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3. Managing the litter from hyperprolific sows

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Abstract

The practice of breeding from hyperprolific sows producing very large litters is becoming a normal occurrence in commercial pig production. However, the relationship between large litter size and piglet mortality is well established. In order to minimise the health and welfare challenges associated with large litters and maximise the economic potential of increased numbers born, various genetic, nutritional and management interventions are required. This chapter outlines the different challenges associated with hyperprolificacy before focusing on management strategies adopted over the farrowing and lactation period to tackle those challenges. These include early interventions to assist vulnerable piglets, such as those suffering from intrauterine growth retardation, as well as strategies involving whole litter interventions (e.g. use of nurse sows, artificial rearing) to help rear supernumerary piglets.

Keywords: nurse sows, artificial rearing, colostrum and energy supplementation, IUGR

3.1 Introduction

In pig production genetic selection for economically important traits, such as number of piglets born, has resulted in a number of health and welfare challenges for pigs, as well as significant changes in management routines for staff, particularly in the farrowing and lactation stages of production. One of the major challenges is the exacerbation of the known relationship between large litter size and piglet mortality (Baxter and Edwards, 2018; Rutherford *et al.*, 2013). There has been some success with curbing the impact of this association through a combination of genetic, nutritional and management strategies. This chapter outlines the genetic trends of litter size, documenting the development of the hyperprolific sow and then highlighting the challenges associated with large litters and the management strategies adopted to deal with these challenges.

3.2 Genetic trends in litter size

Rutherford *et al.* (2013) attempted to classify litter size into zones based on particular thresholds that affect management. 'Very large' (21+ total piglets per sow) and 'large'

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(14-20 piglets per sow) litters were identified as requiring intervention to ensure piglet survival because most mothers are unlikely to be able to adequately rear more than 14 piglets (i.e. equal to the number of functional teats) until weaning. Some authors have suggested that, based on the pig's life-history strategy, a sow is pre-disposed to only support 11-12 piglets (Andersen *et al.*, 2011). In 2013, when Rutherford *et al.*'s paper was published, 'very large' litters were considered relatively rare. However, average data published since then from Denmark (DK), arguably the most successful breeders of hyperprolific sow lines, show that total piglets born has continued to rise, with an extra 2.4 piglets born per litter since 2011 (Figure 3.1). As these are only average results it is plausible that the upper range sees an increasing number of 'very large' litters produced. The United Kingdom (UK) production figures provide an interesting comparison. Figure 3.1 demonstrates that while the UK has not historically reported large litters in their annual statistics (AHDB Pork 1996-2018[1]), there is a growing trend towards increased litter size. Since the start of this decade, UK numbers of born per litter increased by 1.5 piglets; whereas in the previous 15 years there was no significant increase (e.g. average total born was 11.7 in 1996 vs 11.8 in 2010). The stability of numbers born is likely to be, in part, a result of the large proportion of the UK breeding herd being outdoor-bred (40%) and as such genetic selection strategies focus on robustness and mothering ability rather

[1] https://pork.ahdb.org.uk/prices-stats/costings-herd-performance/

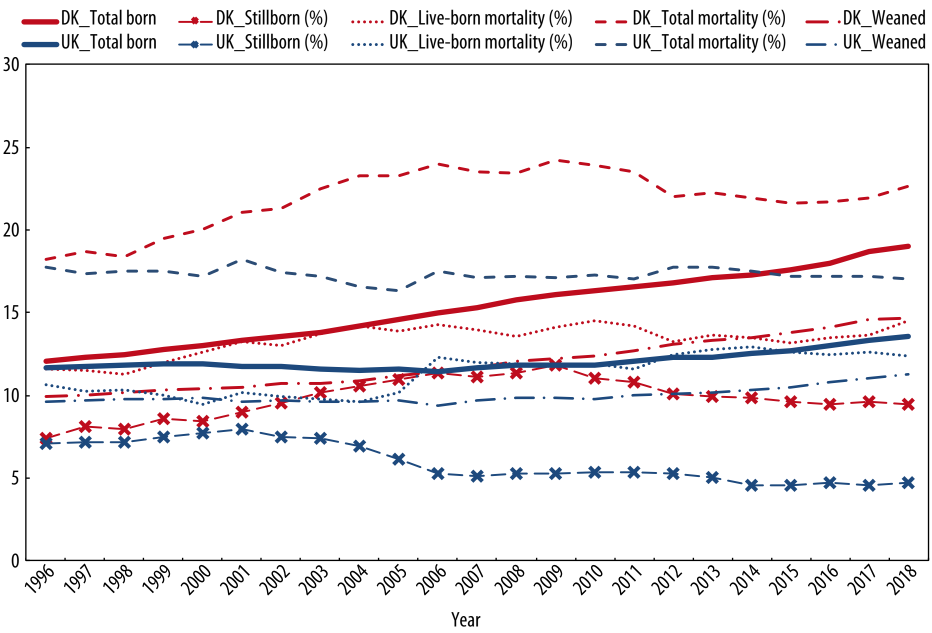

Figure 3.1. Average trends in total number born, total number weaned, percentage stillborn, live-born and total mortality per litter for Danish (DK) and British (UK) breeding herds. The solid vertical lines at 2004 and 2011 represent changes in Danish breeding (introduction of 'alive at five' (LP5)) and recording strategies respectively. UK national herd averages include figures for both indoor and outdoor production.

than hyperprolificacy. However, recent figures suggest Danish breeding 'success' has been exported, resulting in increased numbers weaned but also a concomitant increase in live-born mortality. This mirrors, but is not as extreme as, the Danish experience where the genetic potential for large numbers born filtered through to the production herd and mortality increased. However, since 2011 the Danish reports show that pre-weaning mortality has started to decrease even as litter size continues to increase. There was a change in reporting methods of national data at this time, which might explain the change in trend. However, there was also increased public concern over the high mortality rates and efforts made to identify improvements in management to take care of surplus piglets. In addition, it is possible that a more balanced breeding program (e.g. 'alive at day five' rather than 'total born' started in 2004 – Nielsen *et al.,* 2013) could have filtered through nucleus herds into the wider population and made some impact. Such changes are critical given how many unfavourable pathologies are associated with the production of very large litters.

3.3 Challenges of increased prolificacy

Although some degree of piglet mortality can be seen as an inevitable aspect of reproduction in polytocous species (Baxter and Edwards, 2018; Edwards, 2002), it can also be argued that hyperprolific breeding programs have become superprolific thus altering what might previously be thought of as 'acceptable' levels of piglet mortality. The association between large litter size and mortality is a result of a number of factors, including an increased farrowing duration (see Oliviero *et al.,* 2019 for summary) and an associated increase in stillbirths and piglets suffering from hypoxia (Langendijk *et al.,* 2018). There is increased competition at the udder and reduced colostrum intake per individual piglet (Declerck *et al.,* 2017; Hasan *et al.,* 2019), exacerbated by an increase in within-litter weight variation at birth. There is weakened growth and poorer development of embryos resulting in a decrease in overall piglet birth weight (Foxcroft, 2008; Wolf *et al.,* 2008), thus reducing piglet robustness and increasing the number of piglets suffering from intrauterine growth retardation (IUGR) and its associated pathologies (Matheson *et al.,* 2018; Quesnel *et al.,* 2008; Figure 3.2). This latter condition is thought to affect anywhere between 30-40% of piglets in large litters (Edwards *et al.,* 2019) and dealing with piglets in this condition requires targeted management interventions (covered later in this chapter).

There are also challenges for the hyperprolific sow, with some studies showing reduced longevity when sows produce more than medium sized litters (12-14 piglets) in their lower parities (Andersson *et al.,* 2015) or when sows over invest in their litter when still at a young age themselves (Ocepek *et al.,* 2016). However, it should be noted that abnormally low litter sizes (e.g. ≤7) also threaten longevity due to culling for reproductive failure (Bergman *et al.,* 2018; Rekiel *et al.,* 2014). Where breeding strategies emphasize numbers born, hyperprolific sows with high milk production face physical and physiological challenges. As lactation is a period of high metabolic load, sows nursing large litters are at risk of developing heat stress (Williams *et al.,* 2013). They can suffer from higher losses in body condition (Ocepek *et al.,* 2016) which can increase the risk of shoulder sores

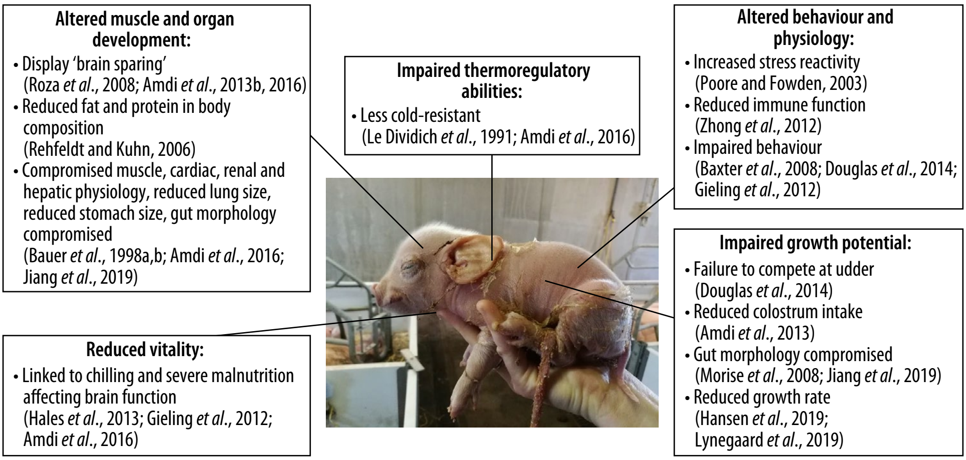

Figure 3.2. Conditions associated with Intrauterine Growth Retardation (IUGR). For a more detailed review, see Edwards et al. *(2019) and Farmer and Edwards (2020). Photo by M. Farish, SRUC.*

developing (see Rioja-Lang *et al.,* 2018 for a review). This condition is also influenced by housing systems that limit posture changes (e.g. farrowing crates, Bonde, 2008). If the period of confinement is extended, as is the case when adopting nurse sow strategies to rear surplus piglets, the risk of developing these injuries is increased (Section 3.5.2). If such challenges to sow health and welfare are not tackled there are negative impacts for piglet growth, development and survival, thus any perceived production gain from extra numbers born will be lost.

3.4 Management strategies for large litters

Breeding for a more balanced selection program that encompasses number weaned, piglet birth weight and mothering ability is an important long-term goal for optimizing piglet survival and reducing the impact of hyperprolificacy (detailed in Baxter *et al.,* 2018). However, this chapter will focus on immediate on-farm managerial interventions that could affect the farrowing process, colostrum quality, maternal behaviour and, ultimately, piglet survival.

3.4.1 Sow interventions

While the focus of this book is on the piglet, any strategy must include mitigating the challenges that sows are faced with. Sows are now superprolific breeding animals with highly specialized needs and there are important interventions that can be made at the sow level that influence piglet viability. An obvious area to target is the unfavourable relationship between farrowing duration, large litter size and piglet mortality. While it may be tempting to hasten farrowing progression pharmaceutically using oxytocin, there are significant risks associated with its misuse, including increased dystocia, stillbirths and piglets suffering from meconium aspiration syndrome (MAS – Alonso-Spilsbury *et al.*, 2005; Kirkden *et al.*, 2013). It is known that farrowing duration is influenced by genotype, sow age, body condition, constipation and farrowing environment (i.e. loose vs crated) (Oliviero *et al.*, 2010). More recent work has detailed the effects of energy status at the onset of farrowing on farrowing duration (Feyera *et al.*, 2018) and thus highlights the issue of maternal fatigue. On entering the farrowing house, sows are already at a disadvantage having been fed a restricted ration of just 50% of what they would eat *ad libitum* during gestation (Read *et al.*, 2020). Their feed is then restricted further to mitigate the risk of developing metabolic disorders, such as post-partum dysgalactia syndrome (PDS) (which includes the previously-used term mastitis, metritis and agalactia, or MMA (Neil *et al.*, 1996; Papadopoulos *et al.*, 2010). In the farrowing house, sows might be fed only once a day or twice with their ration split between two feedings at the beginning and end of the working day (usually 07h00 and 15h00). Feyera and colleagues suspected that the energy status of sows producing large litters was compromised and that sows could be entering the farrowing process at a disadvantage depending on the time that had lapsed between the onset of farrowing and the sow's last meal (Feyera *et al.*, 2018). As disturbance affects parturition (Lawrence *et al.*, 1997) sows often farrow at night when staff are absent and the farrowing environment is quieter. Thus, if a sow receives a restricted feed ration at 15:00 but starts farrowing at 06:00 the next morning she will commence her parturition 15 h after her last intake of energy and may not finish farrowing for a further 7.5 h (i.e. average farrowing duration for hyperprolific sows, Hales *et al.*, 2015). Maternal fatigue is therefore a significant concern.

Providing sows with a fibre-rich dietary supplement (DF) in their standard gestation and transition rations (e.g. Feyera *et al.* (2017) provided 350 g/d of DF from d 102 to 108 of gestation and 700 g/d of DF from d 109 of gestation until farrowing) has a positive effect on energy status at the onset of farrowing and significantly reduces stillbirths (Feyera *et al.*, 2017). High fibre transition diets are also likely to relieve constipation around farrowing (Peltoniemi and Oliviero, 2015). These results are indirectly supported by work showing that hyperprolific sows farrowing under organic conditions appear to be resistant to the effects of litter size on farrowing duration (Thorsen *et al.*, 2017). It is postulated that the availability of roughage could contribute to this resistance, as well as the ability to more fully satisfy nest-building behaviour and farrow unrestrained, which also positively impacts farrowing duration (Oliviero *et al.*, 2010), colostrum quality and sow metabolism (Yun *et al.*, 2014a,b). The UK production figures (Figure 3.1) show that stillbirth rate is currently below 5%, despite recent increases in numbers born, while stillbirth rate of DK organic outdoor herds was 7% (Rangstrup-Christensen *et al.*, 2017). This lower stillbirth rate in UK herds could be attributed to similar farrowing advantages available to the outdoor breeding herd, as well as breeding programs incorporating survival traits (e.g. numbers weaned and high birth weight, Roehe *et al.*, 2010) with less emphasis on numbers born.

Other nutritional interventions through sow diets have focussed on ways to improve embryo quality and subsequent birth weight and uniformity of piglets, given the importance of birth weight and within litter weight variation on piglet survival (Edwards and Baxter, 2015). These include use of fermentable ingredients in sow diets prior to breeding (Van den Brand *et al.*, 2009), and essential amino acids at the time of placental development (Wu *et al.*, 2010). Amdi *et al.* (2013a) have targeted nutritional interventions to deal with the increasing population of IUGR piglets. Such feeding interventions are discussed in more detail in Chapter 1 (Farmer and Edwards, 2020). Campos *et al.* (2012) also published a review on these offspring benefits, while Meunier-Salaün *et al.* (2001) and De Leeuw *et al.* (2008) discussed the influence of nutritional interventions on sow welfare.

3.4.2 Early piglet interventions – identifying IUGR piglets

When the number of piglets born in a farrowing batch exceeds the number of functional teats available in that batch, management interventions are necessary. The stockperson's role is critical in deciding the most appropriate course of action to deal with the different challenges that arise. The first of which involves identifying animals whose immediate health and welfare are at risk.

IUGR piglets are not just piglets of low birth weight. They have certain characteristics that help distinguish them from small for gestational age (SGA) piglets. These include steep, dolphin-like foreheads, bulging eyes and wrinkles perpendicular to the mouth (Chevaux *et al.*, 2010; Hales *et al.*, 2013; Matheson *et al.*, 2018). Severely growth retarded piglets (s-IUGR) display two or three of these characteristics, whereas moderately growth retarded piglets (m-IUGR) only have one characteristic present (Hales *et al.*, 2013). While IUGR piglets are typically smaller than their littermates, these head shape characteristics can be seen in pigs across the birth weight range (Edwards *et al.*, 2019). However, on average, pigs classified as s-IUGR have lower birth weight, body mass index, ponderal index and shorter crown-rump length (Hales *et al.*, 2013). The severity of their IUGR status determines whether or not management interventions to promote survival will be worthwhile. Figure 3.2 shows a piglet suffering from s-IUGR and summarizes the main pathologies associated with IUGR. Once piglets have been classified into SGA, m-IUGR and s-IUGR, management decisions are required to assist them (SGA and m-IUGR) or humanely euthanize (e.g. s-IUGR).

3.4.3 Optimizing the farrowing environment

All newborn piglets are vulnerable to hypothermia (Chapter 1; Farmer and Edwards, 2020) and although hypothermia is seldom recorded as the primary cause of death in commercial herds, it is to a high extent the precursor of crushing, starvation and death due to diseases (Pedersen *et al.*, 2011a). There is an immediate challenge to overcome concerning the thermal environment around the time of birth, since the thermo-neutral zone of sows and newborn piglets differ markedly. A sow's evaporative critical temperature is the upper limit of the thermo-neutral zone and represents the temperature at which evaporative heat loss begins to increase particularly from lung tissues through increased respiration. At this temperature, the sow will reduce its voluntary feed intake (Black *et al.*, 1993). The temperature at which this happens depends on a variety of factors associated with the sow's ability to thermoregulate. Muns *et al.* (2016) compared sows in farrowing crates housed at 20 or 25 °C. They found that sows experiencing 25 °C around farrowing altered their postural behaviour. These sows reacted to the thermal challenge with higher respiration rate, but both their rectal and udder temperatures were elevated, indicating that they were not able to compensate for the higher ambient temperature. High ambient temperature negatively influenced sows' feed intake, with a negative impact on piglets' weaning weight. Hence, Muns *et al.* (2016) postulated that crated sows may have a lower critical temperature than loose sows due to the inability to thermoregulate via altered behaviour. This is supported by a study investigating three room temperatures (15, 20 and 25 °C) for lactating sows kept loose in pens with a partly slatted concrete floor, which showed that sows used the cooler slatted floor for behavioural thermoregulation by resting in this zone of the pen between daily activity bouts (Malmkvist *et al.,* 2012). Neither feed intake nor body weight loss differed significantly across the entire lactation. Thus, loose housing with different thermal zones may increase the upper critical temperature and positively affect piglet growth. This has been indicated by several studies showing increased piglet growth in sows kept loose (e.g. Oostindjer *et al.,* 2010; Pedersen *et al.,* 2011b). On the other hand, it can be argued that some loose housing systems do not have the same protective features that conventional systems have to limit sow posture changes and reduce crushing mortality. Therefore, they may constitute a higher risk for the high numbers of low birth weight or non-viable piglets found in large litters, as indicated by Hales *et al.* (2014).

Quiniou and Noblet (1999) estimated that, at a litter size of 10-11 suckling piglets, the evaporative critical temperature for sows was below 22 °C, while piglet growth was not reduced until ambient temperature was 25 °C or above. However, as litter size has almost doubled since this study, the metabolic load to produce milk for the large litter and thus the sow's own heat production has increased concurrently. Thus, the upper critical temperature of the hyperprolific sow is likely lower than previously estimated. Heat stress is associated with secretion of stress hormones (Biensen *et al.,* 1996; Malmkvist *et al.,* 2009), reduced appetite (Biensen *et al.,* 1996; Prunier *et al.,*1997), reduced lactational output (Black *et al.,* 1993; Stansbury *et al.,* 1987) and thus poor piglet growth (Biensen *et al.*, 1996; Cabezon *et al.,* 2017). In addition, the risk of piglet crushing is likely to increase at high ambient temperature due to sows being less attentive and piglets being more likely to stay close to the sow's udder to perform pre- and post-massage due to reduced milk yield and therefore hunger. The metabolic load, and thus risk of heat stress, is highest at peak lactation after 2-3 weeks. However, during the peri-parturient period sows also have difficulties coping with high environmental temperatures as shown by Muns *et al.* (2016). Considering that large litters prolong the farrowing process with a risk of fatigue, the negative effects of heat stress may further enhance this risk and result in dystocia. Dystocia and related hypoxia in the piglets contribute to piglet hypothermia and piglets born of low birth weight may already have impeded oxygen supply due to inhabiting a small placenta in utero. This causes chronic foetal hypoxemia (Rees *et al.,* 1998). Thus, farmers must tackle this significant challenge of avoiding hypothermia and hyperthermia for the piglets and sows respectively and it is a challenge that has been exacerbated in large litters.

To prevent negative effects on the productivity, welfare and health of sows at high ambient temperatures, the room temperature is recommended not to exceed 20-22 °C.

However, this is difficult in many areas with a hot climate. The need for cooling facilities to prevent heat stress in hyperprolific sows is therefore high. Several studies have shown that different facilities do provide some outlet for heat stress in crated sows; for example water drip cooling, snout cooling by water or cooled air flow or floor cooling (Biensen *et al.,* 1996; Cabezon *et al.,* 2017; Jeon *et al.,* 2006; Perin *et al.,* 2016; Van Wagenberg *et al.,* 2006). These methodologies have been shown to reduce signs of heat stress and improve sow appetite, milk production and piglet growth.

In contrast to the sow, the neonatal piglets are vulnerable to low ambient temperature. At the time of birth, the piglets' lower critical ambient temperature is above 34 °C (Mount, 1963; Herpin *et al.,* 2002). A piglet needs to increase heat production through shivering and increased metabolic processes to maintain its body temperature at this temperature. Piglets have no fur, and are born with limited glycogen reserves (Chapter 1 by Farmer and Edwards, 2020) and also lack brown adipose tissue; thus, their ability to maintain body temperature through metabolic processes is limited at birth (Berthon *et al.,* 1994; Herpin *et al.,* 2002). Therefore, survival strongly depends on the thermal environment of the birth site. At birth, piglets experience a large change in ambient temperature from the homeostatic uterine temperature of 38 °C to a much cooler temperature of the external environment. In nature, sows nest-build, among other things, to provide a warm birth environment for the newborn piglets, and this also helps dry up birth fluids and protects piglets from hypothermia. In contrast, the production environment is very different. Room temperature is kept around 20-22 °C (to prevent sow heat stress as described) and the birth site of the farrowing pen typically consists of a slatted floor surface made of metal, plastic or concrete, and it is rarely provided with any nesting material. Piglets born into such an environment immediately lose heat after birth, causing a drop in body temperature of 2-4 °C within the first 20-60 min after birth (Baxter *et al.,* 2008; Berthon *et al.,* 1993; Malmkvist *et al.,* 2006; Pedersen *et al.,* 2013; Tuchscherer *et al.,* 2000). The extent of this drop is closely linked to the piglet's body weight (Baxter *et al.,* 2008; Kammersgaard *et al.,* 2013; Pedersen *et al.,* 2013) since lighter piglets have a greater surface to body mass ratio than heavier piglets, and thus they lose heat more rapidly through radiation, conduction and evaporation (Herpin *et al.,* 2002). Therefore, low birth weight piglets are at greater risk of suffering from hypothermia. In a recent study, Amdi *et al.* (2016) compared IUGR piglets (mean birth weight (BiW) of 0.7 kg with head morphology characteristics of IUGR) with 'normal' piglets (mean BiW of 1.28 kg) and found that averaging over the first 2 h post-partum IUGR piglets were 1.3 °C cooler than 'normal' piglets (average rectal temperatures: 36.2 vs 37.5 °C respectively). These figures demonstrate the impact of low birth weight on body temperature and the vulnerability of IUGR piglets, as well as highlight the significant decrease in what is considered 'normal' BiWs for piglets from hyperprolific genotypes.

Due to the close relationship between litter size, birth weight and risk of hypothermia it is important to prevent hypothermia immediately at birth for hyperprolific litters. Many farms do provide a separate thermally comfortable area for piglets away from the sow. However, piglets are strongly attracted to the sows' udder at birth to ingest colostrum and get warmth. Attempts to attract newborn piglets to the creep area within the first 24 h after birth have not been successful whether by providing a large temperature gradient between inside and outside the creep (Pedersen *et al.,* 2013), by providing light inside the creep area (Larsen *et al.,* 2015), or by providing a soft floor (Vasdal *et al.,* 2010). Other management measures therefore need to be used to prevent the hypothermic state immediately at the time of birth. One solution is to add extra heat at the time of birth. Andersen and Pedersen (2016) investigated the effects on piglet body temperature and time to ingest colostrum of positioning a radiant heater behind the sow. The radiant heat reduced the immediate drop in body temperature after birth and ensured a faster recovery in body temperature resulting in higher body temperature at 24 h of age. Piglets stayed longer behind the sow while the latency to first colostrum ingestion was not prolonged. Malmkvist *et al.* (2006) showed that floor heating for 48 h at the birth site of litters born to loose-housed sows prevented hypothermia and increased survival. Later studies showed that floor heating for only 12 h around farrowing had a similar effect on hypothermia (Pedersen *et al.,* 2013). Increasing the room temperature as high as 25 °C, compared to 15 °C and 20 °C, significantly reduced the risk of hypothermia (Pedersen *et al.,* 2013) but, as already discussed, this temperature is thermally challenging for the sow (Muns *et al.,* 2016). A study comparing the effect of different heating methods on hypothermia during the first 2 h after birth showed that provision of abundant long straw was as effective as radiant heaters to prevent hypothermia, while water-based floor-heating was less effective (Pedersen *et al.,* 2016). This study also indicated that the postnatal drop in body temperature was higher when piglets were exposed to a solid concrete floor compared to a slatted concrete floor, likely due to a large wet surface (caused by the birth fluid) of the solid compared to the slatted floor. This work complements results from early work by Mount (1967) who demonstrated that piglets in contact with a concrete floor lost 40% more heat than those in contact with 2.5 cm of straw. Providing substrate in the periparturient period would also be beneficial for the sow, especially if the substrate is enough to satisfy highly motivated nest-building behaviour. There are also indirect benefits for the piglets, as demonstrated by work showing a link between provision of ample nest-building substrate and colostrum quality (Yun *et al.,* 2015). To fully satisfy the sow's biological needs at this time, one would need to provide a number of stimuli including both space and substrate (Baxter *et al.,* 2011; Jarvis *et al.,* 2002). However, Swan *et al.* (2018) demonstrated that sows in farrowing crates given access to either straw, newspaper sheets or wood shavings performed plentiful nest-building behaviours, with the straw treatment showing significantly lower piglet mortality than the other groups. Similarly, Bolhuis *et al.* (2018) showed a positive effect on nest-building of providing jute sacks as nest-building materials both in crates and loose-housed sows. This contributes to the growing body of literature demonstrating the indirect benefits of nest-building behaviour on piglet outcomes.

Prevention of the immediate drop in piglet body temperature after birth needs to be followed up by measures that ensure a thermally comfortable lying area where all piglets can rest. The EU Council Directive 2001/93/EC (EU, 2001) regulates this issue for farrowing pens stating that 'a part of the total floor, sufficient to allow the animals to rest together at the same time, must be solid or covered with a mat, or be littered with straw ...'. Either the thermally comfortable lying area can be a heated creep area with solid floor or a heat plate positioned above the slatted floor at the side of the pen or in a corner. The solid and heated area needs to be sufficiently large to accommodate all piglets lying at least in partial lateral position. For a litter of 12 or more piglets the area needs to be at least 1.3 m^2 based on measurements of the size of four-week old piglets (Moustsen and Poulsen, 2004). As genetic selection for hyperprolificacy continues, the number of suckling piglets left at the sow after cross-fostering also increases; 16 suckling piglets are not uncommon. As this is an ongoing process special attention needs to be given to the pen design to continuously ensure sufficient space not only for the sow but also for the piglets. Beside space for resting, there needs to be space enough at both sides of the bars in the crate to ensure that piglets have sufficient space to be able to suckle without difficulties. This topic is also regulated by the EU Council Directive 91/630/EEC stating, 'When a farrowing crate is used, the piglets must have sufficient space to be able to suckle without difficulties'. Based on measurements of the length of a four-week old piglet (approximately 0.5 m) this space needs to be provided at each side of the crate, to avoid fighting over access to teats caused by obstacles blocking access to the piglets' preferred teat. Many pen designs do not allow sufficient space for hyperprolific litters (Pedersen *et al.,* 2013) neither to rest together at a thermally comfortable area nor for suckling. It is therefore necessary to increase the attention given to the space allowance to piglets in farrowing pens, especially as genetic progress rapidly increases litter size beyond the current state.

Investment in optimizing the farrowing environment to accommodate large litters and meet the welfare needs of both piglets and sows could bring significant benefits. Producers and pig building companies should consider that space, the thermal properties of the flooring as well as the ability to provide an optimal radiant heat source and thermally protective substrate are all important details to mitigate the challenges described.

3.4.4 Farrowing surveillance

As an alternative to providing extra heat at the birth site, farrowing surveillance combined with actions to dry and move piglets to a heat lamp or udder immediately after birth has shown to improve survival and growth performance (Andersen *et al.,* 2009; Christison *et al.,* 1997; Rosvold *et al.,* 2017; Vasdal *et al.,* 2011). Ensuring thermal comfort is an important precursor to ensuring that all piglets gain adequate colostrum. These elements are intrinsically linked as colostrum ingestion initiates and helps sustain thermoregulatory processes and is paramount in the behavioural and physiological factors, both direct and indirect, that can influence the occurrence of hypothermia in the newborn piglet.

Other piglet treatments could be applied if farrowings are supervised. Simply helping a piglet find a teat shortly after birth can reduce mortality (Andersen *et al.,* 2007). More intensive protocols have seen piglets be dried, airways cleared, bovine colostrum given and oxygen administered, resulting in an 8.1% decrease in pre-weaning mortality and an increase in weaning weight (White *et al.,* 1996). In attempts to save IUGR piglets, trials have involved giving glucose injections at birth and administering colostrum boluses (Amdi *et al.,* 2017a; Englesmann *et al.,* 2019). These studies are intensive and in order to realize successful outcomes for IUGR piglets, very early interventions (within the first 4 h after birth) and skilled management (e.g. subcutaneous injection of glucose into piglets weighing under 0.7 kg) are required. Such intensive handling protocols will result in extra disturbance at the birth site and may actually be counterproductive as it could disrupt maternal behaviour via increased stress-responses (Lawrence *et al.,* 1997). However, if assistance was targeted and focussed on clear protocols there could be consistently positive outcomes and it appears that very early interventions, such as ensuring early ingestion of colostrum and/or energy, will become more commonplace as the number of vulnerable and supernumery piglets also becomes more commonplace.

3.4.5 Colostrum and energy supplementation

As detailed in Chapter 1 (Farmer and Edwards, 2020), newborn piglets are born immunologically naïve and with low body energy reserves, which makes them dependent on exogenous sources of energy and immunoglobulins (i.e. colostrum) to ensure survival. However, it seems that the failure to acquire a sufficient amount of energy is a greater factor of neonatal mortality than the failure to acquire a sufficient amount of immunoglobulins (i.e. IgG) (Thorup *et al.,* 2015). This hypothesis is supported by experiments in which energy supplementation (i.e. without immune material) and colostrum supplementation (i.e. containing IgG) had similar effects on piglet survival (Muns *et al.,* 2015, 2017). Work specifically targeting IUGR piglets has shown that glucose injections administered at birth were more effective in saving IUGR piglets than just providing supplementary colostrum (Englesmann *et al.,* 2019). These piglets also received 1 h of warming and were placed at a nurse sow to avoid suckling competition. The authors reported that 38% of IUGR piglets died before 21 days of age but they consider the intervention a success based on a 60% mortality rate usually reported for these piglets (Hales *et al.,* 2013). The importance of acquisition of energy is due to the fact that body energy reserves do not cover the high energy needs of the newborn piglet (e.g. to ensure thermoregulation, locate the udder, compete for a teat and escape potentially dangerous movements of the sow). Providing the piglets with energy shortly after birth has gained interest as a means to promote suckling (i.e. acquisition of sufficient amounts of colostrum) and, consequently, neonatal survival and growth.

Supplementing piglets with sow colostrum is a technique used on some farms, based on the assumption that colostrum ingestion increases survival and immunity (Casellas *et al.,* 2005; Devillers *et al.,* 2011). However, Muns *et al.* (2014) found no difference in terms of survival, even though colostrum-supplemented piglets had greater concentrations of IgG than non-supplemented piglets. Moreover, this technique can be difficult to implement, as colostrum must be harvested from farrowing sows. A large part of sow colostrum's energy value (i.e. 40 to 60%) is from long-chain triglycerides, composed of long-chain fatty acids (LCFA) (Le Dividich *et al.,* 2005). As lipids are the most important source of energy for neonatal piglets, commercial energy supplements are mostly fat-based, either using LCFA or medium-chain fatty acids (MCFA) in their formulation. Heo *et al.* (2002) showed that the oxidation rate of MCFA is faster than that of LCFA and therefore, can cover a greater part of the piglets' energy expenditures (i.e. 35 vs 9%, respectively) and, consequently, also sustain their energy needs for a longer period of time (e.g. 5.8 vs 1.2 h in MCFA-fed and colostrum-deprived piglets, respectively).

To date, very few studies investigated the effects of neonatal energy supplementation on piglet survival and growth (e.g. Englesmann *et al.,* 2019). It is difficult to identify an optimal supplementation strategy as the protocols vary substantially in terms of the timing of supplementation, energy type (e.g. fat-based, protein-based, glucose-containing or with immune material or not), energy content, and amount of product supplemented. In addition, 'small piglets' are usually targeted in these interventions but the definition of these also differs between studies. If future studies characterize piglets into IUGR using head-shape classification as well as body weight (see above and Hales *et al.,* 2013), this could provide a clearer interpretation of results and therefore development of more targeted interventions.

Nevertheless, the body of work available does allow identification of some success factors. First, piglets should be warm when receiving supplements (Englesmann *et al.,* 2019). Second, the amount of energy product supplemented should provide enough energy to the piglets without making them lethargic and without giving them a prolonged feeling of satiety that could disrupt normal suckling patterns (Benevenga *et al.,* 1989; Lepine *et al.,* 1989). Third, supplementation should occur while the sow still produces colostrum in order to promote colostrum intake, meaning that supplementation given within the 12 h post-partum should be effective (Declerck *et al.,* 2016; Muns *et al.,* 2017). The earlier in this 12 h time window the better given the significant drop in piglet body temperature in the first hour post-partum. The number of doses of energy supplemented to the piglets is a final factor of success, as supplementing at least two doses within 24 h post-partum appeared more effective than giving only one dose (Muns *et al.,* 2017). The type of energy used could lead to different results. Englesmann *et al.* (2019) used injectable glucose and Moreira *et al.* (2017) used a protein-based energy product to supplement piglets, and there was no comparison with a fat-based product. Moreira *et al.* (2017) found only a numerical difference in survival between supplemented and non-supplemented counterparts, but supplemented pigs had a two-fold weight gain. Englesmann *et al.* (2019) also found better growth rates in glucose supplemented IUGR piglets compared to those only given colostrum.

It is worth noting that in most studies looking at supplementation, all piglets within the same litter were dosed, which does not take into account the sow's contribution to piglet survival and growth, despite the fact that her maternal abilities are critical (e.g. carefulness/crushing – Andersen *et al.,* 2005; nursing frequency – Valros *et al.,* 2002; experience/parity – Muns *et al.,* 2015). Schmitt *et al.* (2019a) controlled the sow effect by administering different supplementations to piglets within the same litter, but their study failed to detect differences of supplementation on survival and growth.

3.4.6 Split suckling

The nursing/suckling pattern of piglets is evolutionary developed to ensure that each piglet takes ownership of a specific teat to reduce intra-litter competition for resources. Thus, when sows give birth to more piglets than the number of functional teats some piglets will not gain ownership of a teat and will be at great risk of hypothermia and starving if no action is taken by the stockperson.

Studies have shown that approximately 30% of hyperprolific sows deliver insufficient colostrum for the size of their litters (Decaluwé *et al.,* 2013; Quesnel *et al.,* 2012). Piglets require at least 200 g of colostrum to survive (Devillers *et al.,* 2011), but above 250 g promotes better growth and survival (Hasan *et al.,* 2019). Colostrum is available continuously for approximately 12 h after birth of the first piglet and its quality drops rapidly over the first 24 h post-partum (Quesnel *et al.,* 2012), with the best quality in terms of immunoglobulin content being within the first 4 h post-partum (Klobasa *et al.,* 1987). Given that the farrowing duration of hyperprolific sows averages 7.5 h, there is an obvious risk that later born piglets are not acquiring good quality colostrum. Colostrum contains factors other than immunoglobulins that are critical for passive transfer of immunity, such as lymphocytes (B and T cells), cytokines, nucleotides, and various growth factors (Bandrick *et al.,* 2011) as well as other important biochemical signalling factors (Power and Schulkin, 2013). Studies have shown that suckling from one's own mother is beneficial for successful passage of these elements and therefore achieving more robust immunocompetence. A newborn piglet's systemic and mucosal adaptive immune system is born immature and partial fulfilment of this deficiency is achieved by ingesting colostral lymphocytes that are able to pass through the gut wall for at least one week post-partum (Poonsuk and Zimmerman, 2018; Tuboly *et al.,* 1988). However, only maternally derived cells are able to cross the gut barrier and experiments in cross-fostered piglets showed that they could not absorb cells from a foster mother's colostrum (Bandrick *et al.,* 2011).

Split-suckling helps to ensure that all piglets have ingested some of their own mother's colostrum. It is used on the first litters born in a batch when fostering opportunities are limited. It involves splitting the litter into two groups, usually based on their weight and/or vitality (Donovan and Dritz, 2000; Kyriazakis and Edwards, 1986). The lightest/weakest are allowed access to the udder first while the heaviest/strongest are enclosed in a heated creep area or a designated box. Once piglets have successfully suckled a number of times (e.g. 90 minutes should ensure at least two successful colostrum ejections if let-down has become cyclical), they are marked and swapped with the heavier group. Alternating these groups during the working hours of the day and reuniting them at night is a typical pattern but 24 h surveillance around farrowing and the first few days post-partum could allow 24 h split-suckling protocols. Split-suckling is an immediate action to promote survival, but once protocols for optimal colostrum intake have been implemented (i.e. 12 h with their own mother recommended, not less than 6 h) decisions are required in order to achieve manageable and stable litter sizes for the remainder of lactation.

3.4.7 Cross-fostering

Cross-fostering involves removing some or all piglets from their birth sow to a foster sow or exchanging piglets between sows depending on their size, vigour and gender as well as physical characteristics of the sow's udder (i.e. IUGR piglets will benefit from access to an udder with smaller teats and inter-teat distance, Balzani *et al.,* 2016; Vasdal and Andersen, 2012). Cross-fostering can be very successful if performed correctly (for reviews see Alexopoulos *et al.,* 2018; Baxter *et al.,* 2013). However, if performed poorly (e.g. too early or too late; Horrell and Bennett, 1981; Price *et al.,* 1994; Straw *et al.,* 1998) or over performed it can be disruptive, stressful and counterproductive (Robert and Martineau, 2001; Straw *et al.,* 1998). There are various reports of long-term impacts on survival, growth, behaviour, reproductive success and immunity because of cross-fostering. Cross-fostered piglets take longer to reach market weight than piglets that were not cross-fostered, suggestive of a long-term effect on growth rate (Stewart and Diekman, 1989). Cross-fostered piglets may also have lower survival during the post-weaning period or nursery stage than resident piglets originally in the litters (Neal and Irvin, 1991), although other studies have found no such effects (Stewart and Diekman, 1989). However, Stewart and Diekman (1989) did find that gilts reared by foster dams had lower reproductive success in their first parity (poorer conception and farrowing rates and fewer live born piglets). This could be due to failure of the gilts as piglets to acquire enough of their own mother's colostrum and milk to transfer some important bioactive factors that appear to be necessary for normal gene expression in gilt uterine tissue (Bartol *et al.,* 2008, 2017; Chen *et al.,* 2011). There is an established appreciation of the importance of early life experience on shaping adult outcomes (Gluckman, 2004; Rutherford *et al.,* 2012) and any disruption to critically important 'life-history stages' (Bartol *et al.,* 2013), such as the interruption of lactocrine signalling could have significant long-term effects.

Cross-fostering does not solve the problem of supernumerary piglets in a whole farrowing batch, which is common place in hyperprolific herds. More extreme fostering strategies need to be adopted to deal with these extra piglets throughout lactation.

3.5 Nurse sow system

3.5.1 Prevalence of nurse sow system and challenges

In hyperprolific herds, one such extreme fostering strategy is to implement a nurse sow system (Baxter *et al.,* 2013). There are two different nurse sow strategies: one-step and two-step. The prevalence of the nurse sow system was surveyed in 631 Danish herds in 2014 (Sørensen and Pedersen, 2015). The study revealed a large variation between herds both in the prevalence of sows/litters being involved and in the methodologies. As shown in Figure 3.3, the percentage of sows in each batch that served as nurse sows ranged from just a few up to 50%. There appeared to be little consistency/agreement among farmers in methodologies used, except that the majority of farms (85%) used the two-step strategy. Criteria for selecting a sow as a nurse sow differed widely between farmers. Only 45% of the farmers used parity as a criterion. Of these farmers that used parity as a criterion, there was great variation in terms of preferred parity. Nurse sows were on average given 1-2 foster piglets less than they have just weaned of their own piglets. In 2013, when the survey was done, the average live-born litter size was 15.4 piglets. Since then, live-born litter size in DK herds has further increased to 17.2 piglets in 2018 (Figure 3.1). Thus, the prevalence of sows that served as nurse sows has likely increased proportionally.

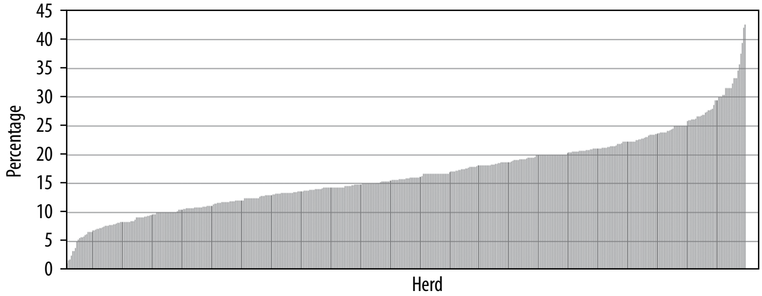

Figure 3.3. Percentage of sows per farrowing batch that serve as nurse sows. Each column represents one pig herd (modified from Sørensen and Pedersen, 2015).

3.5.2 Performance and welfare challenges of the nurse sow system

In the one-step nurse sow strategy, a sow that weaned her own piglets, typically after 3 weeks of nursing, is given surplus newborn piglets (after 6-12 h of suckling from their own mothers) from several litters to nurse for another 3-4 weeks. In this strategy sow lactation is extended by 3-4 weeks compared to non-nurse sows.

The two-step strategy involves two sows. A sow (called the nurse sow) weans her own piglets after 3 weeks and receives an entire litter from a so-called interim sow, who nursed her own piglets for 5-7 days post-partum. The interim sow receives newborn surplus piglets from different litters (after 6-12 h of suckling from their own mothers). The lactation period of the interim sow is thus only extended by 2-3 weeks.

Due to the complexity of the nurse sow system and the huge variation among farms in the methodology applied it is difficult to study its impact on production and welfare. Furthermore, it is impossible to reach general conclusions since results obtained are strongly affected by the criteria used for selecting sows and piglets as nurse sows and foster piglets, respectively. Nevertheless, a few studies have been published (Amdi *et al.*, 2017b; Kobek-Kjeldager *et al.*, 2019; Schmitt *et al.*, 2019b,c). None of them have reported increased mortality in the fostered piglets compared to non-fostered piglets; however, sample size in these studies is too low to be conclusive and there are uncertainties related to overall litter mortality since the smallest piglets within the litter were not always included in these studies. Some (Kobek-Kjeldager *et al.*, 2019) but not all studies (Schmitt *et al.*, 2019b) show impacts on weaning weight. Schmitt *et al.* (2019b) did initially find significant weight differences in the first week of fostering when comparing piglets left with their mother and piglets moved to nurse sows, but by weaning the differences were not significant. These authors selected the heaviest piglets for fostering and sows with good temperament and good udder quality to be involved as nurse sows. This is likely to be a factor in how successful these strategies can be. Kobek-Kjeldager *et al.* (2019) did see an impact on weaning weights. Fostered piglets showed impaired growth relative to similar sized non-fostered piglets. The lower weaning weights may be due to either increased competition caused by unstable teat order when piglets are being moved to a new sow and/or a discrepancy between the nutritional requirement of 5-7 day old piglets and the milk supply/nutritional value of a sow being 4 weeks into lactation. Furthermore, smaller piglets may not be able to perform udder massage and thus stimulate milk production to the same extent as older newly weaned piglets resulting in a reduction in milk production.

Studies have shown increased prevalence of lesions (carpal abrasions) in fostered compared to non-fostered piglets (Sørensen *et al.,* 2016), and increased teat fighting during the day of fostering (Thorsen and Pedersen, 2019). In addition to the above problems, studies indicate that pre-weaning stress does affect the ontogeny of abnormal behaviour post-weaning (D'Eath and Lawrence, 2004; Rzezniczek *et al.,* 2015; Schmitt *et al.,* 2019e). Social instability pre-weaning may thus be a causal factor for development of behavioural problems such as belly nosing and tail and ear directed behaviour post-weaning. However, the link between pre-weaning social instability/high competition and development of abnormal behaviour post weaning needs to be further explored.

Since crating of sows has been shown to induce stress and frustration as well as long-term impairment of muscular strength and cardio-vascular health (see review by Pedersen *et al.,* 2013), the prolonged lactation of nurse sows in a farrowing crate is a welfare threat. Sørensen *et al.* (2016) showed a slightly higher prevalence of teat lesions and bursae on the legs in nurse sows compared to non-nurse sows. Studies investigating the long-term stress effects of being a nurse sow however failed to document any long-term impact on salivary cortisol (Amdi *et al.,* 2017b; Schmitt *et al.,* 2019a), whereas there seems to be some acute stress connected to receiving the foster piglets at day 7 but not at day 21 (Schmitt *et al.,* 2019a). Salivary cortisol is however, easily influenced by minor events such as timing of sampling, disturbances within the room and whether the sow has been moved or not. Therefore, results need to be interpreted with caution. The fact that nurse sows do respond to foreign piglets is shown by their unwillingness to accept the foreign piglets, resulting in an average latency to first milk let-down of 4-5 hours after introduction (Thorsen and Pedersen, 2019). Some sows even completely refuse to adopt foreign piglets while others do so easily.

A wide variety of methods to increase the sow's motivation to nurse prior to adoption are used on commercial farms, including providing beer to the sows to reduce responsiveness, leaving the sow alone in the farrowing crate prior to adopting piglets and grouping her own and foreign piglets together prior to adoption, to reduce olfactory differences. To the best of our knowledge, no scientific studies on the effect of these different foster strategies has been published so far.

The nurse sow system imposes a major threat to piglet health via the breakdown of biosecurity by breaking batch integrity in the batch farrowing system (Díaz *et al.*, 2017). Minimizing exposure of suckling piglets to pathogens is an integral part of controlling pre-weaning mortality and 'all-in-all-out' (AIAO) management of farrowing batches is the key to this. Moving foster sows or foster piglets from one farrowing room to another is considered a violation of the AIAO system as contamination coming from another farrowing room will also be moved in, not allowing a real separation or break between batches (Marco, 2018). Thus, mortalities due to spread of harmful bacteria are likely to increase. Another overlooked problem is bottleneck problems in the farrowing unit arising due to an increasing number of nurse sows staying longer than planned in this unit. Derived consequences are the necessity of early weaning or late introduction of sows to the farrowing unit close to the time of farrowing. Late introduction is particularly stressful for first parity sows since, in Europe at least, introduction into the farrowing crate is their first experience of confinement. Late introduction to crates in first parity sows has been associated with stillbirth and prolonged parturition (Pedersen and Jensen, 2008). The other issue is that early weaning is not meant to be routine. The EU Council Directive 2008/120/EC states that 'Piglets shall not be weaned from the sow at an age of less than 28 days unless the welfare or health of the dam or piglets would otherwise be adversely affected' and if they are weaned early they must be 'moved into specialised housings which are emptied and thoroughly cleaned and disinfected before the introduction of a new group and which are separate from housing where sows (other than weaners) are kept' (EU, 2009). These stipulations are designed to protect the health and welfare of piglets, but the reality of managing large litters using nurse sow strategies is that piglets are more routinely being weaned early and this constitutes a risk to their health and welfare.

3.6 Artificial rearing

3.6.1 Different artificial rearing systems

Discussions regarding early weaning and nurse sow strategies are continued when we look at artificial rearing, which is a method already used on some commercial farms and claimed to save piglets that cannot be reared by their mothers. These systems involve removing piglets from their mother and allocating them to specialised enclosures, usually located in a separate room or sitting above the farrowing crate, where they will be fed milk replacer until weaning age (usually 28 day-old) (Baxter *et al.*, 2013). The enclosures also contain a heat lamp to ensure thermal comfort of the piglets, milk and water cups that can be activated by nudging with their snout, and solid 'creep' food. This management strategy can be used as a substitute for a nurse sow; either to rear the supernumerary piglets from large litters after colostrum intake, or to remove a whole litter of 2 to 7 day-old piglets from a sow that will become a nurse sow for supernumerary piglets from large litters (two-step nurse sow strategy, see previous sections). These systems can also be used as a nursery for sick and starving piglets gathered over the course of lactation.

The fact that piglets are fed *ad libitum* in a controlled environment, where the risk of crushing is removed, is quite attractive to farmers who may not be able to implement nurse sow strategies. However, artificial rearing systems represent a substantial financial investment for the enclosure, the milk replacer and milk delivery system and its associated pipeline washing products. From an animal welfare point of view, artificial rearing raises concerns about early separation from the sow, and thus can be considered a form of early-weaning and maternal care deprivation. Therefore, there is also the question of whether or not this practice contradicts regulations on weaning age (e.g. EU Council Directive 2008/120/EC).

3.6.2 Feeding and growth performances

Theoretically the artificially-reared piglets should show a better growth as they are fed *ad libitum* and do not have to compete anymore for access to a teat (i.e. no more risk of missing nursing episodes), especially towards the end of lactation when sow milking capacity decreases (Quesnel *et al.*, 2012). In line with this hypothesis, Van Beirendonck *et al.* (2015) showed that artificially-reared piglets had a better growth rate (i.e. higher average daily gain (ADG)) during the third and fourth week of 'lactation', compared to piglets reared by their mother or by a nurse sow. Cabrera *et al.* (2010) also showed that artificially-reared piglets had higher weaning weights than sow-reared piglets, even when transferred at a young age (i.e. 2 days post-partum). Surprisingly, when observed, the growth advantage seemed to disappear after weaning as artificially-reared pigs showed similar (Van Beirendonck *et al.*, 2015) or lower (Cabrera *et al.*, 2010) growth performances from weaning onwards. Other studies observed short-term (De Vos *et al.*, 2014) or sustained (Schmitt *et al.*, 2019d) impairments of growth in artificially-reared piglets during the pre-weaning period.

The milk delivery system is a very important feature of the artificial rearing enclosure and has been found to influence the occurrence of belly-nosing and feeding competition when synchronous feeding is not possible. Belly-nosing is the snout manipulation (i.e. rooting or nudging) of another piglet's flanks or undersides (Weary *et al.*, 1999; Worobec *et al.*, 1999) which occurs due to redirected suckling behaviour (Widowski *et al.*, 2008) and reflects frustration caused by unfulfilled nutritional needs (Weary *et al.*, 1999; Widowski *et al.*, 2005). It develops routinely in early-weaning (Orgeur *et al.*, 2001; Weary *et al.*, 1999; Worobec *et al.*, 1999) and when artificially-reared piglets are fed by a cup system in which piglets cannot suckle or perform post-nursing massage (Rzezniczek *et al.*, 2015; Schmitt *et al.*, 2019d; Widowski *et al.*, 2005). However, it occurs less when piglets can suckle on a nipple drinker system, and it does not develop when they are fed by an artificial udder (i.e. baby-bottle nipples mounted in front of a water-filled bag) that allows piglets to both suckle and massage (Widowski *et al.*, 2005). Similarly, Frei *et al.* (2018) also found that a dummy eliciting massage and suckling was the most efficient way to reduce the occurrence of belly-nosing in artificially-reared piglets. Belly-nosing can have consequences on the growth performance of the piglets as it disrupts feeding episodes of both the recipient and the performer (Torrey and Widowski, 2006; Widowski *et al.*, 2008).

The discrepancy between studies in growth performance of artificially-reared piglets could be due to a number of factors including: (1) piglet age at the start of artificial rearing (two to 14 days-old); (2) milk replacer formulation (e.g. protein level, inclusion or not of antibiotics or blood products); (3) types of enclosure (e.g. remaining in the farrowing crate without the sow (Cabrera *et al.*, 2010) vs Rescue Decks® (Rzezniczek *et al.*, 2015)); (4) milk delivery system (nipples (De Vos *et al.*, 2014) vs cups (Cabrera *et al.*, 2010; Rzezniczek *et al.*, 2015)) and; (5) whether piglets are mixed (Rzezniczek *et al.*, 2015) or not (De Vos *et al.*, 2014) at transfer.

3.6.3 Gut maturation and health

There are few studies that have investigated the effects of artificial rearing on the piglets' gastro-intestinal tract function and microbiota, which may be inter-related. De Vos *et al.* (2014) observed an increased absorptive intestinal capacity in artificially-reared piglets and suggested that artificial rearing improved the gut growth and functional maturation, which should help to cope with weaning (i.e. adaption to solid food). Other studies observed a transient impairment of the gut microbiota (i.e. predominant population of Gram negative bacterial strains instead of Gram positive strains at 10 days of age, restored at 28 days of age; Prims *et al.,* 2017) and of the morphology and permeability of the piglets' gastro-intestinal tract (Vergauwen *et al.,* 2017). The latter effect was similar to what is observed at (early – i.e. day 3 post-partum) weaning from the mother (Vergauwen *et al.,* 2017), and could be due to chronic stress related to the early separation from the mother (Smith *et al.,* 2009). Moreover, several studies showed richer and more diverse duodenal and ileal microbiota in sow-reared compared to artificially-reared neonatal piglets (Piccolo *et al.,* 2017; Yeruva *et al.,* 2016), even if the effect of diet could not be separated from the effects of the environment (conventional farrowing pen vs controlled artificial-rearing enclosures) in the analysis of the microbial differences (Piccolo *et al.,* 2017).

Milk replacer formulations may include immune components (e.g. from porcine plasma) to help protect piglets' health but, not only is this a potential biosecurity risk, it may actually increase the occurrence of diarrhoea in artificially-reared piglets (Van Dijk *et al.,* 2001). Indeed, Touchette *et al.* (2002) found that pigs fed a diet containing 7% spray-dried plasma for one week post-weaning (i.e. 14 to 21 days-old) had a depressed immunity compared to pigs fed a normal diet. Artificially-reared piglets present a reduced capacity to induce adaptive immune responses because of their lower density of M cells in the epithelium of the ileal Payer's patch (Prims *et al.,* 2017). This could explain the lower health status of artificially-reared piglets as weaners and finishers observed in the study of Cabrera *et al.* (2010). The incidences of diarrhoea and of administering medication to piglets were recorded only in the study by Schmitt *et al.* (2019d), who also found a higher occurrence of diarrhoea in artificially-reared piglets compared to sow-reared piglets. These authors found a large variation in the percentage of piglets treated for illness or injury in the different treatment groups (12% in sow-reared and 17% in artificially reared piglets), but these were not significant.

3.6.4 Welfare consequences – early weaning and maternal deprivation

The procedure of artificial rearing implies that the piglets go through the same stressors that occur at weaning, i.e. abrupt separation from the dam as well as changes in the social, physical and feeding environments. Indeed, recent studies (Rzezniczek *et al.,* 2015; Schmitt *et al.,* 2019d) showed that artificially-reared piglets displayed the same signs of distress (i.e. vocalisations, growth impairments, development of abnormal behaviours) as those shown by piglets weaned very early (e.g. 6 days postpartum – Orgeur *et al.,* 2001). In addition, piglets in artificial-rearing systems were less playful and showed more aggressive behaviours than sow-reared piglets (Rzezniczek *et al.,* 2015; Schmitt *et al.,* 2019d). The low space allowance in the enclosure (typical footprint: 1 vs 3.6 m^2

in a conventional farrowing pen; Baxter *et al.,* 2012) and at the milk cup, and/or the occurrence of belly-nosing (due to retaliation by recipient) could be factors that promoted aggression between piglets.

The feeding system seems to be a core issue in artificial rearing of piglets since it does not provide any of the behavioural needs of the piglets related to nursing. Indeed, besides the fact that the milk replacer is not real sow milk (components, temperature that decreases with time, etc.), milk cups do not facilitate the natural behavioural pattern of nursing (pre- and post-nursing massages, suckling), nor synchronous feeding of all the piglets in the litter. The latter implies that possible mitigation of weaning distress through social facilitation of feeding (Weary *et al.,* 2008) is not accommodated in these systems (Wattanakul *et al.,* 2005). Furthermore, the grunting of sows that signal a nursing bout (Jensen, 1988) are absent when artificial rearing enclosures are placed in a separate room, hence potentially increasing the difficulty piglets experience in starting to feed after transfer.

Artificially-reared piglets are essentially deprived of maternal care at a very young age, which impairs their welfare and leads to the development of stereotypic behaviours (such as belly-nosing) generally seen in young mammals (see review by Latham and Mason, 2008). Even though maternal care may seem limited in pigs, because sows do not groom or lick their offspring as other livestock mothers do, naso-naso contacts between the sow and the piglets (usually observed around nursing) reflect the creation of mother-young bonds (Blackshaw and Hagelsø, 1990) and the set-up of individual (social) recognition (Blackshaw *et al.,* 1997; Newberry and Swanson, 2008). Unfortunately, the sow-piglet bond and the importance of maternal care for piglets, beyond a nutritional point of view, have hardly been studied. Nevertheless, playing with the sow seems to begin earlier than self and social playful behaviours (Blackshaw *et al.,* 1997), emphasizing the early need for contact with the mother. Early separation from the dam can also have neurological consequences, such as a decreased expression of genes regulating glucocorticoid response in the hippocampus of early-weaned piglets (10 days of age) compared to non-weaned piglets. Such a decrease may reduce the ability of piglets to down-regulate the hypothalamic pituitary adrenal axis function (Poletto *et al.,* 2006), which might in turn impair cognitive abilities (learning and memory) and behavioural organization processes (Poletto *et al.,* 2006).

3.6.5 Welfare consequences – short-term vs long-term consequences

Studies comparing the growth performances of artificially-reared piglets and sow-reared piglets showed that the pre-weaning advantage of artificially-reared piglets was reversed in later-life (Cabrera *et al.,* 2010; Van Beirendonck *et al.,* 2015). These results may suggest that the milk formula failed to completely replace the natural sow milk, particularly in providing immune components to the piglets. The two papers by Schmitt *et al.* (2019d,e) suggested that, from a welfare point of view, the artificial rearing system creates an ambiguous situation where welfare improvements are consequences of previous welfare detriments. The results showed that, compared to sow-reared piglets, artificially-reared piglets were undeniably in a poorer welfare state pre-weaning (more negative behaviours, lower emotional state and slower growth rate), and had a better welfare status post-weaning, as suggested by a higher emotional state and a lower emotional reactivity. This surprising change in welfare state was attributed to the fact that weaning represented a relative improvement in the environment of artificially-reared piglets (e.g. increased space allowance per piglet) and that separation from the mother had already occurred several weeks before.

3.7 Supplementary feeding and optimizing weaning

3.7.1 Supplementary milk

An alternative strategy to nurse sows and artificial rearing of supernumerary piglets is feeding supplementary milk in the farrowing pen. This management method is being used increasingly in commercial herds with hyperprolific sows to substitute or reduce the need for nurse sows. Milk cups are installed in the farrowing pen (Figure 3.4) and milk is delivered to the cup through a pipe system. The pipe system is connected to a tank where the milk supplement is mixed, generally twice daily, to ensure fresh supply of milk. It is recommended and necessary to clean the pipe system frequently using an alkaline mix or acidic water and then flushing with fresh water to avoid bacterial growth in the pipe. Different designs of milk cups are available on the market; either the cup is filled when piglets push a valve inside the cup or the cup is automatically filled regularly or whenever empty. The latter method means that milk is always readily available to the piglets to ingest without the piglets needing to activate the cup manually. It is common to change the type of milk replacer used during the suckling period. Typically, the first milk replacer is based on milk powder as main ingredient while the second is a more grain-based supplement. Some systems even provide less fluid ingredients resembling those of post-weaning grain-based liquid feed. The supplementary milk method is based on an assumption that by supplementing the piglets with milk replacer the sow can nurse more piglets than her number of functional teats. Some farmers let the sow nurse 16 piglets while others increase the number of suckling piglets to as high as 20. There are

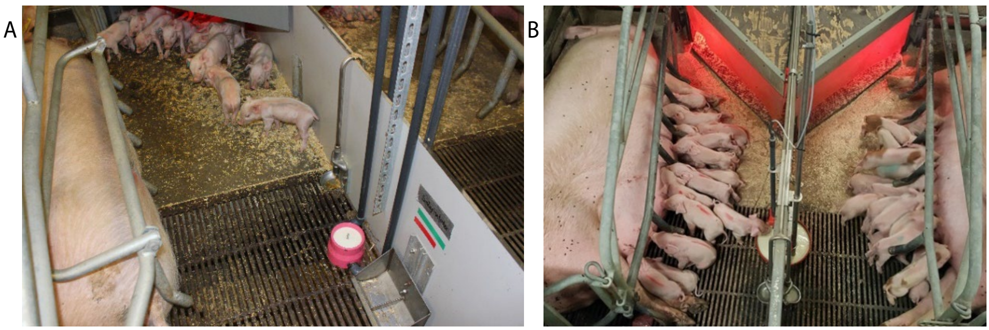

Figure 3.4. Milk cups installed in farrowing pens. (A) shows a piglet-controlled milk cup where the piglet pushes a lever with its snout to receive milk and (B) shows a self-filling larger milk bowl (photo (A) by Cecilie Kobek-Kjeldager and (B) by http://bopil.dk).

considerable costs of installing and using this system; particularly, the cost of the milk replacer which can be very high if milk constitutes the main ingredient of the supplement.

Some older studies have investigated the effect of supplementing litters of 12 piglets with milk provided in a trough three times daily, and observed increased weaning weight (Azain *et al.,* 1996; Dunshea *et al.,* 1998; Wolter *et al.,* 2002). However, the individual intake of milk varied largely between piglets (Dunshea *et al.,* 1999; Miller *et al.,* 2012), as was also found for solid feed intake pre-weaning, which is insignificant up to 3-4 weeks of age (Bruininx *et al.,* 2002; Yan *et al.,* 2011). To our knowledge, only one scientific study has investigated the effect of continuous access to milk supplement using the cup system on performance and behaviour of piglets. The study by Kobek-Kjeldager *et al.* (2019) showed that piglet mortality was reduced and weaning weight increased in litters of 17 suckling piglets given milk replacer from a valve-cup system compared to no access to milk replacer. However, mortality rates were still higher and weaning weights were lower than in litters of 14 piglets irrespective of access to milk cups. Intra-litter weight variation tended to increase rather than decrease with access to milk replacer. Behavioural studies of the same piglets showed a trend for larger (compared to smaller) piglets to be more likely to drink both sow milk and milk replacer, which could explain the larger intra-litter weight variation. Only very few piglets drank milk replacer as their main source of feed. The study also showed that access to the milk replacer did not reduce teat fighting in litters of 17 or 14 piglets, and that small piglets were more likely to engage in teat fighting. Thus, it appears that piglets, irrespective of body weight and access to milk supplement, engage in fighting to get access to a functional teat during milk let-down (Kobek-Kjeldager *et al.,* 2019). As mentioned for artificial rearing systems, drinking milk replacer from a milk cup does not facilitate the behavioural pattern of nursing/suckling nor does it provide the same nutritional quality as sow milk. This likely explains why piglets choose to fight with littermates for teat access even when an alternative food source is available without cost. Due to the inability of this method to reduce intra-litter competition in large litters, the long-term consequences for welfare and behaviour need to be further investigated.

Douglas *et al.* (2014) attempted to reduce the within-litter competition by supplementing litters with milk replacer. Within 24 h post-partum, litters with low birth weight (LBiW, ≤1.25 kg) pigs only and mixed litters (both LBiW and normal birth weight pigs of 1.6 to 2.0 kg) were created. Half of the litters within each type were supplemented with milk and the other half were not. The LBiW litters drank significantly more supplementary milk than mixed litters, with LBiW pigs in the LBiW litters performing better in terms of ADG than those in mixed litters (0.252 vs 0.217 kg/d). At weaning, LBiW piglets in LBiW litters weighed over 500 g more than those in mixed litters. In a separate study these authors demonstrated that, for piglets born under 1.8 kg, it is their weaning weight rather than their BiW that can predict their life-time performance as measured by growth potential (Douglas *et al.,* 2013). It is postulated that such piglets (if they survive the vulnerable neonatal period) have the capacity to demonstrate catch-up growth if provided with the correct food resources. It is not clear whether this catch-up growth would be demonstrated by all piglets with compromised BiW status (i.e. IUGR and SGA) if weaning weights were optimized. Lynegaard *et al.* (2019) followed IUGR and normal piglets from birth until 30 kg and showed that although the IUGR piglets had lower ADG from birth to 30 kg and exhibited some catch-up growth during nursing, IUGR pigs still required six additional days to reach a body weight of 30 kg compared with normal pigs. The weaning weight of piglets from large litters has dropped significantly in recent years, with average weights of 6.7 kg reported in DK herds in 2018 (Hansen, 2019). The IUGR piglets (BiW = 0.77 kg) surviving to weaning had an average weaning weight of only 4.53 kg (Amdi *et al.*, 2020). Therefore, optimizing weaning weight is an important goal to improve life-time performance of pigs.

3.7.2 Early creep feeding and optimizing weaning weight

Weaning is a stressful process for piglets. It leads to a complete change in the pattern and delivery of food and removal of the dam requires both behavioural and physiological adaptations by the piglet. Some of these impacts are detailed in the section above on artificial rearing. If supplementary food is available from at least the third week of lactation, when milk production starts to decline, piglets can express foraging behaviour which has functional consequences in terms of changes in gastric enzyme secretions and gut development (Cranwell, 1995). This allows for a more gradual weaning process. Specialized pre- and post-weaning starter diets are likely to have an impact on how successful this transition is (see Chapter 6, Ferret-Bernard and Le Huërou-Luron, 2020, for further details) but to encourage pre-weaning solid feed intake one must also consider presentation of the food and its palatability. Oostindjer *et al.* (2014) showed advantages of allowing piglets to feed with their mothers and of using more novel techniques of prenatal flavour imprinting to attract piglets to solid feed. There is evidence that feed efficiency (Nissen and Oksbjerg 2011) and carcass quality are reduced in IUGR pigs (Gondret *et al.,* 2006; Rehfeldt and Kuhn, 2006). These effects on life-time performance are suggested to result from long-term changes in gut and muscle morphology, with IUGR pigs at 150 days of age still showing a reduction in duodenal mucosal height, a lower percentage of muscle fibres and a higher percentage of connective tissue in the semitendinosus muscle (Alvarenga *et al.,* 2013). Pre- and immediate post-weaning nutritional interventions for piglets that have suffered from IUGR could be crucial in mitigating these long-term effects but likely need to be highly specialized given the evidence of compromised gut morphology in these animals.

3.8 Conclusions

This chapter has described a number of possible strategies to manage piglets from large litters. All of these strategies come at a cost for at least some of the animals involved and there is no perfect solution to managing large litters. It is likely that a combination of strategies will be required to more fully realize the potential economic benefits of increased numbers born. However, this chapter has not explicitly discussed the wider ethical issues of whether increasing litter size should be a continued breeding goal. The breeding of piglets presenting such severe pathologies as those seen in IUGR should be questioned, as should the extended confinement periods in farrowing crates for nurse sows and the early weaning strategies implemented in both nurse sow and artificial rearing systems.

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