.54 ± 0.141 kg, $P < 0.001$ for day 19), and there was a tendency (5.21 vs. 5.36 ± 0.096, $P = 0.079$), only on day 19, in the sense that supplemented piglets (COL) had lower litter average piglet BW than non-supplemented piglets (CON). An interaction between oral supplementation and cross-fostering ($P < 0.001$) indicates that the later difference was higher in LL than in HL. As expected, at day 1 post-partum CV for piglet BW within litter was higher in HL than LL sows (21.9 vs. 16.2 ± 0.91%, $P < 0.001$). However, at day 10 and day 19 post-partum those differences disappeared ($P > 0.10$) and LL sows reached similar CV for piglet BW within litter than HL sows. At day 10 sows from COL-HL showed a tendency for lower CV for piglet BW within litter than CON-HL sows ($P = 0.082$), this difference became significant at day 19 ($P = 0.035$).

Mortality data is presented in table 7.2. Cross-fostering affected piglet's mortality. Litters with a cross-fostering level of HL had lower number of total dead piglets at day 19 post-partum and, especially, from day 5 to day 19 post-partum than litters with a cross-fostering level of LL (0.80 vs. 1.69 ± 0.307 and 0.30 vs. 1.00 ± 0.310; $P = 0.022$ and $P = 0.007$ respectively). By contrast, colostrum oral supplementation did not affect piglet mortality. Nevertheless, colostration causes a 58% total reduction of piglet mortality in HL sows compared to CON-HL sows at day 19 post-partum ($P = 0.682$). No differences among groups were observed for the percentage of SP piglets that died before day 19 post-partum although COL-HL sows quantitatively had the lower rate (35% and 29% lower mortality rate than CON-HL and COL-LL, respectively).

At day 0, once the litters were allocated to one of the two oral supplementation options, no difference for SP piglets birth BW were observed between CON and COL groups (mean value of 1.12 ± 0.008 kg), and no difference for SP piglets BW at day 1 were also observed (mean value of 1.15 ± 0.009 kg). No difference for piglets RT at day 0 and day 1 were observed between CON and COL groups neither for SP nor for BP piglets (overall mean values of 37.1 ± 0.05 ºC and 37.3 ± 0.05 ºC at daya 0, and 37.3 ± 0.04 ºC and 37.7 ± 0.04 ºC at day 1, for SP and BP piglets respectively).

Body weight and BW gain results for SP piglets during lactation are presented on table 7.3. At day 10 post-partum SP piglets from COL group tended for a higher BW when combined with HL management than when combined with LL (P = 0.050). Body weight gain at day 10 was higher for SP piglets from COL-HL than COL-LL (P = 0.047) and tended to be higher than CON-HL (P = 0.088). At day 19 post-partum, COL SP piglets combined with HL had a tendency for higher BW than COL-LL and CON-HL piglets (P = 0.061 and P = 0.063 respectively); while BW gain at day 19 for COL SP piglets combined with HL was higher than COL-LL and CON-HL SP piglets (P = 0.048 and P = 0.041 respectively). Body weight and BW gain results for BP piglets during lactation are presented on table 7.4. At day 10 and day 19 post-partum CON BP piglets tended to gain more BW than COL BP piglets (P = 0.082 and P = 0.053, respectively).
No effect of cross-fostering level (P = 0.946) nor of the interaction between cross-fostering and oral supplementation (P = 0.938) were observed on piglet's IgG serological concentration at day 4. Nevertheless, oral supplementation did affect piglet's IgG concentration (P < 0.001) on day 4 after farrowing. Piglets from COL group had higher IgG concentration than piglets from CON group (P = 0.001). While piglets from the negative control group had lower IgG concentration than COL and CON groups (5.4 ± 2.32 mg/ml vs. 30.6 ± 1.58 mg/ml and 21.5 ± 0.95 mg/ml. respectively; P < 0.001 in both cases).

Table 7.4 Piglets body weight and growth performance for piglets born weighing more than 1.35 kg (BP). Only HL[1] litters were used to compare BP piglets data (LL litters were composed only by piglets born weighing 1.35 kg of BW or less).

	BIG (n=5)	CON (n=14)	COL (n=19)	SEM	*P*-value
Piglets born weighing > 1.35 kg	57/57*	98/152	134/211		
BW at day 1, kg	1.67	1.76	1.71	0.691	0.342
BW at day 10, kg	3.50	3.78	3.56	0.203	0.356
BW at day 19, kg	6.13	6.29	5.93	0.334	0.248
BW gain at day 10, kg	1.88	2.10	1.91	0.223	0.199
BW gain at day 19, kg	4.51	4.60	4.28	0.361	0.138
BW gain from day 10 to day 19, kg	2.63	2.47	2.37	0.176	0.110

Values with different superscripts differ significantly (P < 0.05)
[1]HL = litters standardized by number, aiming to as minimum movements of piglets as possible from one sow to another, and also ensuring that less than 50% of the piglets of the litter were born with less than 1.351 kg (SP).
*Number of BP piglets / total number of piglets in the treatment group

7.4. Discussion

As we expected, piglets from the negative control group had lower IgG concentration than the others animals. Rootwelt *et al.* (2012) observed that piglets at birth had IgG concentration lower than 3.8 mg/ml. Thus, considering that colostrum secretion takes place for a period of 12 to 24 h (Quesnel *et al.*, 2012) and that piglet's gut closure ends at approximately 24 h of age (Rooke and Bland, 2002), IgG concentration of 5.36 mg/ml for the negative control animals could be anticipated considering that the animals were separated from their dams only for 12 h. Since IgG plasma concentration in piglets at birth is negligible (Rootwelt *et al.*, 2012), concentration observed at day 4 is directly related to colostrum intake during the first day of life, for piglets oral supplementation in COL group resulted in increased level of IgG at day 4. Such effect might be caused by the 15 ml of colostrum directly administered to piglets and also by an enhanced suckling capacity due to concurrently energy contribution.

Differences among groups observed for litter average piglet BW at day 10 and day 19 post-farrowing were expected because of the cross-fostering factor originating the higher initial litter average piglet BW of HL sows due to presence of BP piglets and because of the important effect of birth weight on piglet growth (Muns *et al.*, 2013a). Our results are consistent with Bierhals *et al.* (2012) who also observed that litter average piglet BW differ among groups with different level of cross-fostering. However, COL together with HL enhanced SP piglets BW at day 10 and day 19 and SP piglets BW gain at day 19 compared to SP piglets with CON and HL management; these results are in agreement with Quesnel *et al.* (2012) who pointed out that piglet BW gain increases concomitantly with colostrum intake and Devillers *et al.* (2011) who found long-term effects of colostrum intake on piglet growth, improving their BW gain. Differences observed in BW gain at day 10 and 19 post-partum between CON and COL BP piglets might be caused for the greater performance of SP piglets in COL-HL litters causing more competence to BP piglets. As expected, cross-fostering LL strategy reduced CV for piglet BW within litter at day 1 post-partum for both CON and COL sows. However, LL sows increased their CV for piglet BW within litter at day 19 post-partum under any of the two oral supplemental options. On the contrary, CV for piglet BW within litter for HL sows remained high but constant through lactation in both oral supplemental options. Our results are consistent with Milligan *et al.* (2001) who also observed that litters cross-fostered to uniform litters doubled their body weight CV at the end of lactation.

In our study, cross-fostering to LL litters resulted in higher total mortality and higher SP piglets mortality rate while Akdag *et al.* (2009) and Roehe and Kalm (2000) found a positive linear relationship between variation of birth weight within litter and pre-weaning mortality, and Deen and Bilkei (2004) found that mortality of low-birth weight piglets (0.9 – 1.0 kg) was significantly higher and their growth rate was lower when they were put together with high-birth weight piglets. Nevertheless Milligan *et al.* (2002a) and Quesenel *et al.* (2012) did attribute the increase in mortality with variability in weight to a greater number of piglets with low BW rather to the variability in weight itself. This affirmation is supported by the facts that inherent variation in teat productivity can introduce variation in weight gain and may explain why very uniform litters become substantially more variable during lactation; and that cross-fostering to reduce size disparity between siblings may also increase the level of piglet aggressions (Deen and Bilkei, 2004; Milligan *et al.*, 2001). Both facts could help to understand our results. Deen and Bilkei (2004) also pointed that low-birth weight piglet survival is more related to litter size than to the birth weight of their litter mates. To such considerations, we would also add that cross-fostering low-birth weight piglets to create litters with similar birth weight may lead to maintain in the farm piglets that should not be considered viable, that could contribute to explain the increase in mortality and the increase in CV for piglet BW within litter during lactation in LL sows.

Oral supplementation had little effect on litter mortality and SP piglets mortality rate in our experiment. In contrast, White *et al.* (1996) found a reduction on pre-weaning mortality on piglets supplied with 12 ml of bovine colostrum yet in White *et al.* (1996) experiment, colostrum supplementation was just a part of a complex farrowing management protocol. Nevertheless, COL-HL sows numerically had the lowest values of piglet mortality and SP mortality rate, values ranging from 30 to 80% lower than CON-HL group. Such differences can be considered as relevant at a production level although they were not statistically significant.

Although the improved IgG plasma concentration found in COL group, oral supplementation effect on piglet growth and mortality appears to be less important than cross-fostering management. The lack of significance of colostrum as oral supplementation on piglet performance could be due to an insuficient amount of colostrum administered to piglets. Colostrum consumption during the first 24 h after birth averages 250 – 300 g/kg birth weight (ranging from 0 to 700 g/kg) for sow reared piglets (Quesnel *et al.*, 2012). Since the amount of colostrum ingested is highly variable between piglets (Devillers *et al.*, 2011) we can expect colostrum intake to be lower in low-birth weight piglets. Supplementation of 15 ml of colostrum in one time feeding dose could represent approximately 5 to 10% of the expected colostrum consumption for a SP piglet. Such amount of supplementation could not be enough to clearly enhance piglet growth and survival at a profitable production level; however, from our results, colostrum supplementation to SP piglets increased IgG plasma concentration and seemed to have a beneficial effect on litter mortality and, in combination with HL cross-fostering, it enhanced piglet growth, survival and CV for piglet BW within litter. Our findings contrast with a similar study we performed only with gilts where we observed that colostum supplementation of low birth piglets was of especial interest in litters fixed with most of the piglets being SP (Muns *et al.*, 2013b). From we can conclude that litters from primiparous sows might require a different cross-fostering management than litters from multiparous sows.

On the other hand, and although there are some controversy in the literature concerning cross-fostering, in our experiment cross-fostering was the most important factor influencing litter mean BW, CV for piglet BW within litter, and litter mortality. Litters fostered to LL level did not improve CV for piglet BW within litter at weaning and had higher mortality.

We conclude that, in a farm with a proper vacunal schedule and low clinical incidence of diseases, farmers will obtain no production benefits from cross-fostering low-birth weight piglets to create litters with similar birth weights and that the best management strategy should be to fix litters by number of piglets (considering the number of sow's functionally teats) and to limit stockpeople efforts to orally supplementation with colostrum of low-birth weight piglets during the first hours of life. However, we strongly suspect that those conclusions could be different in commercial farms with lower/different sanitary conditions.

"When thought runs gracefully free of the trammels of precision"

The time machine (H.G. Wells)

Chapter 8:

General Discussion

The literature review of the present work was addressed to describe and to present the aetiological factors affecting piglet mortality in the farrowing room and the dynamics of different processes leading to death of the piglets or leading to growth impairment (chapter 2). In the four result's chapters we tried to study some of the several factors which may be responsible for piglet mortality and growth during lactation. We studied particular aspects of the European sow production system that can influence on dams and piglets welfare and performance (chapter 4); we also studied the real impact of two specific management procedures usually performed in commercial farms (chapter 6 and 7). Finally, we have tried to better understand piglet characteristics that can contribute to decision-making in swine herds/farrowing facilities (chapter 5).

8.1. Management and welfare implications on husbandry practices around farrowing

Sows of different age or parity number coexist in commercial breeding herds. In our experiments we can differentiate between gilts or primiparous sows and multiparous sows. Other authors have opted for a more detailed differentiation: primiparous, second, 3rd – 5th/6th, and >5th/6th parity sows (e.g. Milligan *et al.*, 2002a, 2002b; Wientjes *et al.*, 2012). Such classification would certainly provide us with more valuable information, but it implies the need for more number of animals to be included in the experiment.

From the studies presented in this thesis, it can be observed that given the current production system, with the EU Directive 2001/88/CE being mandatory from January 1st of 2013, and with no modification on crate allocation of sows for the whole lactation, gilts might have their welfare jeopardized when transferring them from gestation to farrowing facilities. Concurrently, we have observed that newborn piglets from group housed gilts have their thermoregulatory capacity compromised. Those findings should emphasise the importance of management towards gilts around farrowing and the environment preparation of the farrowing room.

Sows are usually transferred to farrowing facilities one week before farrowing. However, due to the intensive production flow and occasionally due to the over population of the herd and its subsequent limited number of lactation crates available, it is not unusual in commercial conditions to wait until four/three days before farrowing to transfer the pregnant sows to the farrowing room. From results presented in chapter 4 and according to Cronin *et al.* (1991) and Jarvis *et al.* (2006), sows are able to adapt to the farrowing crate after the initial stress. Nonetheless, according to the previous authors, gilts begin to show signs of chronic stress after 28 days of being crated. It is known that cortisol response is greater in front of a more novel environment (Barnett *et al.*, 1984), for gilts should be more vulnerable when adapting to farrowing crates, thus, it is not surprising that most of the experiments on adaptation to the farrowing crates are performed with gilts.

Although environment conditioning of the farrowing crate is a crucial routine management independent to the parity number of the dam, according to our results, in situations where environmental differences are found within farrowing house, allocation of gilts to the warmer farrowing rooms should be a priority. In addition to what has already been said, in situations were number of stockpeople in the farrowing house might be reduced and proper management can not be guaranteed to all the litters during the first day of life, it was observed in our studies that colostration efforts should be concentrated to piglets born from gilts.

We have seen that colostrum supplementation to low birth weight piglets might have beneficial effects on piglets although being of different magnitude in piglets born from gilts than the ones born from multiparous sows; in addition, those beneficial effects are linked to cross-fostering influence. Besides, other authors have proved that there are different management procedures that help to reduce heat loss by the piglets, and also help to enhance piglet's colostrum intake and survival (Dewey *et al.*, 2008; Holyoake *et al.*, 1995; Vasdal *et al.*, 2011; White *et al.*, 1996). All these studies exemplifies the great diversity of procedures that can be performed on piglets, irrespective of their dam parity number, to enhance their performance; and at the same time, all these evidences state the importance for a minimum management performed to all the piglets early in life to enhance their colostrum intake and their further survival.

Impairment of gilt's offspring neonatal thermoregulation, together with the greater benefits of colostrum supplementation to piglets born from gilts, observed in our studies should be considered in front of the need to set up a hierarchy or in front of the need to optimize employees' tasks.

Cross-fostering is another extended practice performed at different levels and at different magnitude in commercial farms. Indeed, cross-fostering is a husbandry practice which requires high amount of time from the employees. Among other litter related factors, litter size is probably the most influential factor on piglet survival and growth (Baxter *et al.*, 2008, 2009; Deen and Bilkei, 2004; Vasdal *et al.*, 2011). Following from this, with the limited number of (functional) teats per sow and the high variability among sows for total live born piglets, cross-fostering should be considered indispensable. Our results in multiparous sows are in agreement with the importance of the litter size. Fixing litters by number of piglets with a minimum transfer of piglets resulted in better performance; and oral supplementation of piglets in those litters was more effective. Nevertheless, in litters from primiparous sows some divergences were observed, suggesting the need for a better understanding of the cross-fostering effect on gilts' litters. Our results also manifest that the hierarchy of tasks performed on piglets should be different for primiparous and multiparous litters.

Although cross-fostering implications on piglet's health and immunity have not been well studied so far (Bandrick *et al.*, 2011), it is a practice that might be influencing litters health status. Furthermore, we suggest that for farms with different sanitary status, similar cross-fostering strategies might have different impact on litter performance and mortality. It has been observed in our experiment realized in Brazil (chapter 7) that excessive cross-fostering reduced piglet survival. However, in the experiment performed in Lleida (chapter 6), with minimum cross-fostering for all the litters, it seemed that the cross-fostering strategy was not appropriate to enhance benefits of oral supplementation to low birth piglets. One of the main differences between the Brazilian and Catalan farm was its sanitary status; the Brazilian farm has better sanitary status than the Catalan one, for we hypothesise that cross-fostering success could be strongly influenced for the sanitary status of the farm. Further studies to elucidate our hypothesis should be of interest.

All the management procedures studied in the present work, were performed according to piglets' birth weight. The importance of piglet's BW on its survival and growth it has been previously described. However, from our different studies, it rises the concern about criteria on identifying non-viable from viable piglets and, within viable piglets, the ones with more growth potential; and BW it does not always seems to be enough. Better criteria on identifying piglets at risk of dying will be important to economize stockpeople work; and better criteria on identifying piglets with more growth potential will enhance criteria effectiveness when fixing litters during cross-fostering. Findings on piglet's vitality observed in chapter 5 could be useful for these purposes.

Considering a culling rate around 40% in modern intensive breeding herds (Knox *et al.*, 2013), it usually results in a low number of gilts within a production batch (particularly influenced by herd's population). However, given the singularities of gilt's performance, a differentiated management for gilts and their offspring might be of interest in the farrowing house.

Concurrently, in the experience described in chapter 4, one controversial aspect has been manifested between group housing allocation during gestation and the feeding system used. European directive on group housing sows during gestation is vague in details concerning its application (e.g. number of sows per pen, dynamic or static groups, feeding system, etc.). This situation has favoured the appearance of a great diversity of options to producers for both number of sows per group and the feeding system to be implemented. Different housing and feeding systems for gestating sows have been evaluated and reviewed in the literature (den Hartog *et al.*, 1993; McGlone *et al.*, 2004; Spoolder *et al.*, 2009), yet the system used in our experiment had not been previously reported. As described and presented in chapter 4, the feeding system used in our experiments for group housed gilts slightly overfed the animals without reaching an *ad libitum* pattern. Further, few experiments have been performed with group housing sows being overfed or fed *ad libitum* during gestation.

For some productive aspects, our results contrasts with findings long observed in the literature for stall allocated gestating sows. Overfeeding of stall allocated sows during gestation is well known to affect the occurrence of farrowing (Dourmad *et al.*, 1994) contrasting with faster delivery observed in chapter 4 for group housed and slightly overfed gilts during gestation. Oliviero *et al.* (2008, 2010) observed shorter farrowing duration for sows group housed during gestation than sows kept in stalls, restrictively fed in both cases. Although observing increased BF loss during lactation in group housed sows fed *ad libitum* during gestation, van der Peet *et al.* (2004) found no negative effect on reproductive performance during three successive reproduction cycles, with similar lactation feed intake between sows fed a diet with a high level of fermentable nonstarch polysaccharides *ad libitum* (15.9% of crude fiber and 34.3% of fermentable nonstarch polysaccharides) and sows fed restrictedly during gestation. These findings somehow are consistent with gilt's performance in our study.

In brief, our results suggest that the positive impact of group housing during gestation on sows fitness and muscular tone prevails over the negative impact of increased BF thickness at farrowing. Furthermore, negative impact of slightly overfeeding during gestation on subsequent reproductive (e.g. dystocia, live born piglets, stillbirth, mummified, etc.) and lactational performance (e.g. feed intake, milk production, etc.) is of lower magnitude when sows are group housed. Finally, feeding level during gestation does not seem to influence on the impairment of gilts' welfare when transferring them to farrowing stalls from group housing during gestation.

Complexity of our results, difficulty on obtaining categorical treatment effects, and the interaction observed between oral supplementation of piglets and cross-fostering strategy, show that it is difficult to influence on piglet growth and survival through only one single management procedure. Besides, it can be noted that some management procedures can have more impact than others on our productive purpose, and through their proper combination, sows and piglets performance can be influenced at a greater extend. These considerations are consistent with the multifactorial aetiology of mortality and with the complex chain of events underlying both piglet's mortality and growth capacity presented early in this work.

It is not the purpose of the current work to present specific measures to be adapted at each particular environment or farm, but to introduce general guidelines or examples from our results that might be useful to optimize stockpeople work in the farrowing house. Individual farm's idiosyncrasy (e.g. facilities, sanitary status, etc.) and its stockpeople characteristics (e.g. number of employees, skills, etc.) will finally determine the most appropriate husbandry practises to be adopted in order to optimize farm's productivity.

8.2. Methodological considerations, aspects susceptible to be improved, and further studies

Working with sows and their offspring has a strong hazardous component. Every experimental design requires close control of many environmental conditions and different biological characteristics of the animals. Opposite to weaned piglets, sows are much more voluminous, with a much more complex productive cycle, and they also are of more economical value. As a result, it becomes difficult to work with sows in experimental facilities. Therefore, all of the experiments presented in the present thesis (as most of the studies in the literature concerning gilts or sows) were performed in commercial herds.

8.2.1. Group housing and overfeeding during gestation:

The work (chapter 4) comparing two types of management systems during gestation was quite controversial. Despite the study resulted in some very interesting and novel results, it also had the already mentioned confounding effect between group housing and the gilt's body condition. The principal shortcoming, especially in the first experiment, concerning group housing during gestation, was its lack of ambition on obtaining physiological data from sows and piglets to support any casual productive finding. Comparison between group housing and stall allocation during gestation in terms of reproductive performance has been widely studied during the recent past years (see review of McGlone *et al.*, 2004; and Spoolder *et al.*, 2009); and the benefits of loose-housing during gestation on the ease of farrowing are long known (Hemsworth *et al.*, 1982). The most interesting aspects of the first experiment approach were that it was focused on gilts and that the offspring was monitored until weaning, and gilts were also video recorded around farrowing. There are very few experiments in the literature studying the impact of maternal welfare impairment in the farrowing crate on offspring performance until weaning. However, the measures recorded in the experiment were merely productive measures (sows' BF, piglets' BW, mortality, and other routine recordings) with no extra parameter or recording that could add some physiological information or that could allow us to study in deep some specific aspect. In brief, any novel finding that could be expected from the offspring pre-weaning performance would lack any physiological data supporting it. The other relevant critique to the experiment was its lack of prevision of the possible confounding effects of group housing and body condition of the sows. Although the feeding system used in the experiment for the group housed sows was the only one available in the farm, and although we did not have the opportunity to change it, we did not foresee the future problems when discussing the results in the first experiment.

Nonetheless, by happenstance we obtained in the first experiment an unexpected and unusual difference between treatment groups for piglet's rectal temperature shortly after birth (to avoid reiteration, rectal temperature results obtained in the first experiment are not shown in chapter 4 because of the results obtained in the second experiment were even more reliable and conclusive) together with differences in offspring growth. Such results were the origin of the second experiment, which was thought and designed to corroborate and to explain the differences observed in the previous experiment, and also to elucidate between the body condition and housing effect.

Opposite to the first one, the second experiment had a more focused objective, recorded more precise data, included both productive and physiological parameters, and tried to differentiate between housing and body condition effects on sows and piglets performance.

Nevertheless, the study "effect of gestation management system on gilt and piglet performance" resulted in a really interesting novel results, particularly the findings on newborn piglets thermoregulation ability, that should be further studied. Moreover, the results obtained in the study also provided more concerns on gilts' welfare in conventional farrowing crates.

From my point of view, two main lines of investigation should be of interest following from our study:

1. To repeat the experience using a gestation group housing system not associated with overfeeding of the gilts. Such study should help to confirm housing effect on gilts welfare and their offspring thermoregulatory capacity; dispelling any shadow of doubt about the confounding effect with sows body condition.
2. Using the same feeding pattern, to compare different gestation group housing systems to discover whether we are in front of a group housing effect irrespective of the management system or there is a management system specific effect within group housing during gestation.

In both suggested situations, could be of interest to monitor the animals from their introduction to the gestation management system until the subsequent mating, and also to compare the effect of gestation housing management system on gilts and sows, or to monitor gilts for two or three consecutive cycles. That would also be interesting to confirm the validity of the improved maternal behaviour over parities (Thodberg *et al.*, 2002).

Actually, we did try to perform the experimental design described for the experiment 2 in the chapter 4 monitoring gilts from mating, including a gestation group housing with a trickle feeding system as an additional experimental group, and we did also try to record gilt's reproductive performance after weaning. However, we did have problems monitoring the farrowing and we could only obtain reproductive results and few productive data (Muns *et al.*, 2011), insufficient to accomplish our objectives and hypothesis.

8.2.2 Piglet's vitality:

Concerning the vitality experiment (chapter 5), its main shortcoming probably relies in one of its virtues: its simplicity. Due to its novelty, we aimed for a study easy to perform that could provide us with reliable data on the validity of the method tested at a low economic cost.

Because of the already mentioned simplicity of the study, it is easy to wonder why we did not try to relate our vitality scoring based on piglet's behaviour with the long-time studied physiological parameters of vitality (blood pCO_2, blood pH, onset of respiration, time to first suckle, etc.).

Therefore, the logical next step should be, in one hand, the validation of the two described behavioural measures and, on the other hand, to study their relationship with the physiological parameters already described in the literature.

In any case, a score of piglet's vitality, easy to perform in commercial conditions, together with live weight and/or body size, should be a helpful procedure to categorize newborn piglets by their viability and to optimize on-farm management decisions. Concomitantly, the gradual introduction of the vitality score as an additional measure in experimental studies to classify/categorize piglets by their vitality would provide valuable information concerning its real utility and, in the most optimistic scenery, it could become a useful explanatory measure to control variability of experimental models.

8.2.2. Colostrum supplementation and cross-fostering:

The experiments presented in chapter 6 and 7 were probably the most complex of our project. Although they are directly related, and the second one (chapter 7) was the consequence of the first one (chapter 6), due to differences in the final experimental design and geographic location we decided to present them separately.

After the positive experience with a pilot study, from which we obtained optimistic results on the effect of colostrums oral supplementation on piglets with low birth weight (Muns *et al.*, 2010), we designed the experiment presented in chapter 6. Compared to the pilot study, the first experiment was performed in a bigger farm with higher production flow. That allowed us to aim for increased inclusion of animals in the experiment.

The main weakness of the experiment was probably its magnitude together with our lack of experience working with sows around farrowing. For a period of four weeks we aimed to include a great number of sows and their litters, ensuring a sufficient number of gilts, middle-age, and older sows that would allow us to block animals by parity group.

We were probably too ambitious with our experimental design. Working with lactating piglets, protocols are designed to obtain differences in piglet performance but with the sow being the experimental unit, not the piglets. Such circumstance implies the need for a considerable number of sows. Our bigger mistake was to design an experiment with 4 different treatments, and with 3 different parity groups. From a scientific point of view it was really an interesting design, which would provide really interesting information, being of special interest the possible treatment effects on the different parity groups. However, from a practical point of view, the best decision would have been to focus on one parity group and to reduce treatment groups from 4 to 3. Knowing that gilts and older sows are usually the most problematic animals in the farm for reproductive performance (Borges *et al.*, 2005; Gerjets *et al.*, 2011; Wientjes *et al.*, 2012), we should have avoided these 2 groups of age on our first experiment. On this occasion, we did not get enough data from older sows to be included in the experiment.

Reduction in the number of treatments and parity groups would have resulted in lower number of sows required for the experiment. Consequently, length of the experiment, number of farrowing rooms used, and number of stockpeople involved would had also been reduced, thus reducing risks of introducing variability. Such reduction in the number of the animals required for the experiment would have also resulted in a better selection of the animals to be included in the experiment and in a better imposition of the treatments. Additionally, one week of training in the farm previous to the start of the experiment would have helped to adapt the protocol to the farm and to detect further problems.

In the second experiment we tried to solve the problems we had in the first one but without compromising our objectives. We reduced the number of treatment groups, but we did introduce two levels of cross-fostering, so the final amount of treatments was the same but its performance was easier to schedule. Moreover, compared to the first experiment, the farm where we performed the second experiment had an increased number of stockpeople (x3). That circumstance allowed us to control more factors and to improve our treatment imposition and be more accurate in our data recording. However, we did fail to obtain a sufficient number of gilts to be included in the chapter 7.

From my point of view, there are a wide range of possibilities to keep studying the impact of colostrum supplementation or cross-fostering on piglet pre-weaning performance. We are in front of a field of knowledge that has been little studied for the scientific community, and new doubts are easy to arise from every new experiment. However, I would suggest two main aspects that could be interesting to begin with, and that could be of interest for producers:

1. To study the impact on piglet's growth and survival of different number of colostrum supplementation applications (e.g. 1 dose, 2 doses, 3 doses), since from our results it appears that just one application of 10 – 15 ml colostrum supplementation might not be enough for most of the piglets.
2. Focusing on gilts, to compare different cross-fostering strategies, and/or to study the possible advantages of cross-fostering piglets from gilts to multiparous sows, and vice versa. In other words, perform cross-fostering prioritizing dam's parity.

Irrespective of the most successful management strategy, the next step should evidently be to perform an economic evaluation considering the final productive benefits of the selected management strategy and the costs of the time investment associated with it.

Further topics of interest would probably be to assess the benefits of selected management strategies under different sanitary status. Some sanitary problems on the farrowing house could be minimized or avoided through specific colostrum supplementation or cross-fostering performance.

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Studies conducted in commercial farms, particularly the experiments to study the effect of different management strategies on newborn piglets, are usually hazardous to perform. In this kind of studies, work is concentrated as much as possible to facilitate the treatment imposition and to diminish the disturbance to farm stockpeople; in experiments were high number of sows are included, the experimental management imposition becomes harder. Besides, experimental tasks are planned mainly based on a predicted date of farrowing and on a hypothesized number of piglets born alive (or estimated from farm's historical data). Notwithstanding, some sows will deliver out of the scheduled dates; some other sows, although farrowing in scheduled dates, will deliver during night; and, finally, some sows will deliver a low number of live born piglets or will suffer from dystocia and they will have to be excluded from the experiment. Quoting the famous movie, *sows are like a box of chocolates, you never know what you're gonna get*.

Struggle for the inclusion of the necessary number of animals in the experiment, proper imposition of the treatments, and homogeneous management and environment conditions to all the animals are usually the main issues that need to be faced when experimenting with sows in field conditions.

"No estranyar-se de res quan esdevé; i abans que esdevingui, no creure res impossible"

Ciceró

Chapter 9:

General Conclusions

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

1- Allocation to conventional farrowing crates increases dam's cortisol level (*P* = 0.070) and restlessness (*P* = 0.083). Such welfare impairment is at greater extend for gilts that have previously been group housed compared to gilts that have been stall allocated during gestation.

2- Increased maternal stress prior to farrowing, observed in gilts that were previously group housed during gestation, reduces newborn piglets capacity to thermoregulate through reduction in thyroid hormone T4 levels (*P* = 0.078). Consequently, a decrease of 1 ºC (37.0 vs. 38.1 ± 0.27 ºC) in rectal temperature 60 min after birth was observed in piglets born from gilts group housed during gestation compared to piglets born from gilts stall allocated during gestation (*P* = 0.007). In addition, piglets from group housed gilts during gestation had lower body weight at day 2 post-partum (*P* = 0.008) and day 17 of life (*P* = 0.028).

3- Piglet's vitality assessment using the combination of two behavioural traits (*udder stimulation* and *number of completed circles around the enclosure*) is related to piglet's viability (*P* = 0.026) and growth (*P* = 0.023) while it is not related to piglet body weight at birth (r = 0.089, *P* = 0.133; and r = -0.018, *P* = 0.758, for U and N respectively). Besides, as a complement of piglet body weight and other traits, piglet's vitality assessment can be used as a potential tool for predicting piglet's viability (Wald test of significance for the model, *P* = 0.027) and growth (*P* < 0.001, CV = 21.94%, and R^2 = 0.35 for the model).

4- Oral supplementation with 12 ml of colostrum (obtained from 2nd to 5th parity sows) is indicated for low birth weight piglets within 6 hours of life. It improves piglet plasma IgG concentration at day 4 of life (*P* = 0.001). However, in our experiment, oral supplementation with colostrum only had benefits for piglets' survival in litters fixed only by number of piglets, with a minimum number of animal transfers between litters (0.47 vs. 1.14 ± 0.160 dead piglets/litter; *P* = 0.062).

5- Newborn piglets from primiparous sows might be in greater need of colostrum supplementation. For low birth weight piglets supplemented with colostrum, compared to the other treatments, had greater body weight gain during the first day of life ($P < 0.05$) in primiparous sows; while colostrum supplementation to low birth weight piglets born from multiparous sows had no effect on their growth. Litters from primiparous sows might require different management strategies than litters from multiparous sows.

6- Cross-fostering is a management husbandry practice with a strong impact on piglet performance. Under our experimental conditions, fixing litters only by number of piglets, aiming for a minimum number of animal transfers between litters, was more beneficial for piglet survival than cross-fostering low birth weight piglets to the same litter, thus reducing litter's body weight variability (0.80 vs. 1.69 ± 0.307 dead piglets/litter; $P = 0.022$). Such finding confirms that piglet performance is more related to litter size than body weight variability within litter.

"cada dia llegeixo i cada dia m'adono que em falta tot per llegir. I de tant en tant he de rellegir, tot i que només rellegeixo allò que es mereix el privilegi de la relectura."

Jo confesso (Jaume Cabré)

Chapter 10:

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