Enhancing piglet survival and welfare in different farrowing systems

By

Oluwagbemiga Olanrewaju Adeleye

A thesis submitted for the degree of

Doctor of Philosophy (Ph.D)

School of Agriculture, Food and Rural Development

Newcastle University

September 2012

Abstract

Piglet mortality is an animal welfare problem with great economic importance. This study investigated housing and nutritional strategies to improve sow welfare whilst safeguarding the survival of new-born piglets and their welfare and performance from birth to the post weaning period. The first experiment compared the effect of different space allowances in a loose farrowing pen on sow behaviour and piglet survival. The behaviours of sows which lead to crushing of piglets, the main reason for mortality, differed between the two pen sizes.

A second experiment examined the effect of maternal diet supplementation in late gestation and lactation with docosaheaxanoic acid (DHA) on piglet survival and growth in crated or loose farrowing systems. Performance did not differ between systems. DHA supplementation resulted in fewer stillborn piglets, despite prolonged farrowing duration. Sows given DHA had more vital piglets, with reduced latency to stand, to get to the teat and suckle, but also had reduced weaning weight.

A detailed study to investigate the mechanisms underlying this finding measured the behavioural and physiological characteristics of new born piglets. The same effects of DHA on the farrowing process and piglet vitality were apparent, but could not be explained by differences in blood lactate, glucose or thermoregulation of piglets in the perinatal period.

A final experiment investigated a new approach to try and improve weaning weight, by stimulating foraging behaviour through sequential presentation of creep feeds differing in flavour. This treatment increased creep feed consumption in both crate and loose housing systems, with a beneficial effect on post weaning growth.

The thesis demonstrates ways in which piglet survival and growth can be enhanced by appropriate pen design and nutritional strategies in both conventional and alternative farrowing systems.

Declaration

This thesis has been composed by myself and has not been accepted in any previous application for a degree. The work of which this is a record has been done by myself unless otherwise stated. All sources of information have been specifically acknowledged by means of referencing.

Oluwagbemiga Olanrewaju Adeleye

Acknowledgement

My appreciation and deepest gratitude will go to the following for the support and assistance towards the success of this programme:

I thank the Almighty God for keeping me alive to start and finish this degree. His guidance and unfailing love has brought me this far.

I also appreciate the Education Trust Fund Board, Nigeria, for giving me the privilege and providing the grant for my PhD programme through the University of Agriculture Abeokuta, Ogun State.

My sincere appreciation goes to my supervisors, Professor Sandra Edwards and Dr Jonathan Guy. I do not have enough words to thank them enough for the motherly and fatherly role they played in my life and during my research programme. Sandra was instrumental to my survival in all ramifications; guiding, caring, advising and supporting me and my family during hard periods. She also exposed me to the pig industry in the UK meeting some stakeholders and I am proud to have had her as my supervisor. I am also very grateful to Dr Jonathan for his encouragement and excellent contribution during my PhD. He is always asking about the welfare of my family. I say a big thank you.

My heartfelt gratitude also goes to Dr Alan Younger, Mr John Gowing, Dr Peter Rowlinson, Dr Andrew Beard, Dr Mrs Hubbard, Dr Okello, Dr George and Dr Rob Shiel for excellent support and encouragement. I am extremely grateful to Darren Blomfield and Mark Brett for the technical assistance during my field trials, for without them, my experiments would have been grounded.

Many thanks to Dr Sokrates, Fiona, Wendy, Chris, Peter and Brian for sorting me out with laboratory and safety issues. Big thanks to Steven Hall who is always available to bail me out with my computer problems. I would not forget to thank Dr Emma Baxter for her advice and

guidance especially on my first experiment. It was a privilege working with Emma and I look forward to working with you later in the nearest future.

My sincere gratitude also goes to the members of The Methodist Church Dilston Road for their support especially to Stephen Richardson, Rev Rob and Deaconess Kate. I also appreciate David Wilkinson, members of Redeemed Christian Church of God, North Shield especially Pastor and Mrs Dina, Mr and Mrs Opeifa and Dr and Mrs Aribisala for the prayers and support.

I also acknowledge the members of staff of the College of Animal Science and Livestock Production (COLANIM) who encouraged and assisted me at the home front. Special thanks to Professor C.O.N. Ikeobi, Professor S.S. Abiola, Dr Sowande , Dr Adeyemi, Dr Egbeyale, Dr Fafiolu, Professors Oduguwa, Eruvbetine and Onagbesan for their support. Thanks also to Professor Phillips, Dr and Mrs Elemo, Dr Sunday Peters, Professor Adesehinwa and Ejovi for the prayers and advice.

I thank all student helpers especially those who joined me in boycotting sleep during my mechanism experiment.

Finally, many thanks to my wife and son, my Dad and wonderful Mum, the Akinyanju and Ajagbe families and my brothers for their endless words of advice, comfort and support through this challenging period of my life.

Publications and Conference abstracts

- **Oluwagbemiga Adeleye**, Mark Brett, Darren Blomfield, Jonathan Guy and Sandra Edwards 2012. Effects of essential fatty acid supplementation of sow diets on piglet survival in two farrowing systems. Journal of the Agricultural Society, Newcastle University, in press).

- **Oluwagbemiga Adeleye**, Mark Brett, Darren Blomfield, Jonathan Guy and Sandra Edwards 2012. Effects of maternal supplementation with essential fatty acid (Docosahexanoic acid) on neonatal piglet metabolism and vitality. Proceedings of the Annual Conference of the British Society of Animal Science, Nottingham University, Pg 8.

- **Adeleye, O.O.,** Brett, M., Blomfield, D., Guy, J.H and Edwards, S.A 2011. Effect of essential fatty acid supplementation of sow diets on piglet survival in two farrowing systems, Proceedings of the 62nd Annual Conference of the European Federation of Animal Science, Stavanger, Aug 30, 2011, Pg 210.

Emma M Baxter, Oluwagbemiga Olanrewaju Adeleye, Mhairi Jack, Sarah Ison and Sandra A, Edwards 2011. The influence of space and temperature on sow farrowing location and piglet survival in an indoor free farrowing system: the PigSAFE pen. In: Manipulating Pig Production XIII. Proceedings of the Australasian Pig Science Association's biennial conference. Adelaide, Australia. p.239.

Table of Contents

List of Tables and Figures

Figures

Chapter 1
General Introduction

Piglet mortality has been identified as one of the most important causes of reduced efficiency in pig production with total mortality rates varying between 10 and 20% (Tuchscherer et al., 2000) depending on the housing system. In pig herds, piglet mortality has been considered an important welfare and economic issue in both intensive and outdoor farms. Reports indicate that the majority of piglet deaths occur within the first two days postpartum, irrespective of the production system, with stillbirth rates from both crates and loose housing systems ranging between 3 to 6% of the total litter when using references from studies where post mortem examinations have been carried out (Damm et al., 2005a; Tuchscherer et al., 2000; Fraser et al., 1997). Total mortality in modern housing systems for loosed housed sows is rather variable ranging from 9 to 25% of live born piglets (Damm et al., 2005b; Grandinson et al., 2003; Pedersen et al., 2003). The great challenge facing commercial pig industries has been how to improve the survival of the piglets so as to enhance productivity. Early piglet mortality is of great economic importance and constitutes a welfare problem because piglets have been reported to have died from various causes including starvation and traumas caused by treading and crushing, and diseases. All of these can be associated with significant suffering before death.

1.1 Factors affecting piglet mortality

The factors causing piglet mortality are multifaceted and interactive (Edwards, 2002) and causes vary from one herd to another. Examples of causes (Fig 1) are low birth weight, reduced temperature, chilling, reduced colostrum intake and crushing (Edwards 2002). Infectious diseases and congenital abnormalities are also factors that influence piglet survival. Some of the points mentioned above directly affect piglet survival, while other factors such as year, farrowing season, inbreeding and age of dam have been also suggested to indirectly affect piglet mortality (Bereskin et al, 1973).

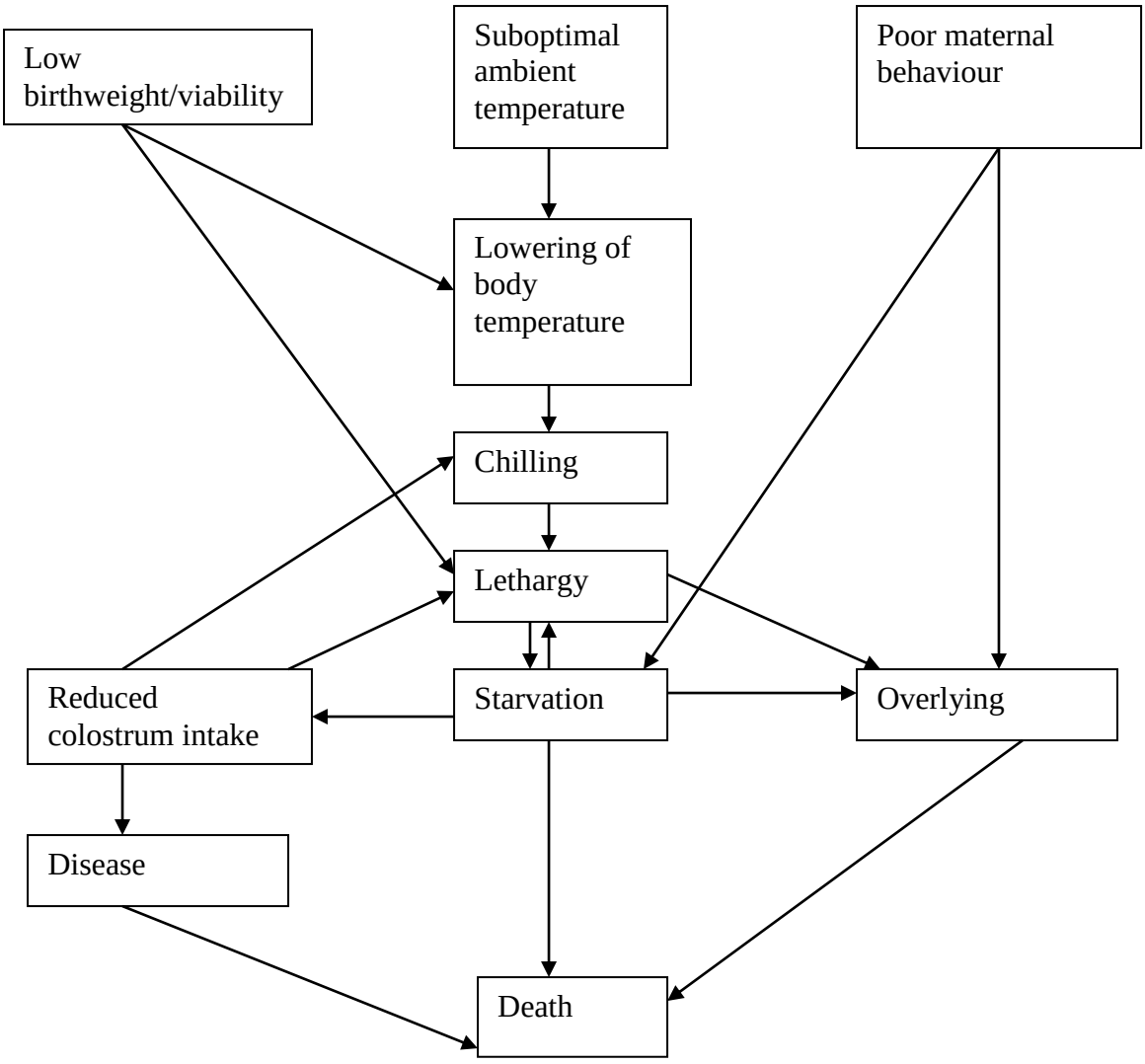

Figure 1.1 Possible complex interactions that results in piglet mortality (Adapted from Edwards, 2002)

Though all the above mentioned factors may have been listed as the causes of piglet mortality, the two most important causes are hypothermia (chilling) and asphyxia around which all other causes evolve. Survival of piglets has been reported to be based on the complex interactions which exist between the sow, the piglet and the environment (Edwards, 2002). For example, small sized piglets are more susceptible to cold and therefore tend to stay near the sow to get warmth. Such piglets are prone to being crushed by the sow's movement while changing posture from standing to lying or vice versa. Maternal factors influencing piglet survival are the farrowing process, subsequent behaviour and maternal ability to produce adequate colostrum and milk. Piglet factors include vigour at birth, teat

seeking ability, acidosis associated with hypoxia, hypothermia and hypoglycaemia, while the environmental factors include change(s) in temperature, housing designs, stress and handling.

Intensive rearing of pigs has been the most viable means of producing more pigs and guarding against piglet mortality for many years. This has involved the use of the farrowing crate, which restricts the movements of the sow so as to reduce risk of harm both to the newly born piglets and the farm personnel. However, welfare issues associated with the close confinement of sows are a growing source of concern in pig farming, since the normal behaviours of the sows are seriously restricted. Housing systems without farrowing crates are being developed, but their successful design involves understanding how they influence the behavior of the animals. This review will focus on the risk factors for piglet mortality in alternative farrowing systems and methods to improve survival and growth.

CHAPTER 2

Literature Review

This section will describe various physiological, environmental and nutritional effects and how they influence piglet mortality. These effects are divided according to how they relate to the sow or piglet as factors.

2.1 Farrowing and intra-uterine asphyxia (Stillbirth)

Farrowing is termed as the act of giving birth in pigs and events associated with it are intricately interrelated with the postnatal performance of piglets. Asphyxiation during parturition is a common event in many animal species (Svendsen and Bengtsson, 1986). Piglets are particularly susceptible to intrapartum anoxia despite the fact that they are relatively mature at the time of birth. Pigs are a polytocous species so piglets born at the end of the litter are likely to suffer asphyxiation to a greater degree because of the cumulative effects of successive uterine contractions. These uterine contractions reduce oxygenation to the unborn piglet and increase the risk of umbilical occlusion, damage or rupture of the cord, as well as premature placenta detachment (Randall, 1972, English and Wilkinson, 1982). Rupture of the umbilical cord lowers placental blood pressure, causes a partial collapse of the chorionic villi and thus facilitates placental detachment (Perry, 1954). Therefore, placental insufficiency plays a major role in the acute, as well as the longer term, aetiology of perinatal mortality and morbidity of piglets (Svendsen and Bengtsson, 1986). Baxter et al. (2009) reported that body conformation traits, which reflect placental insufficiency during gestation, were important indicators of prenatal survival with still born piglets having a disproportionately long and thin shape (see later).

One of the first deleterious effects of intrauterine hypoxia is the expulsion of meconium into the amniotic sac leading to meconium staining of the skin and, in severe cases, meconium aspiration into the lungs (Mota-Rojas et al., 2006). Hypoxia in utero has been shown to increase intestinal peristalsis and relaxation of the anal sphincter causing the expulsion of meconium into the amniotic fluid, gasping by foetuses and subsequent inhalation of amniotic fluid contaminated with meconium (Curtis, 1974). An earlier study suggested that pigs

suffering from lack of oxygen during birth are often born covered in meconium (Spicer et al., 1990). Acidosis also causes hypothermia and reduces survival in neonates (Alonso-Spilsbury et al., 2005). Finally, metabolic acidosis and hypoxia can cause profound health effects in postnatal life due to reduced vigour, poor suckling, reduced absorption of colostrum and inadequate passive transfer of neonatal immunity.

2.2 Piglet factors influencing mortality

2.2.1 Litter size, birth weight and gender

Litter size at birth has been of great importance for all categories of piglet losses. In major pig producing countries, total piglet mortality (stillbirth plus liveborn mortality before weaning) is in the range of 17-20% and is even higher in litters from highly prolific sows. It is a common knowledge that as litter size increases, so does length of parturition and variation in birth weight within the litter with selection for increased litter size responsible for more light weight piglets. The increase in litter size from 11 to 16 increases the proportion of light piglets (<1.0 kg) from 9 to 23%, while the litter is more heterogeneous in birth weight (Quiniou et al., 2002). Quesnel et al. (2008) also observed that an increase in litter size gave rise to a decrease in birth weight and more piglet losses. Weary et al. (1998) explained that this effect could be due to the fact that the underweight piglets, which are relatively more abundant in large litters, do not gather with the rest of the litter before the sow lies down.

Piglet with a higher birth weight and a higher body mass are more likely to survive, with surviving piglets in one study having a higher birth weight by 361g than piglets which subsequently died (Baxter et al., 2009). Marchant et al. (2000) reported that only 28% of piglets weighing less than 1kg at birth survived to seven days. Caceres et al. (2001) also stated that birth weight is inversely related to preweaning mortality. Several studies have concluded that, in addition to the known effect of low birth weight, a lack of uniformity in birth weight is itself an important risk factor for piglet survival (Caceres et al. 2001).

The degree of variation in birth weight within a litter has been reported to be due to the differences in placental transfer of nutrients to individual fetuses, with restricted nutrient supply being associated with the production of low birth weight offspring (Litten et al.,

2003). Zajas-Cruz et al. (2000) showed that piglets of low average birth weight were not competitive if mixed with larger piglets. Litters of piglets usually show strong sibling competition, large differences among litter mates in birth weight and growth, and high mortality rate in the absence of human intervention (Fraser, 1990; Tylor et al., 1990).

Birth weight is a significant survival indicator and many authors have highlighted this trait as the most important survival parameter (Roehe, 1999; Knol et al., 2002a,b; Arango, 2006). It could also be the key trait in selection programmes for decreasing mortality, as it has a greater heritability (0.05 for direct effects and 0.22 for maternal effects (Roehe, 1999)) than piglet survival itself. However, the relationship between birth weight and survival is a quadratic one (Roehe and Kalm, 2000) with the extremes in birth weight at equal risk of mortality, and selection solely for increased birth weight could therefore compromise survival. This strategy could also compromise litter size, with which it has a negative genetic correlation. Within-litter uniformity is as important as high average birth weight for piglet survival (Knol et al., 2002a). This is not a new concept (English and Smith, 1975), yet it is still an area in need of progress. Selecting for an optimum, rather than high birth weight and for within-litter homogeneity of birth weight is a suggested strategy to improve survival in polytocous species (Damgaard et al., 2003).

Prenatal mortality in female piglets has been found to be higher than that of male piglets while significantly more male piglets die before weaning than females, as reported by (Baxter et al., 2009). In another study done in an indoor environment, Baxter et al. (2008) observed more males dying during the prenatal period with no significant effect of gender with respect to postnatal survival. Whilst weight is considered an advantage to survival, this may be influenced by gender since it has been found that females, although having a lighter birth weight, suckled earlier than males (Bate et al., 1985).

Birth weight has, as previously discussed, been shown over the years to be an important factor influencing postnatal survivability since piglets with increased weight stand a better

chance of survival because of the ability to reach the udder early, compete for teat and suckle.

2.2.2 Body mass index and Ponderal Index

Baxter (2008) reported that though birth weight has been known to be an important characteristic influencing survival, it is not in itself a sufficient indicator of survival. The ponderal index and body mass index, which are measures of body shape, appeared to be better indicators of prenatal piglet mortality. These measures give information about each piglet's proportion vis a vis the change in relative weight for length.

The ponderal index (birth weight (kg)/crown-rump length (m) ^{3}) and body mass index (birth weight/crown-rump length^2) have been useful in determining the intrauterine growth retardation a foetus has suffered during gestation. Small for gestational age (SGA) piglets have been reported to be neonates weighing less than the tenth percentile at birth even though they display a mature genetic potential and normal allometry (Baxter, 2008; Bauer, 1998). These contrast with piglets which may be heavier but of immature body conformation with a lower ponderal index. Furthermore, the relative fatness of the newly born offspring can be derived using the body mass index (Gluckman, 2005), although piglets tend to lack adipose tissues (Herpin et al., 2002).

2.2.3 Piglet Vitality

The ability of piglets to overcome physiological challenges associated with the new (extrauterine) environment that they are exposed to is important to the survival of the neonates. Immediately after parturition, piglets compete with each other for teats and establish ownership. Exhibiting traits such quick co-ordinated movement after birth, low latency to reach the udder, finding a functional teat and suckling adds up to what is known as Piglet Vitality (Baxter, 2008; Tuchscherer et al., 2000). It was also described as the display of strength and vigour to get a functional teat to suckle (De Passille and Rushen, 1989).

The vigour at the time of birth has been reported to be a piglet characteristic which is related to the interruption of oxygen flow during birth (Randall, 1972). Prolonged or intermittent

asphyxia in utero and during delivery does not necessarily lead to intra-partum stillbirth; however, such asphyxia weakens piglets and renders them less capable of adaptation to extrauterine life (Trujillo-Ortega et al., 2006). These piglets may have less aggressive suckling behaviour and consequently a reduced opportunity for colostrum intake (Herpin and Le Dividich, 1996). This reduced intake of colostrum leads to an inadequate transfer of passive immunity and an increase in neonatal infections (Edwards, 2002). The importance for piglet growth and survival of an early and sufficient intake of immunoglobulin has been repeatedly emphasized (De Passille and Rushen 1989) with previous studies stating that piglet behaviour is a key aspect in adaptation to extrauterine life and piglet that are quicker to perform landmark behaviours, particularly to suckle colostrum, increase their chances of survival (Tuchscherer et al., 2000; Herpin et al 2001; Baxter et al., 2008).

A recent study observed that medium sized pigs had less cognitive ability compared to the large and small sized piglets (Gunnarson et al., 2009). Though no justifiable reason could be reached, the author suggested the piglet birth weight might be a factor influencing the differences in piglet vitality or vigour in different situations, with larger piglets being more reactive (Gunnarson et al., 2009). A more reactive piglet will be more vital and more successful in getting a good teat at the udder and gaining optimal milk supply as a result of the ability to quickly perform these landmark behaviours (Baxter et al., 2009).

2.2.4 Teat order and latency to first suckling

Survival for the new born pig depends on its ability to stand, move from the birth site to the mammary area of its dam and then to locate and suck from the teats. Attraction to the udder is most likely dependent on odour cues. Piglets have a highly developed sense of smell within 12hours after birth (Morrow-Tesch and McGlone, 1990). When a sow farrows, the majority of the piglets move directly towards the udder and very few venture the long way around the back. Sows remain recumbent during parturition, which allows the young to follow the surface of her body until they reach the ventrum (Alonso-Splinsbury et al., 2007). Parfet and Gonyou (1990) found that piglets were attracted to the odour of sows' milk, whilst Welch and Baxter (1986) found that they were attracted to the tactile and thermal properties of sow's udder. The sow's hair pattern also assists the neonate as piglets consistently move with the direction of hair growth.

The behaviour of the piglet during the first 24hours after birth has a major influence on their consumption of colostral immunoglobulins. A number of studies have reported that piglets with low birth weight compete with their larger and heavier littermates for teats during suckling bouts and consequently ingest less colostrum (De Passille et al., 1988; Milligan et al., 2002). Colostrum is the source of dietary energy which also contains immunoglobulins. These can be absorbed intact through the intestinal wall by piglets for up to 36 hours after birth, prior to gut closure (the act of being unable to absorb macromolecules through the intestinal epithelium) (De Passille et al., 1988).

An investigation on the effect of sex on the time taken to get to the teat found that latency from birth to secure a teat and suckle was shorter in females than in males, but was not influenced by body weight (Bate et al., 1985). These results suggest that the higher serum testosterone levels of male piglets may have detrimental effects on teat seeking ability. However, according to Rhode Parfet and Gonyou (1990), latency to first mammary contact is not influenced by either birth weight or sex, but is affected by position in the birth order, number of pigs at the time of mammary contact and frequency of position changes by the sow. The effects of birth order are generally negligible except among later born piglets, with these pigs taking longer to locate the mammary area regardless of floor type (sloped or not).

During the farrowing period, milk (colostrum) let-down is continuous because of the oxytocin produced during farrowing. However, after a few hours let-down becomes phasic. As lactation progresses, piglets also compete indirectly with their littermates by stimulating and draining their teats more effectively and thus directing a larger fraction of hormones and nutrients involved in milk production towards their respective teats (Algers et al., 1991).

2.3 Sow factors influencing mortality

2.3.1 Maternal behaviour

The behaviour of the sow is an important factor when talking about piglet survival because the changes in posture and movement of the sow around the farrowing period might negatively affect and/or threaten the existence of the piglets. From descriptive ethological studies of domestic pigs in naturalistic environments, according to Jensen (1986) the main elements of maternal behaviour relevant to neonate survival would appear to be: the selection of the birth site and behaviours involved in nest building, farrowing, including the acceptance of the offspring, suckling and defence of the nest and/or the litter.

Pre-farrowing nesting behaviour may be important for the development of maternal behaviour in nulliparous sows (Cronin and Van Amerongen, 1991); sows sometimes have the opportunity of building nests prior to parturition and this favours mother-offspring bonds. The nest also provides physical and thermal protection for the litter (Jensen, 1989), and elaborate nest approach and lying down behaviours by the sow reduce the risk of crushing (Baxter, 1984). Primiparous sows may show aggressive behaviour at parturition against their own litter, resulting in the wounding or death of piglets (van der Steen, 1988), especially for crated sows which are denied the opportunity of exhibiting their nesting behaviour.

2.3.1.1 Crushing

Deaths associated with overlay represent a significant cause of neonatal mortality, especially considering that about 70% of the piglets crushed to death involve healthy, potentially viable piglets (Spicer et al., 1986). Crushing was responsible for the death of 16 piglets (48.5% mortality) out of 33 deaths recorded during one reported experiment (Valros et al., 2003). English et al. (1975) observed that crushing of piglet by the sow after birth accounted as the primary cause for almost 18% of deaths before weaning, although it was often a secondary cause in piglets weakened by other factors.

An environment with poor facilities and badly situated creeps in farrowing environment was reported to facilitate high incidence of crushing (English et al., 1975). Poorly designed farrowing pens, bad floor surface (an abrasive surface or sharp edges) and inadequate

temperature all interconnect with sow and piglet factors to facilitate crushing of new born piglets.

Several studies have pinpointed many maternal factors that could influence crushing; among them are maternal genetic merit, temperament and parity of the sows. Meishan sows are known to produce large litters and crush few, if any, pigs. Hohenshell et al. (1996) indicated that Meishan sows may be more vigilant and aware of their pig's location and then they quickly lie down without crushing pigs.

The status of the piglets may be an important factor influencing crushing. Malnourished piglets appear to be more vulnerable to crushing, perhaps because persistent suckling attempts cause them to spend more time near the sow to obtain warmth and food (Weary et al., 1998). Prevention of crushing thus requires a reduction in malnutrition, not merely restriction of the sow's movement.

Sows are very reactive to the squeals of piglet and, moreover, the occurrence of crushing is significantly related to individual differences in sow behaviour (Wechsler and Hegglin, 1997). In a more recent study, Anderson et al. (2005) found that sows that did not crush any of their piglets showed a more protective mothering style, in terms of more nest building activity, responded sooner on hearing piglet distress calls, initiated more contacts sooner after piglet distress calls, nosed more on the piglet during posture change, were more restless when the piglets were taken away and were more social in a grouping situation, than sows that crushed several piglets, thus concluding that crushing as a neonatal death cause is highly related to mothering style.

The relationship that exists between a sow and her piglets can be influenced by the environment they experience. The farrowing crate will not allow the expression of the sows' maternal capabilities like good nesting behaviour, nosing around and pawing the ground to make sure that there are no piglets around the lying area (Weschler and Weber, 2007). The presence of bedding materials reduced crushing and posture changes of the sow (Herskin et al., 1998), but it has not been ascertained whether the reduction in posture changes and

crushes as result of the introduction of bedding is due to the effect on subsequent restless behaviour of nest building before farrowing or the effect of lying comfort after farrowing.

According to Marchant et al. (2001) piglets are most vulnerable to crushing during the first 24hours of life, when they are spending much of their time near the udder and have relatively poor mobility. Moreover, studies in outdoor farrowing huts have shown that crushing occurs at evening and night, during the first 12hours of farrowing and involves changes between lying, sitting and standing positions, as well as between udder and side lying (Vieulle et al., 2003).

The major sow behaviours causing crushing can thus be classified into two categories;

a) Lying behaviour
b) Rolling behaviour

Several studies have reported lying down behaviour to be a dangerous behaviour, especially at an increased frequency (Damm et al., 2005a; Vieuille et al., 2003; Marchant et al., 2001; Weary et al., 1998). In the transition to lying, crushing involves two distinct behavioural sequences: posterior crushing (beneath the sow's hind quarters) and ventral crushing (beneath the udder and rib cage). The important lying down behaviours of sows can thus be considered as;

a) Standing to lying position
b) Sitting to lying position.

Marchant et al. (2001) reported that posture changes requiring lying down from a standing position of sows resulted to the death of 24 piglets out of a total mortality of 67 piglets. In the same vein, piglet deaths due to crushing by the transition from standing to lying were reported by various other studies to be high (Johnson et al., 2007; Weary et al., 1996).

Crushing has been related to the rate of lying laterally before commencement of farrowing. It has been suggested that sows that crush more piglets lie down longer before farrowing. The explanation for this could be associated to leg weakness, illness and obesity. All these conditions make the movements of the sow very rapid and uncontrolled when changing postures (Damm et al., 2005b). However, in contrast, Pedersen et al. (2006) reported that

there was no connection between the lateral lying of sows before farrowing and the relative effect of crushing during and after farrowing. Falling onto the side is termed ‘flopping’ and it is considered the most dangerous way a sow can lie down when the litter is present (Wechsler and Hegglin, 1997). Lying down in the open rather than by leaning on a surface has also been demonstrated to increase the risk of piglet crushing (Marchant Forde, 2002)

Moving from a sitting to lying position has not been viewed to be as dangerous in pens as the standing to lying transition, as this behaviour has more often been associated with the sows confined in farrowing crates. The farrowing crate does not give sows enough room to manoeuvre themselves, so the only significant movements they perform are sitting up from lying and vice versa, sometimes as a transition phase in standing from lying position and vice versa. The sitting from lying position was reported to have resulted in the death of 3 piglets out of a total live born mortality of 35piglets (Andersen et al., 2005). These changes in posture are influenced by the environment (farrowing environment) and largely depend on the amount of space or freedom the sow has in different housing systems.

Rolling is a behavioural movement that has been reported to be equally dangerous if performed very fast during and after farrowing (Weary et al., 1996). The type of housing and the different features in such housing systems affect the rolling behaviour of the sow. It occurs more often in loose pens than in crate systems because sows are confined in crates while they have some freedom in loose pens and outdoor systems. Weary et al (1996) reported death by rolling behaviour to account for 65% of mortality in a pen environment.

With the increase in the welfare concern regarding sows confined to crates, crushing of piglets as a result of the rolling movement of the sow in pens becomes a subject that needs urgent attention or else many piglets will be lost in the first few days of life. Table 1 shows great variation in the occurrence of rolling behaviour. Only little is known about the factors that affect it and its association with piglet crushing (Damm et al., 2005a). Sows lie down in lateral recumbency most of the time during parturition and the first day after parturition (Pedersen et al., 2003; Vieuille et al., 2003) and in order to do so comfortably they most likely need to move occasionally from lying on one side to lying on the other. Fast rolling seems to be the most dangerous and it has been suggested that inclusion of nest materials

modifies the behavioural rolling pattern of the sows, thus reducing the crushing of piglet (Herskin et al., 1998; Damm et al., 2005b).

Table 2. 1: Frequency of rolling in farrowing pens

Source	Period	Rolling variables	Reported (Changes /Sow)
Bradshaw&	12:00-20:00h	Lateral-lateral	1.5(0-6)
Broom (1999)	(till one day after Farrowing)	Ventral-lateral	1(0-6)
		Lateral-sternal	0(0-2)
Weary et al.	BFP[a]- 4days	Lateral-Ventral	41.2±12
(1996)	after farrowing	Ventral-lateral	48±9.3
Weary et al.[b.]	BFP- 48 later	Lateral-Ventral	0.07
(1998)		Ventral-lateral	0.25
Weary et al.[c.]	BFP- 48 later	Lateral-Ventral	0.45
(1998)		Ventral-lateral	0.63
Herskin et al.	24h on days 0	Lateral-Ventral	0.37±0.03
(1998)	3, 6 and 12 post- partum	(or vice versa)	
Marchant et al[d.]	Over 7 days	Same side	
(2001)	post- partum	Ventral-lateral	75.04
		Lateral-Ventral	60.63
		Swap side	
		Ventral-lateral	112
		Ventral-lateral	163
		Lateral-Ventral	15
		Lateral-Ventral	175
Johnson et al	first 1-3days	Lying laterally	570±105.88
(2007)		Lying sternally	159.5±47.18

a- BFP means Birth of First Piglet, b)The experiment was carried out using pens with concrete floor, c)The experiment was carried out using pens with plasticized floor, d)The figures reported was adjusted to a sows/total period .

Extracted from Damm et al., 2005

Rolling has been seen as part of the natural behaviour sows should display. Even though rolling behaviour might have a great deal of disadvantage leading to loss of piglets, there are positive sides to it, so it might be practically impossible to prevent and/or eliminate rolling behaviour else the sow welfare will be at a disadvantage (Damm et al., 2005a). One of the advantages of rolling, as defined by several authors, is that sows lie down laterally during the

farrowing period and they change sides to ensure a smooth parturition (Damm et al., 2005a; Pedersen et al., 2003; Vieuille et al., 2003; Jarvis et al., 1999; Petersen et al., 1990). Moreover, rolling has been attributed to one of the characteristics a sow undergoing the weaning process utilises, thereby denying her piglets milk to suckle (Jensen and Recén, 1989; Jensen, 1988). The sow turns and lies down on her udder preventing her litters from suckling once in a while and the increase in the frequency of exhibiting this behaviour adapts the piglets to seeking and consuming creep feed to meet their nutritional requirements (Jensen et al., 1991; English et al., 1977).

2.3.2 Placental traits influencing mortality

2.3.2.1 The Porcine Placenta

One of the most important roles of the placenta is to provide an enabling absorptive environment sufficient for the survival of the foetus. The size, number and density of blood vessels have been described to be very important for nutrient exchange (Reynolds and Redmer, 1995). The disappearance of the yolk sac makes it imperative for nutrient transport to the embryo to be assumed by the developing allantois which, after its fusion to the chorion, becomes the chorioallantoic placenta. With the development of the allantois and expansion of the membranous cavity, the embryos become apposed to the uterine surface and attach to it. The attachment of the microvilli to the uterine endometrium marks the beginning of formation of the epitheliochorial placenta of the pig (Mesa et al, 2005). Immediately after the attachment of the chorioallantoic membrane to the endometrium, the membranous tissues undergo numerous changes and they end up as transverse folds or ridges (Randall, 1982). These folds subdivide to create the secondary fold which continues over the surface of the chorion. Afterwards the chorionic surface is divided into areolar and inter-areolar areas (Randall, 1982).

With the increase in days of gestation, the areolar areas increase in diameter and fold inwards to form a cup-shaped structure with folded walls. Measurements taken on the areolae to establish the depth and diameter range were reported to be approximately 1 mm in diameter and 1.5 mm in depth, while the concentrations of areolae present over the surface of the placenta ranged between 2,000 and 2,500 per placenta (Knight et al., 1977).

The porcine foetuses are clearly separated from the maternal bloodstream because of the presence of the connective layers. Previous work reported that the blood vessels of both the sow and the foetuses are arranged in a cross-counter current arrangement within the placenta. Thus, the blood supplies are placed side by side within these microscopic folds, and maternal and foetal blood flows in approximately opposite directions perpendicular to the plane of the placenta (Vallet and Freking, 2007). One of the most important roles of the placenta is to provide an enabling absorptive environment sufficient for the survival of the foetus. The physical size, number and the density of blood vessels is highly important for nutrient exchange (Reynolds and Redmer, 1995). It was reported that the vascular region of the placenta accounts for 4% of the total placenta volume after expulsion (Wilson et al., 1998).

In conclusion to the structure of the placenta as reviewed above, it has been shown that the areolae are very important for the maternal – foetal transport of nutrients for the sustenance of the foetus. In addition, the transfer of nutrients during gestation occurs via two routes; a). Hemotrophic transport – this is the transport of nutrients at the side and on the ridge of the secondary chorionic folds of the chorioallantoic membrane. (b) Histo-trophic transport – this means of transport occurs at the fossa of the chorionic folds by absorbing secretions from the surface epithelium and by the absorption of secretions of the uterine glands.

2.3.2.2 Placental Efficiency

The term Placental Efficiency (PE) was described to be the ratio of the foetal weight to that of the placenta weight (Biensen et al., 1998; Kurtz et al., 1999). The short coming of this definition has been highlighted, since it does not take into account the transfer mechanism for nutrients, gases and wastes that go on in the uterus (Dantzer, 1982; Sibley et al., 1997). It has been suggested that the measure of nutrient exchange between the sow and the foetus through blood supplies can also be referred to as Placental Efficiency. This affects the development of the neonates and thus influences the litter size, birth weights, and survival after farrowing (Mesa et al., 2005; Vallet and Freking, 2007; Baxter et al., 2008). It was emphasized that increase in the total density of areolae results in a good inter-uterine environment (good nutrient transfer) which in turn reduces piglet mortality (Baxter et al., 2008).

During the last trimester of pregnancy in sheep, the growth of the foetus was reported to be affected by nutrition of the mother, uterine blood flow to the placenta and placenta capacity for nutrient transport (Brown et al., 1979). Apart from the placental efficiency having an influence on growth rate of the foetus in late pregnancy, the development of the brain structure is also of utmost importance as placental insufficiency can negatively affect the development and complexity of the brain (Buhi et al., 1982).

The breed effect on placental efficiency in the pig has been studied in an experiment which compared purebred Meishan sows to Meishan sows crossed with Large White pigs to determine how piglet and sow features affect placentation. The Meishan sow's uterus tends to have an increased carrying capacity for foetuses in comparison with the Large White breed, even though it was reported that the placenta size did not increase during the last three weeks of pregnacy (Biensen et al., 1998; Biensen et al., 1999). Piglets from Meishan (high placental efficiency) sows weighed less than piglets from Large White sows, but their relatively smaller placental weight indicated greater efficiency (Lee et al., 1995).

2.3.2.3 Placental factors affecting neonatal growth

There are several placental factors which can influence foetal growth and development. Maternal nutrition during pregnancy determines the availability of nutrients to the foetus while the placenta is responsible for the transport of these nutrients. The blood flow in the uterus to the placenta, size of the placenta (surface area inclusive) and weight of placenta have been reported to have varying effects on foetal growth and neonatal survival. The growth rate of the foetus decreases as the placenta becomes smaller (Vallet and Freking, 2007; Baxter et al., 2008) because a small placenta reduces supply of glucose and fructose. This reduced growth rate results in low birth weight of piglets and predisposes them to hypothermia, which further leads to chilling, starvation and death (Herpin et al. 1996; Herpin et al. 2002; Mellor and Stafford 2004).

Research on how placental efficiency affects piglet survival from birth to weaning has been growing over the years. The relationship between placental efficiency and piglet survival (birth weight) has been studied (Biensen et al., 1998; Biensen et al., 1999; Wilson, 1998; van

Rens and van der Lende, 2004; van Rens et al., 2005; Vallet and Freking, 2007; Baxter et al., 2008) and results obtained have shown that the selection for placental efficiency (a measure of nutrient exchange between the sow and the foetus) in pigs has been successful with a heritability value of 0.37. However, it was further emphasized that, although the heritability value obtained looks good, the continued selection on placental efficiency might result in increased risk of piglet mortality around farrowing (Van Rens et al., 2005). This deduction was made because of the further suggestion that the smaller the placenta, the more vascularised and efficient it is going to be (Wilson, 1998; van Rens et al., 2005). The thickness of the placenta has been found to be positively correlated to the farrowing duration, with piglets given birth to much later in the birth order being at a risk of being weak, less viable and susceptible to crushing.

2.3.3 Lactation

2.3.3.1 Colostrum and milk

The colostrum, which is defined as the first milk produced after birth, is an enriched fluid filled with growth, immune and tissue repair constituents which are vital to the further existence of the neonate at birth (Uruakpa et al., 2002). Colostrum is very important in the development of the neonate, especially just after birth, because it is fortified with antimicrobial agents which help the immune system to be equipped against diseases. It also helps in tissue growth and development.

The piglets are born with a low amount of body fat (<10g mobilizable fat/kg body weight), thus, there is a strong need for them to feed to get energy so that they will not starve. Colostrum, to the neonates, is a source of energy and enables them to withstand the sudden change in temperature they experience in the early hours of life. The composition of nutrients found in the colostrum and milk of mammals can be often related to the nutrient composition of the diet ingested by the mother during pregnancy. Some of the results from research work show that increasing the quality of the sow milk by fortifying the maternal diet (addition of

fat) during late gestation and early lactation increases the fat content of the colostrum and thus increases survival of low birth weight pigs (Shankar et al., 2009).

Apart from being richer in growth factors and antibodies when compared to ordinary milk, colostrum has been considered to be the most potent natural immune booster, which consists of more proteins, immunoglobulins, ash, vitamins, minerals and less fat than the milk. Furthermore, the colostrum has been known to be a vehicle which conveys micronutrients, especially vitamins A, D and E, which are known not to cross the placental barrier in significant amounts (Quigley and Drewry, 1998). Colostrum has been seen not only as food but as a supplement that protects health and that which has the potential to enhance the cell growth and tissue repair (Uruakpa et al., 2002).

While the major causes of piglet mortality (including overlying) are well-known, the underlying mechanisms are less well understood (Edwards, 2002). There is increasing evidence that failure to achieve a regular and adequate intake of colostrum (energy) is likely to be a direct and an underlying cause of the majority of deaths (Dycks and Swierstra, 1987; de Passillé and Rushen, 1989; Edwards, 2002; Damm et al., 2005a). Reports by Le Dividich et al. (2005) and Devillers et al. (2004) also indicated that, with the exception of some piglets where overlying was the primary cause of death, piglets dying in early life gained several times less weight or consumed much less colostrum and hence less energy than survivors during the first 24 h after birth. It is assumed that piglets consuming less colostrum would be less vigorous and less able to compete for productive teats, and hence more prone to die by hypothermia and/ or under nutrition.

Ingestion of colostrums aids the transfer of maternal immunoglobulin from the mother to the offspring for passive immunity (Rooke and Bland, 2002). However, the acquisition of insufficient passive immunity is unlikely to be a major factor underlying these early production losses. This is substantiated by the fact that (i) piglet mortality recorded in a SPF herd did not differ from that recorded in production herds (Cariolet et al., 2004), and (ii) piglet born later in the birth order are not at a higher risk of dying while having less immune protection (Le Dividich et al., 2005).

The ingestion of colostrum is, however, very important in preventing later piglet mortality. The acquisition of passive immunity is closely dependent on both the amount of colostrum consumed and on its immunoglobulin G (IgG) content. Absorption of IgG by the gut of the newborn piglet is saturated by increasing amounts of colostrum intake. Le Dividich et al. (2005) observed that those piglets fed different amounts of colostrum in hourly feeds over the first 27 h of life had plasma IgG concentrations reaching a plateau in the first 20 h of suckling. The position of the piglet in the birth order is one of the main factors cited as affecting immune status, with piglets late in the birth order having access to colostrum of lower IgG concentration and, as a result, attaining reduced plasma IgG concentrations (de Passillé et al., 1988; Bland et al., 2003; Le Dividich et al., 2005). Increasing the vitamin A and E content of the diet of the sow has been shown to influence the IgG status of the piglet (Rooke and Bland, 2002).

Coalson and Lecce (1973) postulated that piglets "can acquire from the dam's colostrum more than adequate passive antibody in the first hour of nursing" corresponding to 15- 17 mg IgG/ml serum. On this basis it is calculated that a piglet consuming approximately 70 g/kg birth weight of the first colostrum would acquire sufficient passive immune protection, although this intake is insufficient to meet the energy requirement for survival. Therefore, as postulated by Tyler et al. (1990), the consumption of colostrum in an adequate amount to provide appropriate immunity to the piglet is not necessarily sufficient to guarantee its survival. From this, it is tempting to speculate that the level of passive immunity is not a determinant of survival. However, inadequate transfer of maternal antibodies to the newborn piglet may increase susceptibility to infections in the latter part of lactation and after weaning (Varley et al., 1987), while low humoral immunity at weaning may influence post-weaning performance (Edwards and Rooke, 1999). The positive relationship between the acquisition of passive immunity and the development of active immunity indicates a high level of passive immunity is desirable.

The newly born piglets are totally dependent on the milk produced by the sows in the first 2-3 weeks of life for growth and development; therefore it is important that the sow should have enough milk for the piglets to suckle especially when there is an increase in litter size.

Improving the quality and quantity of milk produced by the sow is critical for adequate nutrition of the piglets.

2.3.3.2 Lactation failure and starvation

Lactation failure in sows has been seen as a worldwide problem (Alonso-Spilsbury et al., 2007) requiring solutions. Insufficient milk production by the sows and the consequent malnourishment of the piglet may be directly responsible for between 6 and 17% of all preweaning mortality in commercial pig farms. Lactation failures may be due to high environmental temperatures (Barb et al., 1991). Postmortem examinations have typically identified starvation as a leading cause of piglet deaths (Fraser, 1990). According to him, starvation may often result in alternative end-points of a single process. A piglet that is debilitated by being prevented from accessing the teat in time, thereby failing to establish adequate milk intake, is likely to be crushed, but when crushing is prevented, the newly born piglet might become weak and die from malnutrition sometime later. A sow's milk production in the first days of lactation can vary from excellent to disastrous and many litters of piglets experience mild to severe malnutrition soon after birth.

A malnourished piglet will become too weak to go to the udder for food or it might be outcompeted by other piglets and therefore starve to death. Therefore, the inability of a piglet (or piglets) to suckle, ingest and digest colostrum just after birth might lead to starvation of such a piglet. Starved piglets are always very prone to being crushed by their dams because of the lack of energy and warmth which makes such piglets stay close to their mothers and as a result get crushed. Factors responsible for starvation are weakness, competition with litter mates (especially in a large litter), inadequate mothering and inadequate or deficient milk production (Tuchscherer et al., 2000; Varley, 1995; Vermunt, 1995; Alexander, 1984). Starvation should be minimised by ensuring that pregnant sows are given a quality balanced gestation and lactation diet.

2.4 Environmental factors influencing piglet mortality

The health and the development of the newborn piglets are strongly influenced by environmental conditions and the care which they receive in the first hours and days after birth. Up to 80% of piglet losses occur within the first 3 days of life (English and Morrison, 1984) and these losses could be curtailed if an adequate environment is made available for the neonates, such that they experience less shock in their transition to the new extra-uterine life. Adequacy in terms of temperature, creep area (housing), creep feed and presence of human assistance, in cases where the piglets become compromised and need quick intervention, is important. Some of the parameters which will be reviewed under this part as key environmental factors influencing piglet survival therefore include; housing, thermoregulation and handling or presence of humans.

2.4.1 Housing

The total peri- and postnatal mortality of piglets has been reported to be in the range of 14.4 to 32.1% (Knol et al., 2002; Grandinson et al., 2002; Serenius et al., 2004; Su et al., 2006) under indoor conditions. Under indoor conditions, the piglets are often protected by the use of farrowing crates. However, farrowing crates have been reported to restrict maternal behaviour of sows and raise substantial sow welfare concerns (Lawrence et al., 1994; Jarvis et al., 2001; Edwards, 2007), contrary to outdoor conditions, where sows are more able to express their maternal behaviour. With increasing pressure to abolish the farrowing crate, investigations into improving survival in alternative farrowing systems are essential. In general, outdoor systems are perceived by consumers as more humane, environmentally friendly, traditional and sustainable (Edwards, 2005). However, several studies reported that animals kept outdoors face significant challenges, particularly with respect to climatic extremes (Algers and Jensen, 1990 Edwards and Zanella, 1996) and potential bio-security risks (Callaway et al., 2005), even though the freedom the sows kept outdoors enjoy can facilitate the full expression of their maternal ability.

It has been estimated that around 70% of UK sows farrow in crates while 27% of sows farrow outdoors and 3% of sows farrow in loose-housed indoor systems (BPEX, 2004). Since

this estimate, the proportion of outdoor sows has increased, although indoor loose farrowing is still very rare. Many studies have been conducted to determine the influence of farrowing environment/housing on sows around parturition and its effect on preweaning mortality (Blackshaw et al., 1994; Cronin et al., 1998; Weschler and Weber, 2007). The farrowing crate (about 0.6 x 2.2m in size) is the most common type of housing system used even with the controversy about the welfare issues it stimulates, especially in Europe and North America (Lay et al., 2002). The menace of piglet mortality was the reason behind the introduction of the farrowing crate, which can enhance piglet survival; for example Blackshaw et al. (1994) reported a decrease in piglet mortality in crate sows (14%) compared to sows housed in pens (32%).

2.4.1.1 Conventional Farrowing Crate

The numerous farrowing crates used worldwide are designed to individually house the sow during the farrowing and lactation period (Phillips and Fraser, 1993; Skorupski, 2001). There are lots of different designs of farrowing crates but with common features (Figure 2.1). Different materials have been used for flooring, which can be slatted or meshed at the rear of the crate to allow for ease of removal of manure, which falls through into a separate collection area regularly emptied or flushed with water. A drinker and feeding trough are located at the front of the crate. There are spaces at either side of the bars (usually 0.3-0.45 metres wide on one side, and 0.6-0.75 metres wide on the other) where the creep is located, into which the piglets can escape when the sow is standing up or lying down. A heating lamp or mat is also provided for the piglets in the creep area, which is their safety zone, to preventing them from chilling (Skorupski, 2001). The way the crate is designed and the available space is very important as it has been reported that more mortality due to crushing occurred in a wide crate (64cm width) than in narrow crate (55cm width) (Shankar et al., 2009).

2.4.1.1.1 Advantages and Limitations of farrowing crates

Farrowing crates were welcomed by the pig industry for various reasons, including ease of sow management, higher stocking density of sows/unit of building space and reduction in piglet mortality (Fraser and Broom, 1997; Johnson and Marchant Forde, 2009). The management of the sow becomes a lot easier with crate confinement since it serves as a means of restraint, thereby allowing the stock person or veterinarian to carry out routine management practices on and around the sows without fear of being attacked or hurt.

However, with all these benefits the farrowing crate has brought to pig farming, and especially its advantage in reducing mortality of piglets, it has been receiving criticism of late because of the detrimental effects it has on the welfare of sows, such as ulceration on the legs of the sows (Rountree et al., 1997) and the prevention of sows to choose a nest site (Damn et al., 2003), carry out natural farrowing behaviours (Haskell and Hutson,1996) and hindrance of postural adjustments before, during and after farrowing. The farrowing crate thus compromises sow welfare by reducing their possibility for movement, confining them to a small sized area just enough for them to stand up, lie and feed. The sows do not have the opportunity to access a separate dunging area and so they are compelled to defecate within their perceived nesting area. They are also unable to express their strongly motivated nest building behaviour. From a holistic point of view, ranking of the motivational effects of internal and external factors of nest-building behaviour is pointless (Jensen and Toates, 1993), but more moves to adapt the present farrowing systems to these behavioural needs are required. Farrowing accommodation restraining the sow's movements has repeatedly been shown to improve piglet survival (Edwards and Fraser, 1997), but for ethical reasons these systems require reconsideration (Edwards, 2002).

Figure 2.1. Conventional metal farrowing crate. (Photo source: Adeleye Oluwagbemiga)

2.4.1.2 Alternative Farrowing systems

The welfare issue of sows housed in farrowing crates has been much emphasised, and this has led some researchers to investigate alternative methods of housing sows in a more spacious environment, allowing them freedom of movement and expression of behaviour but still maintaining a low incidence of piglet mortality (e.g. McGlone and Morrow-Tesch, 1990; Cronin et al., 1996). Not only is the space investigated, but also the features present in pens which might aid the sows and piglets to live comfortably, thereby enhancing piglet survival (Weary et al., 1996). The possibility of designing a farrowing system for commercial use which will not conflict with one or more maternal behaviours expressed by sows in the wild has been a challenge. A major welfare problem that might be faced by sows and piglets in these systems is the ability of the sow to farrow anywhere other than the nest provided for her to give birth, thereby increasing the risk of chilling and starvation of piglets. There are many different ways in which sows are kept prior to farrowing and any of these may be combined with a variety of possible farrowing systems (Figure 2.2). Some of the more widely investigated systems will now be examined in more detail.

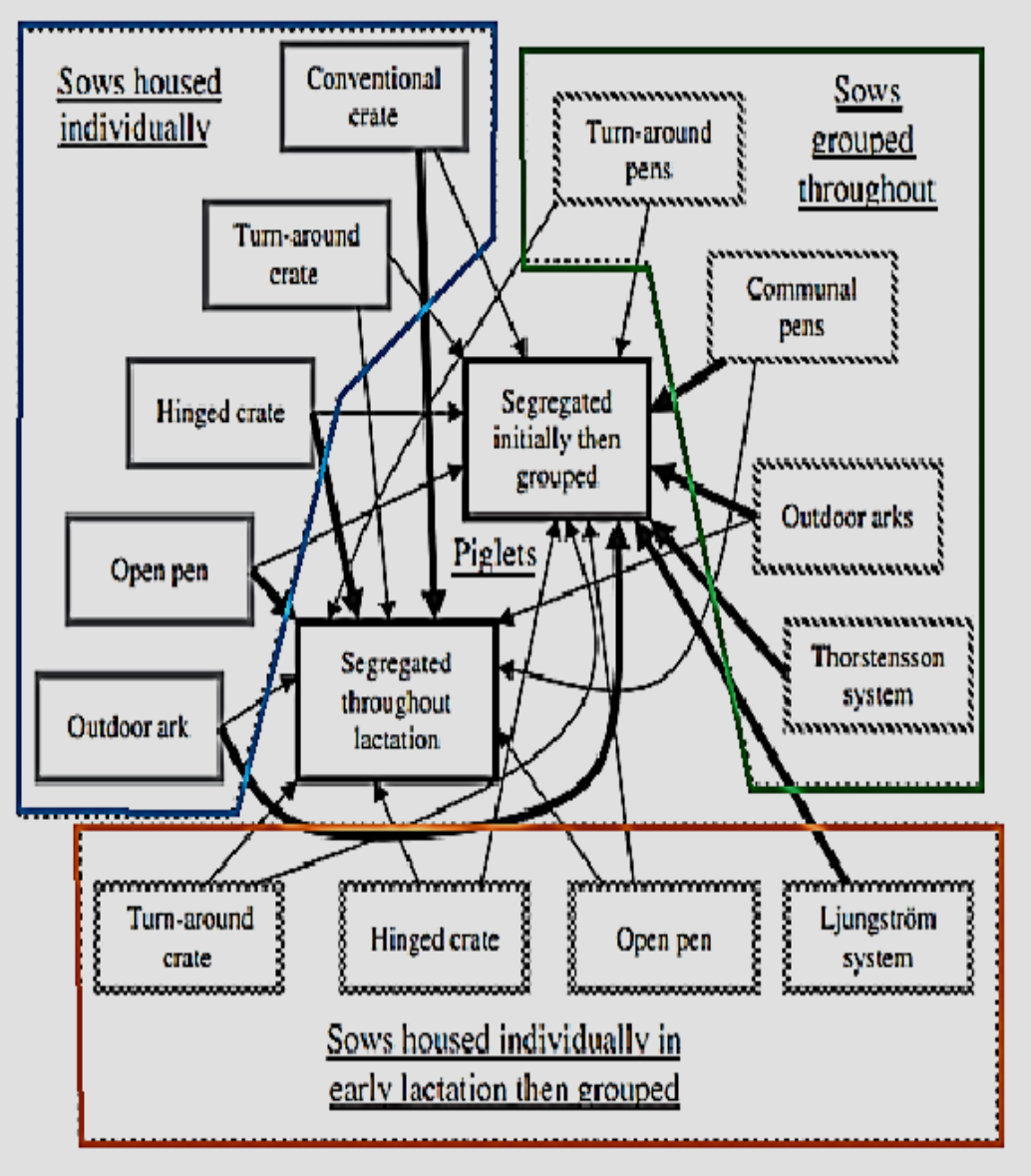

Figure 2.2. Diagrammatic representation of possible combinations of farrowing and lactation systems. Most common combinations joined by thick black arrows. (Johnson and Marchant Forde, 2009.)

2.4.1.3 Alternative Farrowing Environments developed over the years

There exist various housing options for sows during farrowing and lactation. They range from conventional crates to outdoor pens or huts (Collins et al., 1987; McGlone and Morrow-Tesch, 1990; McGlone and Hicks, 2000). The adoption of alternative farrowing systems has been reported by Edwards (2008) to be challenging and might be problematic, even though some European countries have introduced these (some by legislation). Though these systems look better in terms of sow and piglet welfare, their ability to enhance piglet survival under large scale conditions has yet to be affirmed.

2.4.1.3.1 Turn-Around Crates

This type of farrowing accommodation is similar to the farrowing crate, only with a slight modification. They are made out of tubular metal in a circular, oval or triangular shape with the pen having a designated place for the piglet creep area. The systems are more usually placed on a fully-slatted floor than on a solid concrete floor because of the ease of cleaning. There are two main types of crates that look similar and have been used in experiments as 'Turn around crates'. They are ellipsoid farrowing crates (Lou and Hurnik, 1994) (Figure 2.3) and modified triangular farrowing crates (McGlone and Blecha, 1987) (Figure 2.4). The amount of space required for these modified farrowing pens has been reported to be slightly larger than that used by a conventional crate pen; the above designs utilize an overall pen size of 2.0 m x 1.75 m (ellipsoid) and 2.6 m x 1.5 m (triangular) (as reviewed by Johnson and Marchant Forde, 2009).

There have been different views on the presence and the type of rails (fixed and adjustable) in modified farrowing crates, as larger farrowing pens with adjustable rails (according to sow size) are expected to result in a higher number of weaned piglets and greater piglet weight upon weaning in comparison with those kept in small pens with fixed rails (Johnson and Marchant Forde, 2009). The shape of rails in the modified crates has also been suggested to influence piglet productivity with the ellipsoidal shaped rails proven to be better than the usual rectangular shaped crate in terms of increase in the number of weaned piglets (Lou and Hurnik, 1994). Lou and Hurnik (1994) further reported that the ellipsoid crate allowed sows to perform more behavioural activities like turning around, communicating with young,

monitoring surroundings, and lying down more smoothly without increasing the amount of floor space unnecessarily. The study showed that the design improved the well-being of sows and pigs and, most importantly, did not cause a higher pig crushing rate.

Figure 2.3. Ellipsoid farrowing crates (Photo source: J.J. McGlone in Johnson and Marchant Forde, 2009).

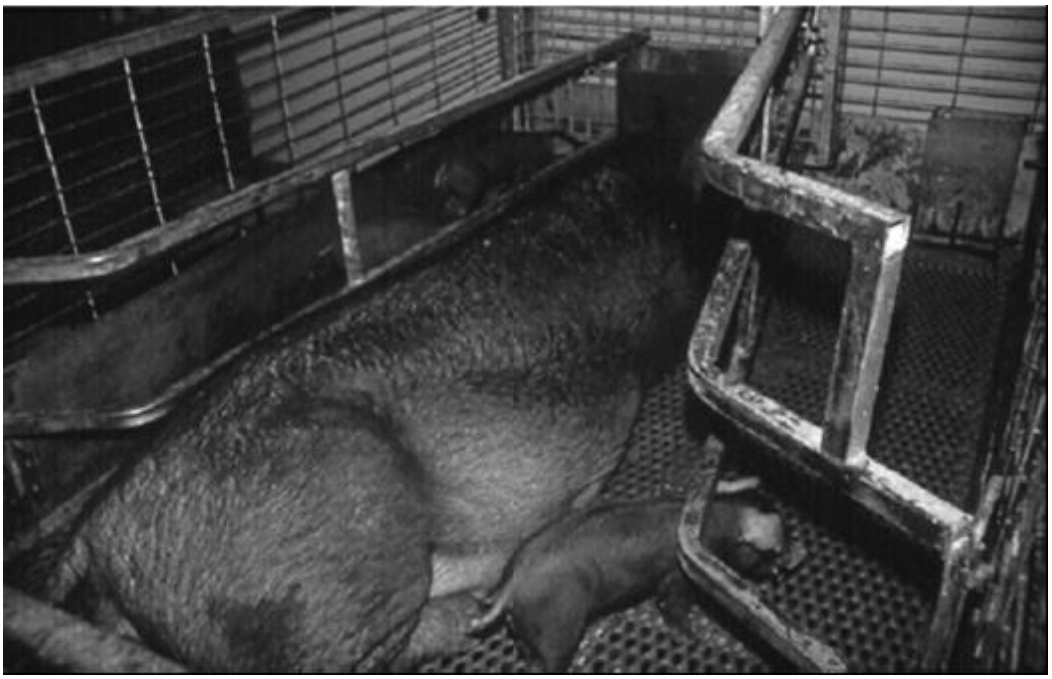

Figure 2.4. Triangular turn-around'' farrowing crates (Photo source: J.J. McGlone in Johnson and Marchant Forde, 2009).

2.4.1.3.2 Hinged Crates

This type of farrowing crate has been seen to be on the increase in terms of usage in Europe (Johnson and Marchant Forde, 2009). This system is constructed such that it takes the shape of the farrowing crate around farrowing (Figure 2.5) and, after parturition, the crates are opened up to give more space for the sow and the piglets (Figure 2.6). This system gives room for a creep area and can be installed with solid floors and bedding or using a fully-slatted floor (Johnson and Marchant Forde, 2009). Similar to the farrowing crate, the hinged crate takes up almost equal space but the stock person will have to find means of restraining the sows while carrying out management routines during lactation (MLC, 2004). The sow is given a little bit of freedom and opportunity to come in contact with her piglets from about 5 days after farrowing, when the crate is hinged open and she too can express some behaviour in a more conducive environment when compared to the conventional farrowing crate.

Figure 2.5. Tubular metal hinged farrowing crate, showing crate in a closed positions (Photo source: Johnson and Marchant Forde, 2009)

Figure 2.6. Tubular metal hinged farrowing crate, showing crate in an open positions (Photo source: Johnson and Marchant Forde, 2009)

2.4.1.3.3 Open Pens

Before the advent of the farrowing crates, farrowing sows reared indoors gave birth in open pens which did not have any complex design or features other than the feed trough and the water trough. They are mostly rectangular in shape and have a nesting area which is bedded with straw. The creep areas are sometimes not demarcated, although more recent pens have defined areas for the piglets creep areas (Figure 2.7). The recent 'designed pens' that have been studied have made provision for separate lying and excretory areas for the sows. Examples of such pen designs are the Schmid box (Schmid, 1993), the Weribee Farrowing Pen (Cronin et al., 2000) and Swiss designs developed at FAT, Tanikon (Weber, 2000).

With the survival of piglets in open pens being questioned because of high live born mortality records, there have been several attempts to modify the pens by fixing various support features that will minimize death of neonates in the early hours after birth. Such

support features consist of bars and/or rails, usually about 15–20 cm up from the floor and out from the wall (McGlone and Blecha, 1987; Blackshaw et al., 1994). Another protective feature is the sloping wall (which slope outwards, Figure 2.7) which is being incorporated in some other pen designs. These walls give some allowance at the bottom, leaving some space for the piglet to escape underneath while the sow is lying down (Cronin et al., 1996; Marchant-Forde, 2002).

.

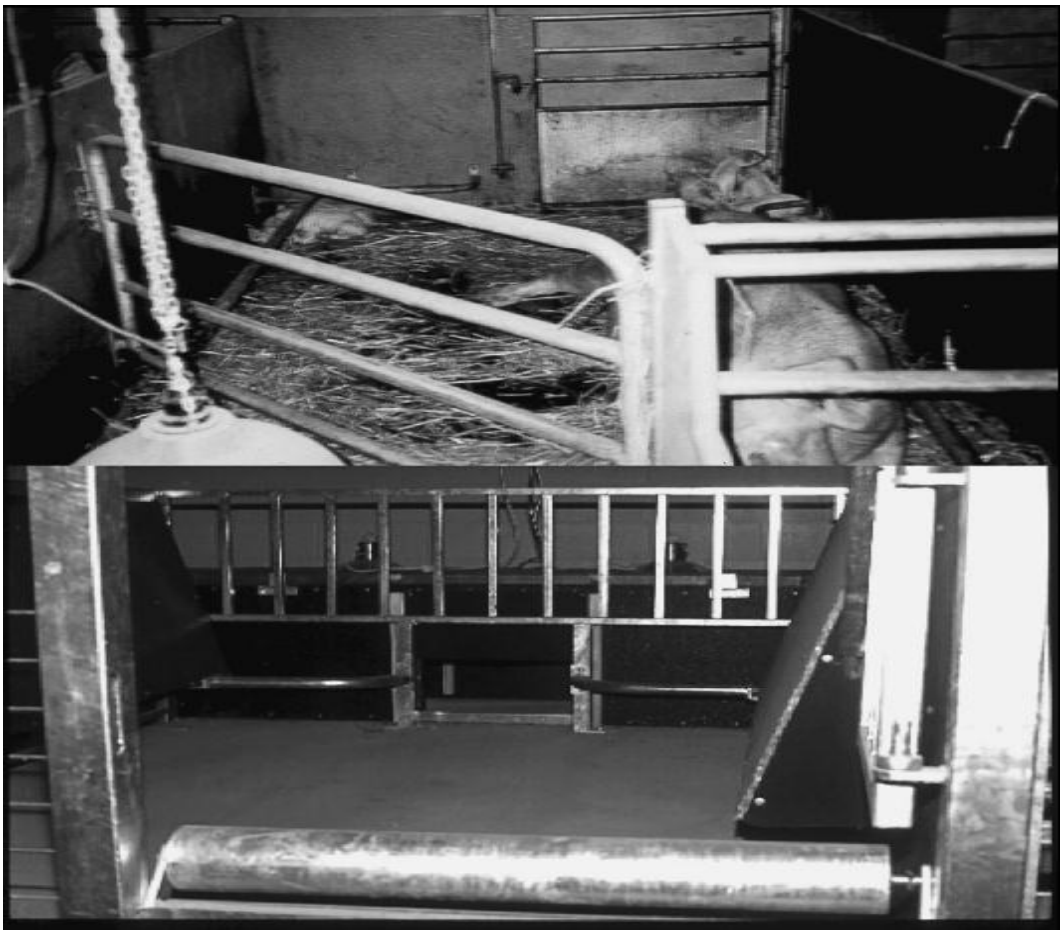

Figure 2.7. Open pens showing rail and sloping wall protection system (Photo source: Johnson and Marchant Forde, 2009)

2.4.1.3.4 Werribee Pen

The 'Werribee Farrowing Pen' is one of the most recent developments of alternative farrowing systems. It is large enough to house a sow and her litter, with the sow having enough room to perform nesting and all other behavioural tendencies. It has a protected area

for the piglets and a wide space for the nesting site (Figure 2.8). The production performance of sows housed in these pens has been good, with the number of piglets weaned per sow found to be similar to sows that farrowed in conventional farrowing crates (Cronin et al., 2000). However, a major limitation to the use of this type of farrowing accommodation (in terms of commercial production) is the increased floor space requirements. This makes the pen less suitable and commercially viable despite all the benefits.

Figure 2.8. Werribee farrowing pen (Source: Primefact, 2006)

Table 2.2. Size of alternative farrowing systems relative to typical commercial farrowing crate of 2.2 x 1.5 m

Alternative Pen	Size (m)	Increase in floor space needed (%)	Reference
Turn around	1.5x2.6	21	McGlone and Blecha (1987)
Sloped pen	2.1x2.1	40	McGlone and Morrow- Tesch (1990)
Ellipsoid crate	2.0x1.8	9	Lou and Hurnik (1994)
Werribee pen	2.3x3.5	147	Cronin et al. (2000)
Outdoor English hut	2.8x1.7	41	Johnson et al. (2001)

Source: McGlone. (2006)

Table 2.3 shows a selection of results from studies in which performance in crates and pens has been compared. In these earlier studies, performance in non-crate systems was usually inferior. However, more recent studies with better pens designs have yielded much more promising results (Baxter et al., 2011)

Table 2.3. Comparison of piglet mortality (%) levels in farrowing systems with crates and open pens.

Source	No. of litters	Crates	Pens
Robertson et al. (1966)	150	18.7	26.6
Devilat et al. (1971)	46	10.2	13.5
Glastonbury (1976)	614	15.9	31.3
Nielsen (1980)	2000	5.5	8.4
Aherne (1982)	21	12.7	34.6
Svensden et al. (1986)	702	4.4	6.5
McGlone and Morrow-Tesch (1990)	40	10.8	27.1
Grissom et al. (1990)	162	6.3	13.5
Cronin and Smith (1992a)	64	10.5	16.5
Blackshaw et al. (1994)	16	14.0	32.0

(Source: Edwards and Fraser, 1997).

2.4.1.3.5 Outdoor huts

The outdoor huts, as the name implies, are placed outside in paddocks. These huts vary in size, shape and construction material (tin, wood or plastic). Examples of these huts are; A-Frames huts which are tall and have a flattened triangle shape, and English style "half round" huts. The outdoor huts usually do not have floors, although some possess plywood floors, and they all make use of a large amount of straw as bedding. Sows placed in this type of housing have no restriction of straw and are placed in large paddocks with individual farrowing huts which they make use of when they want to isolate themselves. However, it has been difficult to replicate such an environment in the indoor situation (Edwards, 2008).

There has been a lot of study on the different types of designs of alternative farrowing pen and how it affects building requirements and piglet survival around farrowing. Different pen designs have very different space requirements (Table 2.2). In comparing results from experiments of different alternative farrowing systems, EFSA (2007) suggested a $5m^2$ minimum pen size was necessary to reduce piglet mortality in alternative farrowing pens.

In pens and farrowing huts, the design can improve maternal behaviour and increase the sows' welfare, which is proposed to lead to a better survival and growth of the piglet (Algers, 1994; Damm et al., 2003). Some alternative housings systems have resulted in similar piglet mortality rates compared to conventional systems (Weber et al., 2007; Wechsler and Weber, 2007), but the number of crushed piglets was significantly higher in pens with loosed housed sows (Weber et al., 2007). In loose-farrowing systems, piglet mortality by crushing can be further reduced by a careful selection of environments and sows showing a genetic determination of positive maternal behaviour (Johnson et al., 2007).

2.4.2 Thermoregulation

There is always a drastic change of piglet body temperature at farrowing because they move from the intra-uterine to extra-uterine environment. This drop in temperature leads to chilling and later cold stress which reduces the activity of the piglets and makes them prone to

crushing (Herpin et al., 2002). Hypothermia in neonatal pigs is promoted by their wet, heat-conducting surface (skin with birth fluids), and their poor insulation combined with a poor ability to thermoregulate due to low amounts of mobile lipid/glycogen reserves and no brown adipose tissue for metabolic heat production (Herpin et al., 2002). The ability of the piglets to produce heat depends on the coordinated actions of various organs and tissues (Herpin and Le Dividich, 1995). When exposed to temperatures below thermoneutrality (around 34–36 °C), neonatal pigs partly rely on muscular thermogenesis in terms of shivering, the efficiency of which gradually improves during the first 5 days after birth. Behavioural thermoregulation also develops after birth and includes actively seeking warm places and huddling with littermates. Initiation of suckling is essential for the early provision of both heat and energy to the piglet, in particular for piglets born with a low vitality which increases their vulnerability.

Recent research in indoor loose-housed systems (Malmkvist et al., 2006) has recognised that, even in a temperature-controlled environment, the newborn piglet is highly susceptible to chilling. In detailed experiments on environment–temperature interactions (Mount,1967), the insulating properties of straw (2.5 cm deep) were measured and found to reduce heat loss to the floor by 40% when compared to uninsulated concrete. Deep bedding slows the rate of heat loss and has a thermal resistance 11 times greater than that of concrete slats and 22 times greater than that of solid, wet concrete flooring (Wathes and Whittemore, 2006). Detailed experiments by Algers and Jensen (1990) on the nest-sites of free-ranging pigs concluded that deep-straw nests provide an optimum microclimate for the neonate. A deep-straw bed simulates a more natural nesting site, and the straw facilitates physical removal of membranes and absorption of birth fluids, reducing the impact of placental fluid evaporation and buffering the piglet from immediate susceptibility to the extra uterine environment (Baxter et al., 2009). Domestication of the pig over centuries has failed to alter the innate need for a sow to nest-build (Jensen, 2002), probably because of the extremely high survival value of this function under natural conditions.

2.4.3 Handling/ Human presence

The presence of farm personnel around the time of farrowing is important and helps in reducing mortality of piglets. Around the time of farrowing, the sow might need help in facilitating a smooth farrowing progress. Delayed farrowing and malpositioning of piglets may occur, which will warrant assistance of farm staff. However, it has been reported that the presence of humans during farrowing may induce restlessness of the sow thereby increasing the frequency of standing-to-lying movements and predisposing the piglets to crushing (Valros et al., 2003). Although lower fearfulness of humans tends to be associated with more resting behaviour around farrowing (Andersen et al., 2005), the relationship between fear of humans and postural change frequency was not clearly exhibited. High parity sows were more fearful of humans and crushed more piglets, while high fearfulness was also associated with more crushing in other studies (Lensink et al., 2009).

2.4.4 Management

Prenatal stress (PNS) can modify the foetal environment and affect the development and physiology of the progeny (Seckl, 2004). The consequences of PNS have been less investigated in farm animals, where reproductive females are often exposed to stressors during gestation. For example in intensive pig husbandry, pregnant females have to face stressors such as transport, space and feed restrictions, social isolation and grouping. These widespread stressful management practices might generate PNS with consequences on physiology, behaviour, health and survival of the piglet. Species-specific studies are needed because the generalization of rodent data to ungulates is limited by major inter-species differences like gestation length, in utero developmental time-line (Merlot et al., 2008) and placenta permeability to hormones (Klemcke, 1995; Fisher, 1998).

2.5 Approaches to improving neonatal survival

Various approaches to solving the problem of piglet survival are being investigated. With the diversity of factors affecting the survival of piglets, especially in the first few days of life as reviewed in this chapter, it is clear that a combination of strategies will be the best approach. A combination of genetic improvement, nutritional and management strategies has been

reported to be the best way of addressing pre weaning piglet mortality (Edwards, 2002; Edwards 2005). Causes of piglet mortality have been found to be due to reduced vitality as a result of hypoxia during parturition, hypothermia and lack of adequate colostrum intake (Malmkvist et al. 2006). Therefore, assisting the piglets during farrowing will prevent the piglets from dying from anoxia and helps the weak piglets to have intake of colostrum, which is an important factor determining piglet survival during the lactating period. Various genetic improvement methods and a good plane of maternal nutrition such as the supplementation of additives to improve the vitality and viability of the piglets could be looked into.

2.5.1 Genetic improvement of key traits in animals

2.5.1.1 Breeding for reduced piglet mortality

It has been suggested that the pre-weaning live born piglet mortality ranges from 12.9% to 13.6% per year, (MLC, 2007) in indoor and outdoor systems respectively, in the United Kingdom (Roehe et al., 2009). With this high level of mortality, enhancing piglet survival through genetic improvement (sow traits and piglet traits) ought to be of immense benefit in sustaining increase in pig production. Several aspects of the genetic make-up of both the sows and the piglets have an effect on piglet survival.

The number of live born piglets, and subsequently total number of surviving piglets, can be increased by as much as 0.2 piglets per litter if human intervention in terms of proper selection of traits that aid piglet survival is carefully implemented. This increase in survival rate, if achieved with the assumption that a sow produces 2.5 litters per year, will increase the total number of piglet born alive per sow per year. A study in the United States of America reports the calculated genetic improvement between 1988 and 1998 for number of piglet born alive in Hampshire American Landrace, Duroc and American Yorkshire to be 0.0039 piglet per year, respectively (Moeller et al., 2000). However, more recent developments in Europe have seen significant increases in litter size; in Denmark, litter size has increased by 5piglets over the last 15years. In a bid to further reduce the incidence of pre weaning mortality in pig herds, selection for traits of both sow and piglets that supports survival should be concentrated upon (Edwards, 2002).

Earlier studies suggested that direct selection on litter size, selection for a combination of components of litter size, such as ovulation rate, uterine capacity (Zimmerman and Cunningham, 1975; Johnson et al., 1984) and selection for increased placental efficiency (Ford, 1997; Wilson et al., 1999) might all aid litter size improvement. To achieve this, selection on ovulation rate alone and on a combination of ovulation rate and embryonic survival until day 50 of pregnancy were not successful (Cunningham et al., 1979; Johnson et al., 1999) but selection on an ovulation rate/uterine capacity model of litter size was suggested to be an effective method (Johnson et al., 1999). This improvement in litter size also resulted in increase in percentage preweaning mortality of piglets. Previous studies have reported a negative relationship between litter size, birth weight of piglets and piglet mortality; the higher or larger the litter size, the higher the tendency of having reduced piglet birth weight, hence, the increase in mortality (Kerr and Cameron, 1995; De Passille et al., 1993).

Enhancing piglet survival using genetic interventions can be approached in two ways; through the sow's genetic effect and the piglets' genetic effect (Roehe et al., 2009). Maternal traits in terms of good gait, gestational traits such as placental area, farrowing behaviour, milk yield and health status should be considered. In the same vein, birth weight has been indicated to be the major piglet trait that genetically influences survival (Roehe et al., 2009; Edwards, 2002; Knol et al., 2002a).

The heritability of survival of the litter is approximately 0.05 when considered as a trait of the sow (Siewerdt and Cardellino, 1996; Rothschild and Bidanel, 1998; and Knol, 2001). Maternal effects have earlier been categorised as prenatal and postnatal maternal influences on piglet survival. The heritability for the maternal effect, when calculated for piglet mortality as a litter trait (percentage piglet loss within the litter), is close to 0.1 (Knol, 2001). Although this heritability is relatively low, the genetic variation in maternal effect is substantial and therefore selection on maternal effect can be successful. Next to the heritability for maternal effect, it is also possible to calculate the heritability for mothering ability, i.e. the ability of a sow as a nurse sow. This mothering ability is calculated as the percentage of piglets weaned out of the total number of piglets nursed, taking into account cross-fostering. The heritability for mothering ability has been widely demonstrated to be

lower than that for maternal effects, falling within the range of 0.02 to 0.06 (Hanenberg et al., 2001; Knol, 2001). Hanenberg et al. (2001) found a relatively high genetic correlation of approximately 0.40 between gestation length and mothering ability. The heritability for gestation length is approximately 0.25. This means that selection for increased gestation length will lead to a better chance of suckled piglets to survive until weaning.

There are several reasons why pig breeders have suddenly increased their interest in selecting traits for improved survival. One of the reasons is based on the economic importance that piglet mortality has on the final net profit of the pig industry. Another reason is the increasing evidence that selection in pigs for lean growth (i.e. increased growth with less back fat thickness) has led to decrease in maturity at birth and increase in piglet mortality (Herpin et al., 1993). The growing awareness in the animal welfare circle of the issue of high piglet mortality has been another factor contributing to the use of genetics in solving the challenges around piglet survival.

It has been suggested that until the factors that influence the control of reproductive traits are extensively evaluated and understood, including the DNA, mRNA protein and phenotypic levels of these traits which should be sequenced and analysed under functional genomics, the problem might still persist (Spötter and Distl, 2006). It is also important to estimate genetic parameters that will aid survival of piglets in the actual environment where they are kept (Baxter et al., 2011).

2.5.2 Nutrition

In a bid to enhance piglet survival, research on improving the vitality and vigour of piglets via the nutritional status of the mother has been an ongoing subject of investigation. The supplementation of the maternal diet with polyunsaturated fatty acids, which include essential fatty acids (EFA) and particularly the long chain omega-3 fatty acid Docosahexaenoic acid (DHA), has been a particular focus (Edwards, 2009). Recent investigations have shown that neonatal vigour in various species could be enhanced by including long chain omega-3 fatty acid in the diet of the mother, especially during late pregnancy (Rooke et al., 2001b; Capper et al., 2005; Pickard et al., 2006). Long chain essential fatty acids have been shown to be crucial to survival of neonates through the

development of brain, eye, and neural tissue function (Birberg-Thornberg et al., 2006; Edwards, 2002; Uauy, 2000). Marine oils (Salmon and Tuna) and flaxseed meal and flax oil have been used in different studies as supplements in sow diets. The improvement of vigour of neonates has contributed to the reduction of piglet mortality, even when the birth weight is low (Rooke et al., 2001a; Rooke et al., 2001b).

2.5.2.1 Fatty acids

Fatty acids are carboxylic acids derived from lipids. They show the general formula

R-COOH (R-COO-)

(Where R is usually a linear (unbranched) carbon chain with an even number of carbons). They can be classified based on several criteria as follows;

- According to the presence of double bonds in the carbon chain,

Saturated (no double bonds)

CH_3-CH_2- CH_2- CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH

Unsaturated (one or more double bonds)

CH_3- CH_2- CH=CH-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH

- According to the numbers of double bonds,

Monounsaturated (Just one double bond)

CH_3- CH_2- CH=CH-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH

Polyunsaturated (More than one double bond)

CH_3- CH_2- CH=CH-CH_2-CH=CH-CH_2-CH_2-CH_2-CH_2-COOH

- According to the position of the double bond relative to the last carbon of the chain (sometimes called Metabolic classification)

Omega 3 (the double bond nearest the last carbon of the chain (Cω) is 3 carbons apart from the end of the chain)

CH_3- CH_2- CH=CH-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH

Omega 6 (the double bond nearest to the last carbon of the chain is 6 carbons apart from the end of the chain)

CH_3- CH_2- CH_2-CH_2-CH_2- CH=CH-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-COOH

- According to the number of carbons,

Short chain fatty acids: 2 to 6 carbons
Medium Chain: 8 to 14 carbons
Long Chain fatty acids: 16 carbons and up.

2.5.2.2 Omega-3 fatty acids

Omega-3 fatty acids are polyunsaturated fats found naturally in oily fish, nuts, seeds, and leafy green vegetables. The inability of mammals to synthesize fatty acids with double bonds (especially those closer than carbon atom 9) is due to the absence of Δ-9 desaturase enzymes and makes the supply of Omega-3 fatty acids in the diet essential. The C18 omega-3 fatty acid known as alpha linolenic acid (LNA or ALA) cannot be manufactured by the body but can be converted to produce eicosapentaeonic acid (EPA) and docoshexaeonic acid (DHA), though only a small percentage of LNA can be converted by mammals. These are the reasons why foods consumed by humans and animals (livestock) should be fortified with omega-3 fatty acids.

2.5.2.3 Sources of Omega 3 fatty acid for livestock diets

Sources of omega 3 fatty acids are vegetables, vegetable oil seeds, meat, fish and fish oils (Table 4). The major source of omega 3 fatty acids used predominantly for livestock feeds are fish oil and vegetable oil. The use of fish oil has been criticized on ethical grounds because of the inability to sustain the fish stocks available at the moment, giving rise to sustainability challenges (FIN, 2006). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are found in cold-water fish such as salmon, mackerel, halibut, sardines, tuna, and herring. ALA is found in flaxseeds, canola (rapeseed), soybeans, pumpkin seeds, purslane, perilla seed, and walnut. Other sources of omega-3 fatty acids include sea life such as krill and algae.

Marine plankton and algae generate high concentrations of long chain omega 3 fatty acids which are ingested by the fish and marine animals. These contribute to the high tissue concentrations of omega 3 fatty acids present in fish and marine animals. Grasses have also been reported to have a high concentration of omega 3 fatty acids, making up approximately 16% of total lipid (Dewhurst et al., 2006).

Marine sources (algae), which are categorized as a plant source, have been researched upon since 1996 (Behrens and Kyle, 1996). It was suggested that species of microalgae can be induced to commercially produce particular fatty acids through simple manipulations of the physical and chemical properties of the culture medium. It was further stated that if this algal source would be used as feedstuff for the production of livestock, it would be required that these organisms be grown at large scale under controlled conditions (Behrens and Kyle, 1996). The mass production of these micro algae excludes them from the sustainability issue which has questioned the use of fish oil.

Table 2.4. Fatty acid classification, nomenclature and sources

Molecular Name	Common Name	Sources
	Saturates	
14:0	Myristic acid	Nutmeg butter
15:0	Pentadecanoic acid	Dairy fats
16:0	Palmitic acid	Fish oils, milk fats of lard, Animals, vegetable fats, Cotton seed oil, palm oil, Animal fats and Sunflower
18:0	Stearic acid	Animal fats, vegetable butter Sesame oil and Peanut oil
20:0	Arachidic acid	Peanut oil
	Monounsaturates	
14:1 n-5	Myristoleic	Whale blubber, shark liver, Eel, milk fats
16:1 n-7	Palmitoleic	Animal, Vegetable and Marine oils
18:1 n-7	Vaccenic	Butter and Animal fats
18:1 n-9	Oleic	Olive oil, Canola oil, lards Palm oil, tallow, sesame oil Sunflower and Soybean oil
	Omega-3 family	
18:3 n-3	Alpha-linolenic	Linseed, flax, canola and Soybean oils
20:5 n-3	Eicosapentaenoic	Fish oil, Animal phospholipids
20:5 n-3	Docosapentaenoic	Fish oil, Animal phospholipids
22:6n-3	Docosaheaxanoic acid	Fish oil and sea foods
	Omega-6 family	
18:2 n-6	Linoleic	Cottonseed, soybean, peanut, Corn, sunflower, sesame, Canola, walnut and pine oil
18:3 n-6	Gamma-linolenic acid	Primrose and Black currant
20:4 n-6	Arachidonic acid	Animal fats

Extracted from Pickard (2006)

2.5.2.4 Synthesis of Omega-3 fatty acids

The Omega-3 fatty acid α-linolenic acid (ALA) harbours three carbon-carbon double bonds. It has a site of unsaturation between the third and fourth carbons from the omega end of the fatty acid chain. EPA and DHA are the two types of omega-3 fatty acids that serve as important precursors for lipid-derived modulators of cell signalling, gene expression and inflammatory processes.

Desaturation and elongation are important processes which occur when precursors of omega -3 fatty acids have been ingested and these processes lead to the formation of DHA. There are always conflicts and competition for the elongation enzymes, especially when large amounts of omega-6 fatty acid sources are ingested, and therefore an increased intake of omega-6 fatty acid sources leads to reduced generation of long chain omega-3 fatty acids, hence the intake of ALA and LA should be balanced. One of the factors which has been considered as affecting elongation activity of omega-3 fatty acid is age. It was suggested that the ability of the Δ-6 desaturase enzyme to elongate fatty acids reduces with age in mammals (Yehuda et al., 2002). This means that increase in age will lead to increased requirement for inclusion of long chain PUFAs in diets. Although ALA can serve as the precursor for EPA and DHA synthesis in humans, this pathway is limited in its capacity and also varies between individuals. Therefore, direct dietary intake of omega-3 fats rich in EPA and DHA are of the most benefit.

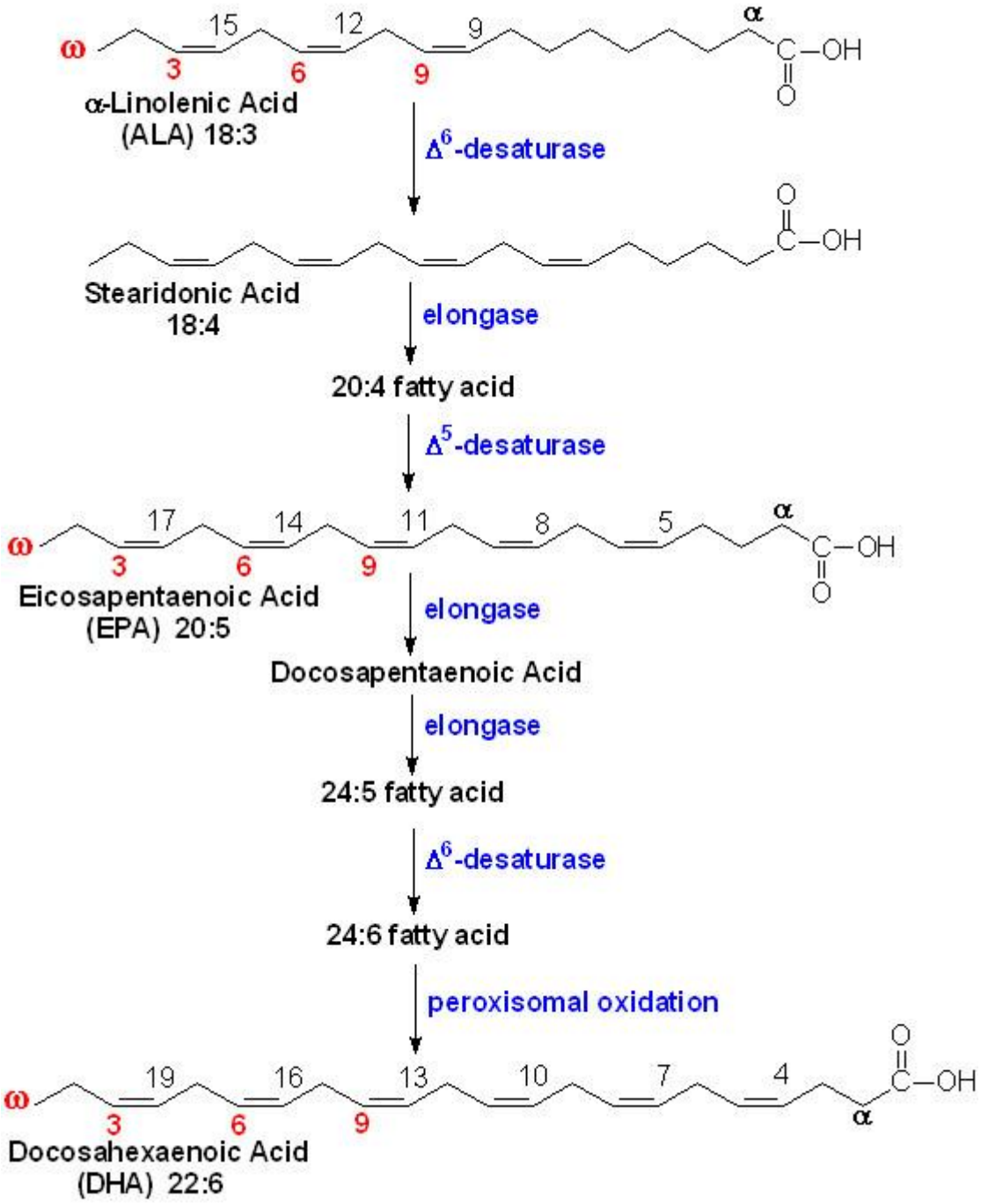

Figure 2.9. Pathway for ALA conversion to EPA and DHA (King, 1996)

2.5.2.5 Effects of omega 3 fatty acids

Omega-3 PUFA have been found to play a major role in human and animal health in relation to their anti-atherogenic, anti-thrombotic, anti-carcinogenic, and anti-inflammatory activities; they also contribute to improvements in cardiac and vascular functions, mental health and reproductive functions (Calder, 2001; Simopoulos, 2009). However, the health challenges faced by farm animals can be related to acute respiratory or gastrointestinal diseases rather than chronic problems. The inclusion of omega-3 fatty acid (PUFA) in the diets of livestock animals may be of immense benefit to the livestock industry in modulating mediators of humoral and cellular immunity (Rossi et al., 2010). Research has shown that diets rich in omega-3-fatty acids reduce platelet aggregation, blood triglyceride levels, the occurrence of blood clots and cholesterol (Nash et al. 1995; Leeson and Caston 1996; Simopoulos 1996). So also the porcine semen quality, fertility in sows, piglet survival, and fertility in dairy cows and development of neurones and vitality/vigour in neonates has been improved through the supplementation of long chain omega-3 fatty acid in the maternal diets of livestock (Matteo et al., 2006; Mattos et al., 2000; Innis, 2000; Rooke et al., 2001a; Webel et al., 2003).

The omega-3 fatty acids (DHA and EPA) have been shown to be important for normal brain development and function. Several studies have demonstrated that DHA is essential for proper development of the prenatal and postnatal central nervous system. Some investigations have studied the effect of supplementing maternal diets with long chain omega-3 fatty acid during gestation in pigs (Rooke et al., 1998; Rooke et al. 2001a; Rooke et al., 2001b; Spencer et al. 2004), ruminants (Dawson and Edgar, 2005; Capper et al. 2006), rats (Ikemoto et al., 2001) and humans (Muskiet, 2004).

The brain is lipid-rich in nature and the presence of myelin in the brain accounts for most of the lipid. However, brain grey matter is also rich in lipid (mostly glycerophospholipids) by comparison with other tissues. Fatty acids are known to be present in a considerable amount or concentration in the brain and nervous tissue (Capper, 2005). The inclusion of fatty acids in the maternal diet has been found to be important to the neural development of rats and monkeys (Neuringer et al. 1988; Levant et al. 2004).

The movement of fatty acids within animal tissues depends mainly on the blood, which serves as the transport mechanism within the body system. Fatty acids are transported in the plasma in chylomicrons. Increase in the rate of inclusion of unsaturated lipid in the

diet increases the flow of unsaturated fatty acids to the duodenum (Jenkins, 1993). Though increased inclusion rate of omega-3 fatty acid might lead to increased flow of these fatty acids to the duodenum, the uptake of these fatty acids from the duodenum might be limited due to micelle formation and lipase enzyme production (Bauchart, 1993). The activity of lipase is assumed to be at its best at a pH level of 7 while a drop in the pH level below 7 may result in incomplete digestion of fat, thus, micelle formation is hindered (Bauchart, 1993).

The assumption has always been that an increase in the level of supplementation of PUFAs in maternal diets will increase the fatty acid content in milk, especially the long chain fatty acids. It is well documented that feeding fish oil and marine algae during lactation increases omega-3 fatty acid concentrations in milk (Franklin et al., 1999; Kitessa et al., 2003; Papadopoulos et al., 2002; Capper et al., 2005). Formaldehyde-protected flaxseed and Linola, within acceptable levels of fat supplementation, provide sufficient by-pass fat to greatly increase the levels of C18:2 and C18:3 in the milk fat of dairy cows (Goodridge et al., 2001). However, it was reported that supplementing ruminant diets with a source of unsaturated lipid results in reduced milk fat percentage due to the inhibition of rumen microbial activity, causing a reduction in the amount of volatile fatty acids produced from the rumen.

Free fatty acids do not cross the placenta of pigs or sheep easily but they readily cross the placentas of rabbits, guinea pigs, rhesus monkey and humans. The transfer of omega-3 fatty acids, especially DHA, from the mother to the foetus through the placenta has been researched extensively. It has been emphasized that omega-3 fatty acids, especially DHA, can cross the placenta to reach the foetus in pigs (Rooke et al., 1999; Rooke et al., 2001c). These studies reported increase in the concentration of DHA in the foetal tissues due to inclusion of omega-3 fatty acid in maternal diets. Rooke et al (1999) reported a lower plasma concentration of DHA in piglets at birth (about 20 times lower) when compared with the sow plasma concentration, indicating that placental transfer is to a limited degree. This finding was also exhibited in sheep with the concentration of DHA found to be lower in the neonate than that observed in the dam (Pickard et al., 2006). There is a dearth of knowledge on the actual process involved in the placenta transfer of omega-3 fatty acid from sows to foetal piglets.

2.5.3 Docosahexaenoic acid (DHA)

Docosahexaenoic acid (DHA) is a type of omega-3 fatty acid with a 22 carbon chain and six double bonds. It is found in cold water fatty fish and fish oil supplements, along with eicosapentaenoic acid (EPA). Vegetarian sources of DHA come from algae. DHA is essential for the proper development and functioning of the brain (Holman et al., 1982; Innis, 2000) and for the development of the human nervous system and visual abilities during the first 6 months of life. Commonly available dietary sources of EPA and DHA include certain types of algae, fish oils and seafood.

The abundance of DHA in mammalian tissues depends on the adequate inclusion of the fatty acid in the maternal diet. The dietary supply and uptake into tissues determines the concentration of DHA in milk, blood and spermatozoa. The concentration of DHA has been extensively reported to be found mostly within the brain tissues (Innis, 2000; Crawford et al., 2001).

2.5.3.1 Advantages of supplementing DHA in maternal diets

The requirements for long chain omega-3 fatty acid have been reported to be high during fetal brain development (Sinclair and Crawford, 1972) around the last trimester of pregnancy (when the neural cells are formed) because it is found in high concentration in the gray matter of the brain (McNamara and Carlson, 2006). It is equally instrumental to the function of cell membranes of the brain which are important for transmission of brain signals. However, dietary alteration in fatty acid composition in maternal diets can result in omega-3 and omega-6 PUFAs competing for incorporation into cell membranes.

Including omega-3 fatty acid (fish oil) was reported to improve the development of the brain and immunity of neonatal piglets (Leskanich and Noble, 1999). Using salmon oil instead of tuna oil in the maternal diets resulted in a higher ratio of n-6 to n-3 acids and eicosapentaenoic acid (EPA) to docosahexaenoic acid (Rooke et al., 2001a; Rooke et al., 2001b). Ng and Innis (2003) demonstrated that piglets that had a low concentration of DHA in the frontal cortex performed less exploratory behaviour and were more fearful. Piglets spending more time closer to their mother's faeces may be interpreted as being more fearful while, conversely, a short latency in tonic immobility tests is generally considered to reflect lower fear levels.

The effects of DHA on the reproductive performance of livestock (especially pigs) have been the major focus in the past ten years. The supplementation of fish oil in pig diets was reported to improve reproductive performance of sows while supplementing fish oil to sows throughout pregnancy at a level of 1.75% improved piglet survival and the supplementation of a DHA source to the sow during pregnancy improved brain development of piglets (Rooke et al., 2001a). Piglets born and reared on sows fed 10g/kg of FA from a marine source from day 60 of gestation till 21 days of lactation have been reported to have a higher weight at weaning (Mateo, 2009). A decrease in piglet pre-weaning mortality was also reported when the sows' diet was supplemented with 16.5kg/t of salmon oil from mating till weaning (Rooke et al., 2001a). Previous studies have also shown that maternal fish oil supplementation enriched the omega-3 fatty acid content of sow milk (Fritsche et al., 1993).

Additionally, Papadopoulos et al. (2009) reported that dietary supplementation of fish oil from 8 days before farrowing ensures an improved sow feed intake and piglet growth during the first days postpartum. In contrast to the reports from all these initial study benefits of DHA, a recent study (Smits et al., 2011) suggested that there was no effect of including an omega-3 source in maternal diets of pigs (3g/kg of fish oil) from eight days before farrowing till weaning on piglet birth weight, pre-weaning growth rate, piglet weaning weight and sow feed intake. However, the supplementation of omega-3 PUFA in sows' diets had an influence on the number of piglet born in the subsequent litter (10.7 ± 0.3 vs 9.7 ± 0.3 total born; 10.2 ± 0.3 vs 9.3 ± 0.3 born live; $P < 0.05$) (Smits et al., 2011). This result was similar to the findings of Webel et al. (2004) who reported an increase in subsequent litter size by 0.8 pigs when sows were fed a protected omega-3 polyunsaturated fatty acid supplements from fish oil from 5 days before farrowing to 7days post weaning. It has been assumed that including omega-3 polyunsaturated fatty acid during gestation and lactation periods could improve oocyte quality, consequently conception rate, embryo survival and litter size (Smits et al., 2011). This inclusion has been suggested to be more important to sows of older parities than gilts (Estienne et al., 2006, Foxcroft et al., 2006). Older parities have been reported to have a lower embryo survival than gilts and parity 1 sows and this further suggests that the performance of piglets fed omega-3 polyunsaturated fatty acid supplemented diets may therefore be dependent on the age of sow, with a greater response in older sows, (Perez-Rigau, 1995).

Interestingly, increased survival of piglets brought about by the inclusion of fish oil in the maternal diet was earlier associated with increased length of gestation, resulting in greater maturity of piglets at birth (Cordoba et al., 2000) whereas the supplementation of salmon oil in maternal diets was found to have resulted to increased gestation period but decreased birth weight when compared with control groups (Rooke et al., 2001a). Cools et al. (2010), however, reported that supplementation of 1% fish oil in maternal diets from 110 days of gestation to 2days after farrowing had no influence on gestation and number of still born piglets.

The effect of supplementing the maternal diet with omega-3 fatty acid and the resulting effect it has on foetal composition was further elaborated by Brazle et al. (2009), who fed sows omega-3 fatty acids (Protected fatty acid) beginning at 30 days before breeding. Their results showed that the inclusion of this supplement in the sows' diet increased the endometrial, conceptus, and foetal fatty acid composition in early pregnancy.

However, it has been reported that supplementation of omega-3 fatty acid (fish oil) has led to reduced growth of the foetus (Rooke et al., 2001c). The reason for this contrasting result was explained by Raz et al. (1997), when he suggested that the feeding of fish oil might be associated with oxidative stress which negatively affects growth in pigs. The value of omega-3 fatty acids supplemented in fish oil form can be deleterious if adequate care is not taken in the handling, preparation and storage of feeds. Increasing the intake of PUFA results in the stimulation and oxidation of precarcinogens to reactive intermediates by affecting the configuration and induction of membrane-bound enzymes (e.g oxidase and epoxide hydratase).

Despite the important benefits derived from including omega 3 fatty acid in pig diets which have been demonstrated by research over the years (though the findings are not consistent), it is surprising that there exist no standard recommendation in terms of nutritional requirements for pigs for eicosapentanoic acid (20:5 n-3) and docosahexaenoic acid (22:6 n-3) inclusion levels (NRC, 1998; Whittemore et al., 2003). In addition, the costs of purchasing omega-3 polyunsaturated fatty acid supplements are high, and hence pig producers were advised to be cautious before including it diets, especially on a commercial scale, because of the dearth of knowledge that still exists with the few experiments conducted in few production systems (Reese, 2004).

2.6 Conclusion

In spite of the technological changes and improvements in husbandry, housing designs and preventive measures, piglet mortality remains a major economic and welfare problem. There have been welfare concerns about the use of farrowing crates preventing the sows from exhibiting certain behavioural traits like rooting and gathering of straw (nest building) and moving from one posture to another in a way which shows the mothering ability of sows to take care of the newborn piglets. The curtailing of these behaviours in sows housed in crates has been condemned; hence there is a need to look for alternative systems for farrowing sows.

The farrowing crate was introduced to reduce pre-weaning piglet mortality. This informed the construction of numerous alternative farrowing systems being developed, with different designs which are geared towards reducing pre-weaning mortality. The abolition of the gestation stall in 2013 has put more pressure on the quest to find suitable alternative farrowing accommodation which will reduce sow restraint without increasing pre-weaning piglet mortality.

Nutritional strategies to reduce piglet mortality are another option, as suggested by Edwards (2002). The findings in humans that omega-3 fatty acids are responsible for neural development and good blood flow during pregnancy, stimulated studies in pigs. The summary of the results (though not always consistent) showed that the inclusion of fish oils prolonged gestation and enhanced survival, though birth weight might be reduced. This effect on birth weight has been linked to the content of EPA in fish oil. Sources of omega-3 fatty acid which will bring about increased DHA relative to EPA should therefore be investigated.

The challenge of finding an alternative farrowing system which gives pregnant/farrowing sows' ample freedom to move around and perform certain behaviours in a similar way to their counterparts in the wild have brought about the need to improve the vitality of piglets to enhance piglet survival. This generated the aim of this project: to find ways of enhancing piglet survival through improving piglet vitality in different housing systems.

CHAPTER 3

Effect of alternative free farrowing pen designs on sow behaviour and piglet survival

3.0 Abstract

Crushing has been reported to account for a large percentage of live born mortality in litters during the first few days, and especially in loose farrowing pens. The effect of the pen size in a novel free farrowing pen, designed as an alternative to the farrowing crate which allows the sows to exhibit behaviours considered to be helpful during parturition, on survival of piglets during farrowing and the first three days of life was investigated in this experiment using a small space pen (SSP: 7.9m^2) and a large space pen (LSP: 9.7m^2). The effect of the pen size (space) on the farrowing duration, sow position during farrowing, posture changes during farrowing, frequency of pen features used, locations of birth in the two pens and posture changes that lead to crushing of piglets was examined. Analysis of variance using a general linear model was used in analysing production data, while behavioural records, location of birth and crushing were analysed using Chi square tests. 69 sows were observed in total, with 37 sows housed in SSP and 32 sows housed in LSP. Comparing the SSP sows to the LSP sows, there were no effects of treatment on the number of piglets born alive, farrowing duration and live born mortality. Though there was no significant effect of pen size on the location where the first piglet was born, the total number piglets born at different locations and from different sow postures was significantly influenced by the size of the pen. The sows in LSP crushed significantly (P=0.02) more piglets than sows in SSP while transiting from a sit to lie position and rolling from side to side. More piglets were crushed while the sows made the stand to lie transition in the SSP than in the LSP, suggesting that the risky crushing behaviours differed with space allowance.

3.1 Introduction

Piglet mortality is a welfare problem with great economic importance. In pig production, it is essential for piglet mortality to be reduced to the minimum achievable in order to get an increased number of weaned piglets and eventually an increased number of finished pigs. This has been a major challenge, as pig farms have struggled hard to keep their pre-weaning mortality rates below 10% of live born piglets. Reported estimates of pre-weaning mortalities have ranged between 10-20% (Leenhouwers et al., 2002; Marchant, 2000; Cronin and Smith, 1992) even though intensive rearing of pigs has been implemented as the most viable means of producing more pigs and guarding against piglet mortality for many years.

Two of the major factors that farmers consider in animal production are feed and housing. In a bid to best manage the production of pigs on a large scale, the intensive indoor confinement of pigs was embraced, with use of the farrowing crate for parturition and lactation. The use of the farrowing crate is still the most common practice in the pig industry, since it is difficult to convince large scale pig producers that any alternative system of farrowing is better when considering the mortality rates. The neonates, when expelled, show a strong instinct to be near their mother to get some warmth and quickly take in some colostrum, so as to have more energy and vigour to survive the extra-uterine environment in which they find themselves. The closeness of these piglets to the sow at the time of farrowing and during the first 1-2 days after parturition predisposes them to being crushed.

Reducing the pen space for sows, especially around parturition, was the recommendation given in the early 1960s' to 1970s' which brought about the use of farrowing crates to reduce piglet mortality, especially within the first few days of life. Although this innovation was widely utilized, and initially was associated with improved pre-weaning survival, it has subsequently been found that the number of piglets that died before weaning between 1991 to 2000 remained at a high stable rate (Shankar, 2009), although total litter size at birth and weaning has increased progressively over this period. The growing concern about animal welfare amidst members of the public may lead in the future to the abolition of the farrowing crate. Though this system of confinement reduces piglet crushing, it has been unable to meet all the behavioural needs of the sows (Hötzel et al., 2004; Arey et al., 1992), thus posing a threat to the welfare of parturient and lactating sows. The sows' movements are restricted and they are unable to nest build

immediately prior to farrowing or to show the interactions with their piglets that they would normally exhibit when free.

The lack of further recent improvement in piglet survival, coupled with the growing concern about sows' welfare, highlighted the need for further research into the best alternative farrowing system which could be adopted. In recent years, there has been an increasing interest in the use of alternative non-crate systems which allow the sows free movement and maternal behavioural expression. The use of many loose farrowing systems has been explored, with some studies concluding that, with good management, alternative systems can prevent an increased rate of piglet deaths (Andersen et al., 2005; Grandinson et al., 2003). Results from these earlier studies may help in further developing and enhancing the success of alternative housing systems.

Despite the restriction of maternal behavioural expression which is associated with the crate system, piglet survival is still a major issue in both crate and alternative farrowing systems. Most deaths are attributed to crushing and occur during the first three days after birth (Jarvis et al., 2006; Pedersen et al., 2006; Edwards, 2002). It has been reported that farrowing sows which show poor maternal behaviour and normally spend appreciable amount of time sitting with no support crush more piglets in the postnatal period (Valros et al., 2003). The rolling movements of sows, coupled with the changes in position from sitting to lying in a loose farrowing system, have been identified as the major cause of piglet mortality (Damm et al., 2005; Vieuille et al., 2003; Weary et al., 1998; Weary et al., 1996), even though it was reported that loose housing systems provide space for pre-lying behaviour and a controlled lying down sequence, which is instrumental to prevent piglet mortality (Damm et al., 2005). Just as these above mentioned posture changes have been causes of piglet death in alternative systems, so it is also the case in the crate system (Weary et al., 1996).

The exact amount of pen space which will give an optimum welfare of sows and enhanced piglet survival is still the subject of on-going research with existing pen designs and fabrication of new ones. Variations in piglet losses due to crushing in the alternative farrowing systems need to be fully explored and the performance of pigs kept in these alternative systems needs to be monitored over time to be able to ascertain how the farrowing pens or systems influence piglet survival. In order to explain any difference in performance between different pen designs, study of the behaviour of the sows and the

way in which they use the pen space provided is necessary. The hypothesis of this study is that the large spaced pens will aid the sows to show more maternal behaviour during farrowing, thus reducing piglet pre-weaning mortality when compared with the small spaced pen. This study aims to investigate the effect of space on piglet survival (peri-partum and post-partum) in two different versions of a recent alternative farrowing pen design, the PigSAFE system (Edwards and Baxter 2010).

3.2 Methodology

3.2.1 Animals and pen designs

69 crossbred farrowing sows (Landrace x Large White) were observed in this experiment. The sows' mean parity was 2.35 (sem 0.18). These sows were housed at the research farm of the Scottish Agricultural College (SAC), Edinburgh, Scotland. The sows were housed 5 days before farrowing into two different versions of a prototype alternative farrowing pen, the PigSAFE design, in which the sows had the opportunity of performing nesting behaviours, moving and turning around. The two pen variants had the same general layout, but different dimensions: small space pens (SSP) of 7.9 m2 and large space pens (LSP) of 9.7 m^2.

Figure 3.1 shows the layout and dimensions for the large space pen, with the corresponding dimensions for the small space pen given below; the pen design is the same but is on a smaller footprint. The pens were located together in a block of 12 pens, 6 of each size, in a single, temperature-controlled room with an average temperature of 21^{o}C during farrowing. The piglet creep area in each pen was covered and lit, with underfloor heating set to a temperature of 30^{o}C. It was also bedded with sawdust.

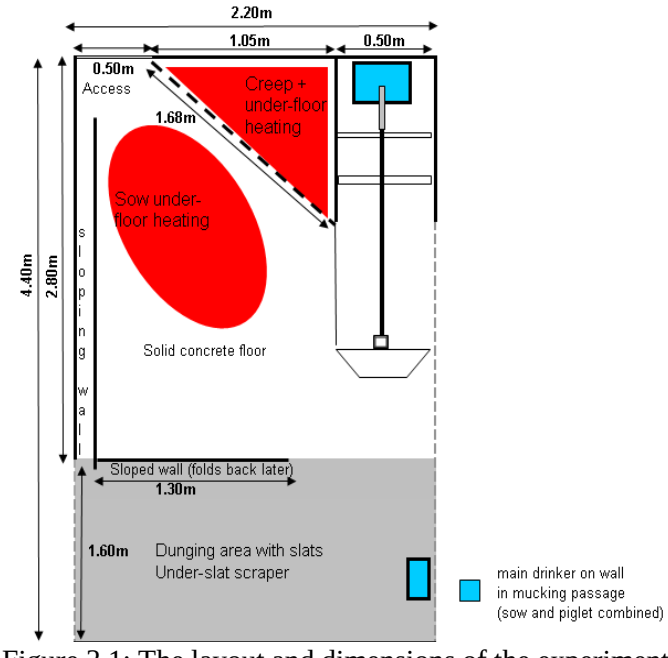

Figure 3.1: The layout and dimensions of the experimental pens. Edwards and Baxter 2010

DIMENSIONS:

Large space pen = Total space is 9.68m^2 (2.2m wide x 4.4m long)

Nest area = 4.34m^2 (2.80 x 1.55m)

Dunging passage = 2.2m wide x 1.6m deep

Feeder area = 0.50m wide x 1.00m high

Sloped dividing wall between dunging and nest area = 1.3m long

Creep area = 0.75m^2

Small space pen = Total space is 7.9m^2 (2.2 x 3.6m)

Nest area = 3.72m^2 (2.40 x 1.55m)

Dunging passage = 2.2m wide x 1.2m deep

Feeder area = 0.50m wide x 1.00m high

Sloped dividing wall between dunging and nest area = 0.90m long

Creep area = 0.75m^2

3.2.2 General management

Feed was provided twice a day while water was given *ad libitum* from a drinker located in the dunging area. Before farrowing the sows were fed 3kg/day of a commercial lactation diet and the ration increased according to litter size after farrowing.

The pens were given 2kg of fresh long straw at sow entry and this amount was maintained by replenishment as necessary when pens were cleaned out for the first seven days. After 7days the sow was maintained with 1kg straw which was replenished when needed throughout the experimental period.

3.2.3 Behavioural recording and data collection

38 sows were observed in the small space pens (SSP) while 31 sows were observed in the large space pens (LSP). Sows and piglets were filmed continuously using time lapse video equipment from one day before farrowing till 48hrs after farrowing. The cameras were positioned strategically to capture the sows from the front and the rear so that whatever was happening inside the pen and the dunging area could be seen clearly. One sow per replicate was recorded by the front cameras while the rear cameras viewed two sows concurrently. Night time video recordings were aided by illumination from an overhead light source. Behavioural activities during parturition and the post-partum period (48hrs after farrowing) were recorded.

3.2.3.1 Duration of farrowing

With the aid of the cameras, the duration of farrowing for each sow was determined starting from the birth of the first piglet (BFP) to the expulsion of the last piglet. The expulsion of the placenta confirms the birth of the last piglet (BLP) after which the total time taken was calculated. For each individual piglet, the Birth Interval (BI) and Cumulative Farrowing Duration (CFD) were calculated:

Time of BFP- Time of BLP = Duration of farrowing (minutes)

Total duration / Total number of piglets born = Birth Interval (minutes)

The accumulated total time taken for each piglet to be expelled since the birth of the first piglet = Cumulative Farrowing Duration.

3.2.3.2 Farrowing Location

The farrowing location for the first piglet and for each subsequent one was recorded .The farrowing locations were coded according to the following criteria (see Fig 3.2);

1- Rear end of sow at the access door, near the creep, and the head of the sow nearest the nest entrance
2- Rear end of sow further into the nest area between access door and creep protruding bar but head still towards nest entrance.
3- Rear end of sow at dividing sloped wall and head at access door.
4- Rear end of sow in corner where small sloped wall and large/long sloped wall meet, sow lying along small sloped wall with head in dunging passage/feeder area.
5- Rear end of sow at opening into dunging passage, head at access door.
6- Rear end at the nest opening/feeder; head at meeting point between small sloped wall and long sloped wall.
7- Sows farrows anywhere in the dunging area.

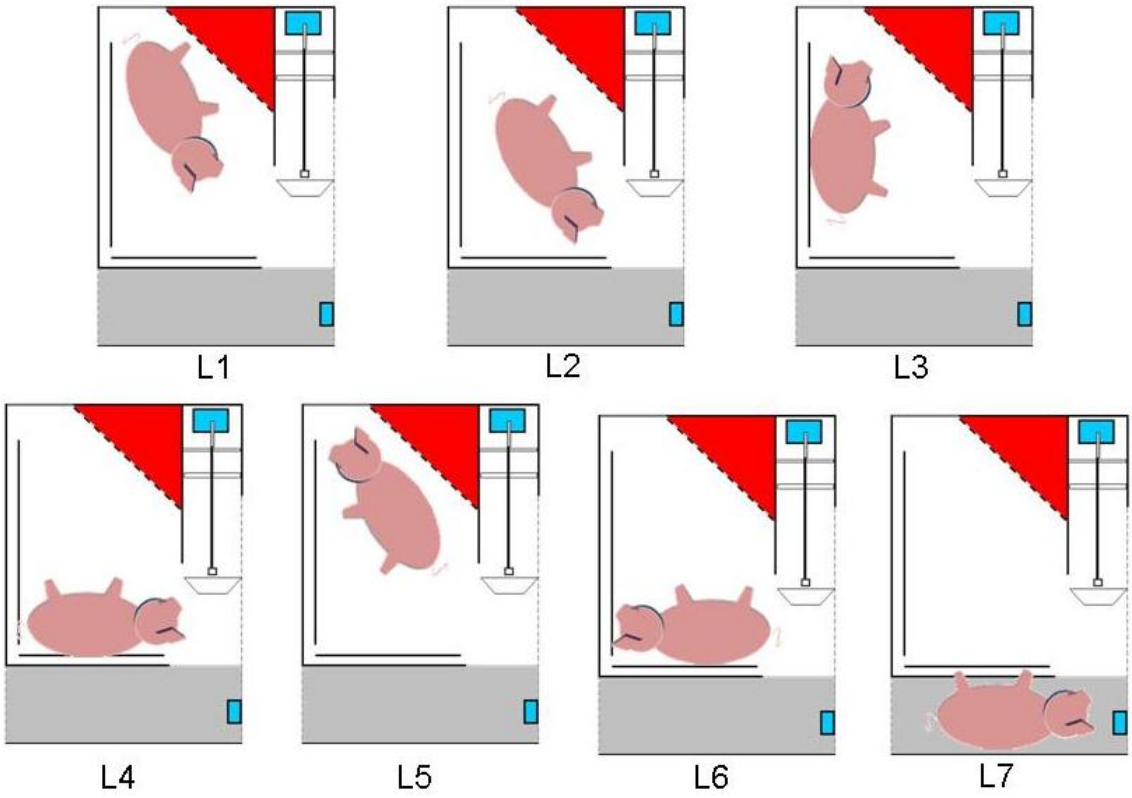

Figure 3.2: Locations where piglets were born and associated sow orientation

3.2.3.3 Changes in Posture

The posture of the sow at the birth of each piglet and the frequency of changes in posture made were recorded. The postures attained by lactating sows were classified as follows:

1. Lateral lying: Lying with the udder exposed and one shoulder completely on the ground. This farrowing position is further divided into two;
   a) Lateral lying on left side (LL) and b) Lateral lying on right side (LR)
2. Ventral lying: Lying with the entire udder completely hidden and inaccessible to the piglets.
3. Sitting
4. Standing

Movements between these postures were recorded. These included Rolling: Movement of sow from one lateral lying position to another (Right to Left and vice versa). It also included movement from lateral positions to ventral position.

3.2.3.4 Use of Support

The use of supporting materials (present in the farrowing pen) by the sows during farrowing was also taken into consideration. These were defined as the pen feature with which the back of the sow was in contact. The support materials were coded as follows;

SW- Sloped walls- This consist of the small and large sloped boards.

CB - Creep bar – the bars protruding from the front of the creep area

CW- Creep wall- These are the railings which demarcate the creep area from the nest.

OTHER- No support

3.2.4. Data on Death and Injury

With the aid of the videos, data were recorded as regards the death or non-fatal crushing of piglets, taking into cognisance the activities of the sow that led to their mortality. The time of injury, location where the injurious activity took place, the type of injurious behaviours, and the support structure which aided the aforementioned behaviours were recorded The behaviours of the sow which lead to crushing of the piglets were categorised as described in Table 3.1.

Table 3.1: Protocol for recording Sow crushing behaviours

Sow crushing behaviours	Code	Description
Kicking and Stepping	A	Sow put prolonged pressure on the piglet by stepping or kicking the piglet while walking.
Sit to lie	B	Sow puts prolonged pressure on the piglet when moving from a sitting posture to lying down. Piglets are often trapped underneath the sow's sternum
Stand to lie	C	Sow puts prolonged pressure when moving from a standing posture to lying down. Sow may kneel before dropping her flank either to the side into a lateral lying posture or straight down into ventral posture.
Rolling	D	Sow puts prolonged pressure on the piglet while rolling from a ventral lying posture to a lateral lying posture or sow is already lying laterally but stretches to fully expose her udder and traps a piglet.
Stand to sit	E	Sow puts prolonged pressure by moving from a standing to a sitting posture by lowering rear directly down without kneeling.
Clamp	F	Sow puts prolonged pressure on a piglet by trapping it with her leg when lying in a fully lateral position.
Bite	G	Sow uses its mouth to bite a piglet.
Others	H	This refers to other behaviours that are injurious to the piglets which are not categorized in the above classifications.

The location of injury or death was recorded according to the categories shown in Table 3.2 and Figure 3.3.

Table 3.2: Protocol for recording location where death occurs

Code	Location of injury or death
1	Open nest space
2	Area beside the creep bar
3	Space between the pen nest and feeder area
4	Corner between access door wall and sloped wall
5	Area beside the dividing wall between pens
6	Dunging area
7	Beside the sloped walls

Figure 3.3: Location where death occurs

The response of the sow when a crushing occurred was coded as shown in Table 3.3. The nature of any support used in changing posture was also recorded.

Table 3.3: Protocol for recording response to crushing and support used by sows when lying

Sow behaviour	Code	Description
Response to crush	R	Crushes piglet and responds to crush within two seconds of the crush by changing her posture.
No response to crush	N	Crushes piglet and does not respond within two seconds.
Support	**Code**	**Description**
Supported lie	S	Sow uses sloped walls (SW), creep bar (CB), creep wall (CW) or no support (n).

3.2.5 Statistical methods

The total litter size, number of piglet born alive, birth intervals, cumulative farrowing duration, still birth mortality, liveborn mortality and frequency of different posture changes made during farrowing (posture changes per minute per sow) were compared between the two treatment groups (SSP and LSP) using analysis of variance (General Linear Model (GLM) in Minitab version 15). Total changes in posture made by the sows during farrowing and locations where the piglets were overlaid was analysed using Chi square tests. Different positions attained by the sow during farrowing, locations where the first piglet and subsequent piglets were born, number of sows that crushed piglets and number of piglets that were crushed at different times, including the various sow movements that led to the crushing, were analysed using Chi square tests.

3.6 Results

Mean values of total litter size, piglets born alive, birth interval, cumulative farrowing duration, still birth and mortality in each treatment are presented in table 3.4. Results from this table revealed that none of the above listed parameters were significantly (P>0.05) influenced by the difference in the two alternative farrowing pens (Table 3.4).

Table 3.4: Piglet production and mortality data for litters

Parameters / Treatments	Litter Size (n)	Born Alive (n)	BI (minutes)	CFD (minutes)	Still Birth (n)	Mortality (n†)
SSP	12.66	11.09	21.18	277.53	1.57	2.93
LSP	12.58	11.29	22.91	293.02	1.29	3.85
SEM	0.74	0.73	2.50	31.50	0.22	0.75
P value	0.98	0.71	0.54	0.41	0.26	0.19

n† - The values presented in the mortality column are average numbers of dead piglets per litter excluding still birth.

The total numbers of piglets born in different sow postures at the time of parturition are presented in table 3.5. The result showed that there was a significant difference between pen sizes (P<0.05) in the side on which the sows lay during farrowing even though, they still assumed the lateral lying position.

Table 3.5: Number of piglets born in different Sow postures at farrowing

Parameters	SSP	LSP	P value (test)
[a]BP/LL	195 (42.4%)	241 (63.9%)	$\chi^2 = 34.81$
[b]BP/LR	264 (57.4%)	132 (35.0%)	P< 0.001
[c]BP/VP	1 (0.2%)	3 (0.8%)	

The values presented are actual numbers of piglets (percentage of total piglets born in each posture)

a- Actual number of piglets born in Lateral Left birth position

b- Actual number of piglets born in Lateral Right birth position

c- Actual number of piglets born in Ventral birth position

Since the pens were built in pairs, with alternating feeder and nest orientation, this might affect the lying orientation of the sow. The orientation of the pen (pen arrangement), with the number of sows housed and number of piglets born in the similar pen arrangement for each treatment, is presented in table 3.6. The result showed that there was no significant effect of the pen orientation on the side on which the sows tend to lie while giving birth within each pen treatment.

Table 3.6: The pen orientations/ arrangement within treatment, showing the number of sows housed, the total number of piglets born and the farrowing posture

	Small Space Pen		**P value**	**Large Space Pen**		**P value**
	CFL	**CFR**	**(test)**	**CFL**	**CFR**	**(test)**
Number of Sow	19	18		19	14	
Number of piglets born	267 (57.5%)	197 (42.5%)		230 (59.6%)	156 (40.4%)	
VP	1 (0.4%)	0 (0%)	NS $\chi^2 = 1.79$ P= 0.25	0 (0%)	3 (1.9%)	$\chi^2 = 4.69$ P= 0.10
LL	121 (45.3%)	78 (39.6%)		147 (63.9%)	94 (60.3%)	
LR	145 (54.3%)	119 (60.4%)		83 (36.1%)	59 (37.8%)	

CFL: Creep facing left; CFR: creep facing right, VP- Ventral position, LR-Lateral right position, LL-Lateral left position.
The actual numbers of piglets given birth to is presented (percentages).

The number of piglets expelled while the sow was using different pen support features in the two types of pens is presented in table 3.7. The results indicated that the pen space did have an influence ($P<0.05$) on the support used during farrowing. The sows preferred leaning against the sloped walls (SW) and creep bars (CB) while farrowing. Sows in the smaller space pens made use of the creep bars and creep walls more than the sows in the large spaced pens while giving birth.

Table 3.7: Number of piglets born using different support features

Parameters	SSP	LSP	P value (test)
[a]SW	195 (42.0%)	229 (59.9%)	$\chi^2 = 38.06$
[b]CB	146 (31.5%)	104 (23.2%)	P <0.001
[c]CW	98 (21.1%)	32 (8.5%)	
[d]Others	21 (4.6%)	11 (2.9%)	

[a-d]- The values are actual numbers of piglets born using different options (percentage of total piglet born using each support feature)

a- Actual number of piglets born using Sloped walls

b- Actual number of piglets born using Creep bars

c- Actual number of piglets born using Creep walls

d- Actual number of piglets born using other supports other than those mentioned above/ no support at all

The number of sows farrowing at different locations at the birth of first piglet (BFP) is compared in table 3.8. The area where the access door is situated (L1) was preferred by 60.9% of sows (SSP and LSP) during parturition. In summary, locations 1 to 3 were used more often by the sows in the two treatments though there was no significant difference (P>0.05) between the two treatments.

Table 3.8: Different pen locations of the birth of the first piglet

Parameters/Treatment	SSP	LSP	P.Value (test)
L1	27(72.9%)	16(50.0%)	$\chi^2 = 6.49$
L2	4 (10.8%)	8(25.0%)	P= 0.090
L3	2 (5.4%)	6(18.8%)	
L4-7	4 (10.8%)	2(6.3%)	

SSP- Small space pen; LSP -Large space pen

L1-L7- Location of birth of first piglet (see figure 3.2).

Table 3.9 presents the total number of piglets born in each location. Overall, most piglets were born in locations L1 and L2, and very few in L6 and L7. The result showed that there was a significant increase (P<0.05) in the percentage of piglets born near the access door and creep (L1) within the SSP. More piglets were born at location 1 and 5 in SSP than LSP, which had a higher proportion of piglets born in L4 at the junction of the sloping walls. This indicates that sows in LSP were more often lying crosswise in the pen along the longer dividing wall.

Table 3.9: The percentage and number of piglets born at different locations

Parameters/Treatment	SSP	LSP	P.Value (test)
L1	[a]226 (49.2%)	154(40.96%)	$\chi^2 = 62.16$
L2	83 (17.7%)	92 (24.3%)	P< 0.001
L3	42 (9.4%)	65 (16.6%)	
L4	13 (2.8%)	30 (6.4%)	
L5	81 (17.6%)	19 (5.0%)	
L6	11 (2.3%)	16 (4.2%)	
L7	4 (0.9%)	0(0%)	

[a] The values are actual total number of piglets born at different locations (percentage of total piglet born at different locations)
SSP- Small space pen; LSP -Large space pen
L1-L7 (see figure 3.2)

The number of sows (out of the total number of sows housed in each treatment) that farrowed at least one piglet in a location and using at least one pen feature is presented in table 3.10. There was no significant difference (P>0.05) between the sows housed in the small space pens and the large space pens. The preference for the sloped walls was highest, followed by the creep bars, creep walls and other features not designed for the sow to lean against during farrowing.

Table 3.10: Total number of sows farrowing at least one piglet in different locations and using different pen features and birth positions

Parameters/Treatment	SSP (n/37)	LSP (n/32)	P.Value (test)
VP	1 (0.03%)	2 (5.4%)	$\chi^2 = 0.56$
LR	34(91.8%)	28 (87.5%)	P= 0.76
LL	33(81.9%)	30(96.8%)	
Pen Features			
SW	32(86.4%)	31(96.8%)	$\chi^2 = 2.36$
CB	21(56.7%)	18(56.3%)	P= 0.50
CW	15(40.5%)	7 (21.9%)	
OTHERS	10(27.0%)	6 (18.8%)	

n- actual number of sows out of the total sows housed per each treatment (percentages)

VP- Ventral position, LR-Lateral right position, LL-Lateral left position.

The total number of different posture changes during farrowing, and the frequency of posture changes per minute, and the support used by the sows during posture change are presented in table 3.11. The result showed that there was no significant difference in how active the sows were in the two pens, expressed as number of posture changes during farrowing. The major changes include stand-ventral, stand-sit, stand to lie and sit to lie, while minor changes comprise of lie-ventral, ventral-lie and lateral-lateral positions (Rolling). The support used by the sows while changing postures during farrowing was influenced significantly ($P<0.05$) by pen size, with sows in SSP more often supported by the creep while sows in LSP more often changed posture without support.

Table 3.11: The number of posture changes during farrowing, the support used when changing posture, and the frequency of different posture change per minute of sows in farrowing pens of small (SSP) or large (LSP) size

Parameters/Treatment	SSP	LSP	P.Value (test)
Total changes/sow	9.54	8.81	
Major changes/sow	4.65(48.7%)	4.34(49.3%)	
Minor changes/sow	4.89(51.3%)	4.47(50.7%)	
Pen feature used as support			
SW	[c]88	85	$\chi^2 = 18.12$
CB	59	42	P< 0.001
CW	57	30	
Others	24	48	
Posture changes per minute/sow	**SSP**	**LSP**	**SEM**	**P.Value**
Stand- Lateral Lie	0.0110	0.0084	0.0061	0.271
Sit-Lateral Lie	0.0055	0.0070	0.0013	0.616
Stand-Sit	0.0008	0.0001	0.0002	0.099
Stand- Ventral Lie	0.0096	0.0032	0.0017	0.638
Lateral- Ventral Lie	0.0090	0.0114	0.0017	0.590
Ventral- Lateral lie	0.0140	0.0110	0.0030	0.482
Lateral- Lateral lie	0.0062	0.0009	0.0012	0.189

c- Actual value (frequency)

The total number of sows that crushed any of their piglets and the number of piglets crushed during different time periods after farrowing are presented in table 3.12. There was no significant difference (P>0.05) in the number of sows that crushed at different times within the first 3days between the treatments.

Table 3.12: Total number of sows that did not crush or crushed at least one piglet during different time periods in a small (SSP) and large (LSP) space pen

Death Time	*DNC*	*<24hrs*	*>24hrs*	*P value(test)*
SSP	20	9	8	
LSP	17	10	5	$\chi^2 = 0.63$
				P= 0.73

DNC- Number of sows that did not crush

Table 3.13 presents how early piglets were crushed from birth of the first piglet to 2days after birth. No significant difference was observed when comparing the number of deaths recorded in the two treatments. The support features used by the sow during posture changes causing crushing did differ significantly (P<0.05) between the two treatments, with sows in the LSP more often crushing piglets when changing posture without support.

Table 3.13: The number of piglets crushed during different time periods and the support used by the sow when crushing occurs in small (SSP) and large (LSP) space pen

Parameters/Treatment Time	**SSP**	**LSP**	**P.Value (test)**
Day 1	25 (50%)	20 (35%)	$\chi^2 = 2.43$
Day 2	25 (50%)	37 (65%)	P= 0.119
Support			
CW	7 (14%)	6 (10%)	$\chi^2 = 15.13$
SW	26 (52%)	15 (26%)	P= 0.002
CB	13 (26%)	14 (25%)	
OTHERS	4 (8%)	22 (39%)	

CW-Creep wall, SW-Sloped walls, CB- Creep bars, others-no support features

The movements of sows that lead to crushing and the number of piglets crushed as a result of each type of posture change are shown in table 3.14. Sows in LSP crushed significantly more piglets while walking, rolling from one side to another and while

changing from sitting to lie (P<0.05) than sows housed in SSP. More piglets were crushed in SSP while the sows were lying down from a standing position.

Table 3.14: Movements leading to crushing and number of piglets crushed

Postures/Treatment	SSP	LSP	P value (test)
Stand to Walk	2(4%)	7 (12%)	
Sit to lie	6 (12%)	14 (28%)	$\chi^2 = 15.13$
Stand to lie	29 (58%)	15 (26%)	P= 0.002
Different rolling movements	7 (14%)	20 (35%)	
Stand to sit, Clamping, Lying to sit	6(12%)	1 (1%)	

Results of the locations where crushing occurred are presented in table 3.15. The sows crushed more piglets beside the creep bars and in the open nest space than all other locations. Very few piglets were crushed by the sloped walls. There was no significant effect of the pen size on the location where piglets were crushed

Table 3.15: Location where crushing occurs

Location/Treatment	SSP	LSP	P value (test)
Open nest space	20 (40%)	13 (22.8%)	
Beside Creep bars	23 (46%)	35 (61.4%)	$\chi^2 = 3.78$
Beside sloped walls	3(6%)	4 (7%)	P= 0.286
***Other places**	4(8%)	5 (8.8%)	

*Between access door and sloped walls, between access door and sloped walls and beside dividing pen walls

3.7 Discussion

This study aimed to investigate the influence of farrowing pen size (LSP and SSP) on piglet survival and to understand how sows used the available space in ways which might increase mortality risk. This study is a subset of a larger production experiment to test a pen design aimed at enhancing the survival of piglets and improving the welfare of sows. The sows in both pen sizes showed a preference in farrowing at locations 1 and 2, facing the nest entrance. The reason for the preference could be due to natural instinct of the sows housed in the two pens to face the place where potential danger would be expected to come from. The pens were designed for the sows to give birth close to the creep to reduce piglet mortality and this feat was achieved in this experiment. It could also be argued that the sows preferred locations 1 and 2 more because of the pen features present (sloped walls and bars) around the area which support their lying down gently without having to flop down. In addition, the location looks narrow and this forces the sows to lie down slowly before turning to a lateral position. This supports the suggestion of Pedersen et al. (2011) who suggested that pen designs should be made narrow for ease of farrowing. The frequent use of this location during farrowing can be seen in the number of piglets given birth to in the two locations though there are tendencies for sows housed in the large space pens to farrow more often away from the creep, where piglets are at greater risk of chilling.

The birth interval values recorded for this experiment showed no significant difference from the 16-27mins reported in other recent studies (Oliviero et al., 2010; Pedersen and Jensen, 2008), and total farrowing duration was similar to the range of 197 to 262min for sows housed in pens (Gu et al., 2011; Oliviero et al., 2010; van Dijk et al., 2005). The duration of farrowing in the two pens showed no significant difference, hence it is possible to conclude that the nest space designed for farrowing was adequate. The average number of stillbirths in the two pens in the current study was similar.

This study did not show a significant difference between the two pens in the number of liveborn piglets which subsequently died, although numerically, the LSP sows recorded a higher preweaning mortality and a higher number of crushed piglets. This pattern was replicated in the full production experiment, in which space significantly influenced live-born mortality, with more piglets dying when sows were afforded the larger farrowing space (LSP=20.6% vs. SSP=14.3%, P=0.041) (Baxter et al., 2011). The high mortality of liveborn piglets can be attributed to the freedom given to the sows to move around in a

more spacious environment which predisposes the piglets to being crushed (Baxter et al., 2011). Crushing in this study accounted for 56.6% of the total deaths recorded for the first three days of birth, which is similar to reports from previous studies stating that crushing is a major factor causing the death of piglets in the first two to three days of life (Weber et al., 2009; Marchant, 2001; Marchant, 2000; Spinka et al., 2000; Wechsler and Hegglin, 1997).

Due to the larger space which the LSP sows enjoy, the numbers of crushed piglets were higher than in SSP. This is similar to findings reported by Marchant et al. (2000) when comparing crushings in conventional farrowing crates and free crate systems. It was further observed in the current study that a higher number of piglets die as result of the sows stepping on them while walking around, attaining a lying position from standing and lying from a sitting position. This corroborates findings that the behaviour of the sow is key to crushing of piglets in farrowing pens. The SSP sows were confined in a more closed environment, almost synonymous to a crate, making it difficult for sows to roll from one side to the other (Marchant, 1996). This reduces the number of piglets crushed, even though the sows stand to lie many times since that is the only movement they can easily perform (Marchant, 2001).The increase in the number of times the sows lie down without support in the middle of the pen, the more dangerous and fatal it is for the piglets (Marchant, 2001). The large spaced pens might have furnished the sows too much space, allowing more rolling and flopping down of sows in the open space region which posed more threats to the piglets, movements which eventually lead to crushing of piglets (Baxter et al., 2011).

It was observed that most of the crushings in this study took place in the open nest space which is surrounded by the creep bars and the sloped walls, though no significant difference in location was seen between the pens. This indicates that the bars did not protect the piglets enough, making it possible for them to get trapped when the sows were performing their posture changes. This is in contrast with a report which suggested the positive impact of piglet protection bars in loose pens in commercial herds(Andersen et al., 2007).

The influence of the pen space was observed in the crushing of piglets when related to the movement the sows made that led to the death of piglets in this study. The SSP sows crushed the majority of their piglets while changing posture from standing to lying. This

has been reported to be more common in farrowing crates rather than pens (Weary et al., 1996). The SSP might have curtailed the rolling movements exhibited by the sows in LSP. It was reported that rolling behaviour is a common occurrence in sows housed in loosed pens, with increased frequency of rolling from one side to another which is classified as dangerous (Damm et al., 2005a; Thodberg et al., 2002; Marchant, 2001). Sitting to lying down posture was also a frequent movement that led to piglet death in LSP. This behaviour was also reported to be dangerous and detrimental to the survival of piglets in other farrowing environments (Johnson et al., 2007; Damm et al., 2005a; Marchant, 2001).

The pens design features had a significant influence on the total piglets crushed and also affected the sow movements leading to crushing and the ways in which piglets were crushed. It was observed that the sloped wall was used most in small space pens for support during posture changes, while the sows housed in the large space pens made use of nothing or other features apart from the three major support features which were designed for them to use while lying down. The results obtained indicate that the larger pen gave more room for the sows to change posture at will and this led to the increase in the number of piglets that died, especially through rolling of the sows (Weary et al., 1996).

It was observed that sows in both pen sizes showed a greater preference for the use of the sloped walls as support during farrowing, as suggested by previous studies (Damm et al., 2006; Marchant, 2001). This probably reflects the aid provided by the sloped walls while lying down, making it a preferred location. It has been reported in an earlier study that sows prefer to lie down using plain sloped walls rather than iron rails or bars (Damm et al., 2006). Sows prefer to use solid sloped walls as support while lying down because of greater ease to perform the end of the lying down sequence, with the hind quarters otherwise flopping down to the ground fast and hard. This last element in the sequence of lying down has been described to be very fast and uncontrollable for sows, making it very dangerous to any piglet trapped during transit (Wechsler and Hegglin, 1997).

The expectation was that the solid sloped walls would prevent flopping down (fast lying down) (Damm et al., 2006; Marchant, 2001; Wechsler and Hegglin, 1997) which should reduce the number of piglets crushed. However, there was no significant effect of the pen size or orientation on the posture of the sows during farrowing, with no evidence of a

preference for right or left lateral lying according to the orientation of the sloped wall within the pen. Since sows initially adopt the side they go down on when lying, this suggests that a change of laterality during lying was frequently occurring. This is supported by the fact that the number of minor posture changes was as high as the number of major changes.

The frequency in posture changes of sows during parturition in the two pen types might indicate how restless or uncomfortable the sows in the small space pen were during farrowing. An increase in number of postural changes might be thought about to be a risk to the survival of piglets (Pedersen and Jensen, 2008) but reports on past research findings have not always supported this line of thought (Pedersen et al., 2006). In accordance with an earlier report that sows housed in tight confinement, especially in farrowing crates, prefer to lie in most cases rather than sitting and standing up (Marchant, 2001; Cronin and Smith, 1992), results from this study indicated that there was no difference in posture changes of the sows during parturition.

3.8 Conclusion

In summary, space and pen features can be said to be a major influence in survival of piglets. The present study showed that out of the two farrowing pens, neither showed any significant effect on piglet mortality, although the larger production experiment which was curreied out concurrently at the same site reported that the larger pen recorded higher piglet mortality (Baxter et al., 2011). This was made possible by the freedom that the sows had to express behaviours that are dangerous to the survival of the piglets (Stand to lie, sit to lie and rolling movements). The sows had enough room to flop down and roll without using any support features, movements that have been reported to be very hazardous to the piglets (Andersen et al., 2005; Wechsler and Hegglin, 1997; Weary et al., 1996). The smaller space pen also makes it easier for piglets to be crushed because of the sows' inability to make sure that they have been pushed away totally from danger while lying down (pre-lying behaviour). Sows that perform these pre-lying behaviours have been reported to crush fewer piglets in pens (Andersen et al., 2005; Valros et al., 2003).

Whlie changing posture with the support of the sloped walls, the sows crushed more piglets in the open nest area in SSP, while rolling was the predominant crushing movement in LSP. The optimum nest space requirement for loose pens or freedom pens is not yet known (Weber et al., 2009). It can be concluded that the open nest space in this design was adequate for the sows to farrow normally, but the subsequent sow behaviours and the detailed design of pen features might still be factors contributing to piglet mortality. Whilst a smaller nest appears beneficial to promote a better farrowing location and reduce crushing, improvements to the creep barrier might still be considered.

Chapter 4

The effect of DHA (Docosahexanoic acid) supplementation in maternal diets on piglet survival in two housing systems

4.1 Introduction

Piglet mortality is a major problem contributing a huge loss to the pig industry. The death of piglets occurs during the early stages of life when the newborn piglets are expelled into a new environment (extra-uterine environment), an environment which poses several challenges to the neonates. The inability of the newly born piglet to surmount these challenges, such as hypothermia and insufficient energy arising from inadequate milk supply, eventually threatens their existence and leads to death (Lauridsen and Danielsen, 2004). The newly born piglet is physiologically immature (Tuchscherer et al., 2000) and lacks energy reserves which, when combined with hypoxia or hypothermia, results in lack of vitality, and hence inability to survive.

In an effort to increase energy supply to the neonates, supplementation of dietary fat in the maternal diet has been shown to increase fat concentration of both colostrum and the sows' milk (Pettigrew, 1981) which, in turn, increase the chances of survival. The welfare of the piglets in terms of nutrient intake is a function of the sow's metabolism (and the maternal diet), since the trans-placental transfer of nutrients to the developing piglet and the nutrient composition of the sow's milk is a reflection of the maternal diet composition during gestation and lactation (Wu et al., 2006). The essential fatty acids supply in gestation, and in the colostrum and milk of the sow, is of immense benefit for the piglets as this enhances their cognitive performance, development of vision and nervous systems (Lauritzen et al., 2001).

Fatty acids serve as building blocks for cell membranes and provide energy for skeletal development of man and animals (Woods and Fearon, 2009). Essential fatty acids are those which cannot be synthesized by the body and are required in appreciable quantity in the diets of animals. Fatty acids can be classified as saturated or unsaturated, with unsaturated fatty acids further classified into mono-unsaturated or polyunsaturated fatty acids (see chapter 2). Polyunsaturated fatty acids (PUFA) are present in appreciable quantities in oilseeds (such as linseed, sunflower, camelina seeds and hemp), oil-rich cereals and fish oil (Kenelly, 1996; Rooke et al., 2000 and Wood and Fearon, 2009).

Oilseeds generally have a predominance of omega-6 fatty acids (see chapter 2), whereas marine sources are richer in omega-3 fatty acids. Since pig diets contain mainly cereals, they are considered to be relatively low in omega-3 fatty acids yet rich in omega-6 fatty acids, a composition which has been reported to be less beneficial in the development of piglet neural tissues (Rooke et al., 2000).

Docosahexanoic acid (DHA) is a long chain, omega-3 fatty acid which is essential in maternal diets and more abundant in marine oils (fish oil, marine algae) rather than the cereals. DHA is a major constituent of the biomembranes of the brain and retina (Uauy, 2000) and is taken up and mostly used by the brain. There have been an increasing number of trials aimed at determining the effects of DHA on piglet survival. Recent reports suggest that litter sizes are improved upon supplementation with DHA (supplied from a number of different sources and in varying levels in the diet), especially during the mating period (before and after service) (Webel et al., 2003; Smit et al., 2011). However, Rooke et al. (2001c) observed that piglets born to sows' fed a diet supplemented throughout gestation with salmon oil (as a source of DHA) had a reduced birth weight (1.47kg) compared to the piglets from sows fed basal diet (1.54kg) (Rooke, 2001c). Despite this, the inclusion of the DHA source resulted in an increase in gestation length and reduced pre-weaning mortality.

The reduction in birth weight has been suggested to arise as a result of the high level of Eicosapentaenoic acid (EPA) found in fish oils (Rooke, 2001c). Eicosapentaenoic acid is prominent in fish oils, and can inhibit the synthesis of arachidonic acid (AA) (Kurlak and Stephenson, 1999). AA deficiency is a known cause of reduced weight gain in human neonates (Carlson et al., 1993). Selection of appropriate marine algae allows the possibility of supplying DHA without an associated high level of EPA. A study by Edwards et al. (2009) showed that inclusion of DHA Gold®, an algal biomass product, during the last 4 weeks of pregnancy to supply 3g DHA /kg feed did not adversely affect birth weight.

In addition to welfare concerns about piglet survival, there is pressure to abolish use of the farrowing crate and change to alternative systems in which sows have freedom of movement. Since the farrowing crate was introduced to reduce the risk of crushing of piglets, and to facilitate localised heating and stockperson aid for weaker piglets, alternative systems will require that piglets are more robust at birth to promote high

survival. Supplementation of sow diets with DHA may be one means to achieve this outcome.

Different levels of omega-3 PUFA inclusions have been reported to have a positive effect in enhancing piglet pre- or post natal survival (Rooke et al., 2001a; Rooke et al., 2001b; Rigau et al., 1995; Baidoo et al., 2003; Farmer et al., 2009). Although progress has been made in reducing preweaning mortality by this approach, the optimum amount (dosage) of DHA required in maternal diets is still unknown. The level of DHA supplement shown to maximise piglet brain weight (Rooke et al., 1998) and enhance survival (Rooke et al., 2001c) is relatively high in comparison to the level recommended for human supplementation (Simopoulos, 2009). Reducing the level of DHA inclusion, providing that efficacy to improve survival is maintained, could have cost savings for farmers since the algal source of DHA is a relatively expensive feed ingredient. It was proposed that the reduced DHA supplementation level (0.03%) will enhance piglet survival. This will make it affordable to the farmers to incorporate into their sow diets. Therefore this study aims to vary the level of DHA supplementation in the diets of sows in two different types of farrowing system and to determine the effect of DHA inclusion on piglet survival from birth to weaning.

4.2 Materials and Methods

4.2.1 Experimental design, animals, housing and management

The experiment was carried out at the pig unit at Cockle Park Farm, Newcastle University using a total of 60 crossbred sows (Landrace x Large White) with a mean parity of 4.7 (sem 0.32). Sows were allocated according to parity, live weight and previous litter size records to one of six treatments in a 3x2 factorial design comparing three levels of DHA inclusion from algal biomass and two types of housing system (farrowing crate or an alternative PigSAFE loose farrowing pen). The farrowings were in batches of nine sows, with three sows allocated to each DHA level while six sows and three sows were alternated between farrowing crates and PigSAFE pens except in the last batch which gave a total of 10 sows for each treatment combination.

During pregnancy the sows were group-housed in kennelled, straw based accommodation with individual feeding stalls. They were fed once per day (at 07:00h) a 3kg quantity of a

cereal/soyabean diet with the appropriate level of DHA supplement. The sows were moved from the gestation accommodation to the farrowing accommodation (at 110days of gestation) five days before the expected farrowing date. Sows that had not farrowed by the expected due date were induced with the administration of 2ml of prostaglandin (planate) from Intervet company. In order to maintain a batch synchrony, sows that had not farrowed on 115days gestation were induced. Seven sows in total were not induced (four control sows and 3DHA sows). After farrowing, sows were fed twice daily (at 07.00 and 16.00h) with the same level of DHA supplement as previously given. The level of feed offered was gradually increased daily after the point of farrowing according to appetite and any feed refusals were weighed and recorded throughout the study. Water was provided to sows *ad-libitum*. General management was standardised across all treatments and farrowing was allowed to occur naturally with the presence of the staff only for necessary intervention. Cross fostering was carried out on the first or second day after farrowing to equalise litter sizes, according to normal commercial practice, and litter of origin and destination was recorded.

4.2.2 Experimental treatments

4.2.2.1 Housing systems

The two farrowing systems compared were the conventional farrowing crate and the PigSAFE pen. The farrowing crate used was a standard farrowing crate (2m long x 1.60m wide) (see Figure 4.1) with a total pen area of 3.96 m^2 and comprised a part-slatted floor with side creep area for piglets which was heated by means of a heat lamp. The second system was designed in the Defra-sponsored project to develop an alternative farrowing environment, with the acronym PigSAFE. The total area for the PigSAFE pen, excluding service passage, was 7.9m^2 (Fig 4.2). The feeding area (Figure 4.2) gave the sow ample opportunity to stand up and move away from the nesting area to feed in a secluded part. The dunging passage was 0.95m long and 2.36m wide while the nest area was 1.74m by 2.40m long. The heated piglet creep area was triangular, had an area of 0.75 m^2 and was covered with a wooden lid to which was attached a heat lamp so that when the lid was lowered the lamp was suspended about 0.5 m above the floor level. There was a sloped wall on the side of the nest and slanted iron railings in front of the creep area which were designed to assist the sow lying down from a sitting or standing position and thus to protect the piglets from being crushed.

Figure 4.1 Farrowing crate layout Photo source: Adeleye O. O

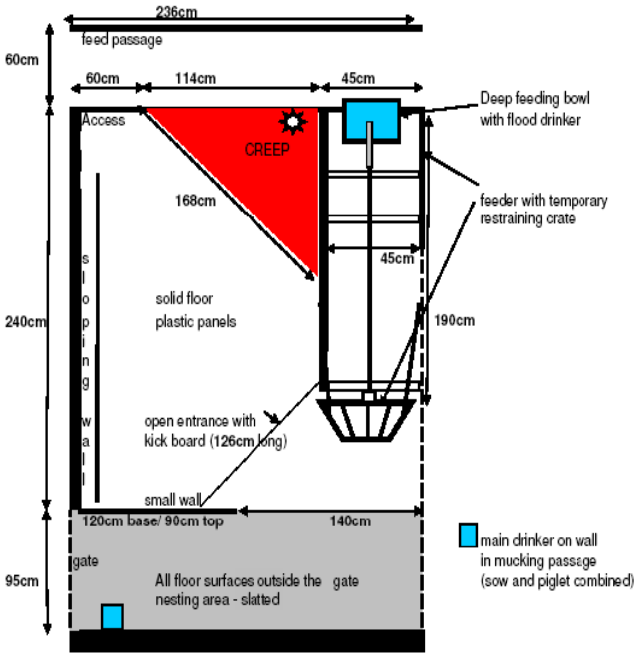

Figure 4.2 PigSAFE pen layouts (Edwards and Baxter 2010)

4.2.2.2 Dietary treatments

Sows were fed diets supplemented with DHA for the last four weeks of gestation and throughout lactation until weaning at approximately four weeks post-partum. The sows were fed home mixed basal diets (see Tables 4.1 and 4.2) which were supplemented according to treatment with either 0, 0.03 or 0.3% DHA, delivered by the addition of either 0, 1.5 or 15g/kg algal biomass (DHA Gold® , Novus Europe). The estimated nutritional composition of diets is shown in Table 4.3.

Table 4.1 Dietary ingredients used in the production of gestation diets

	Level of DHA supplementation (%)		
Component	**0**	**0.03**	**0.3**
Barley	86.0	86.0	86.0
Soya bean meal	10.0	10.0	10.0
Soya oil	1.0	1.0	1.0
*PS/310 SI PE	3.1	3.1	3.1
Algal Biomass	0.0	0.15	1.5
Total	100.10	100.25	101.60

* Vitamin A- 403,225iu/kg, Vitamin D3- 64,516iu/kg, Vitamin E- 1,612iu/kg (alpha-tocopherol acetate), Copper- 645.16mg/kg (Cupric Sulphate), Selenium- 9.68mg/kg (Sodium Selenite), Phosphorus- 2.56%, Sodium- 4.58%, Selenium- 1.61mg/kg (Alkasel R379), Calcium- 26.00%.

Table 4.2 Dietary ingredients used in the production of lactation diets

	Level of DHA supplementation (%)		
Component	**0**	**0.03**	**0.3**
Barley	74.0	74.0	74.0
Soya bean meal	14.0	14.0	14.0
Sunlustre	5.0	5.0	5.0
Soya oil	2.0	2.0	2.0
Dicalcium phosphate	2.0	2.0	2.0
*SI	2.7	2.7	2.7
Algal Biomass	0.0	0.15	1.5
Total	99.70	99.85	101.2

* Vitamin A- 462,979iu/kg, Vitamin D3- 74,076iu/kg, Vitamin E- 1,852iu/kg (alpha-tocopherol acetate), Copper- 740.76mg/kg (Cupric Sulphate), Selenium- 11.11mg/kg (Sodium Selenite), Phosphorus- 2.70%, Sodium- 5.10%, Selenium- 1.85mg/kg (Alkasel R379), Calcium- 25.50%.

Table 4.3 Calculated nutritional content of sow diets

Nutrient Supplied %	**Dry Sow**	**Lactating Sow**
Dry matter	87.67	88.25
Protein	13.82	17.93
Oil	2.47	4.43
Fibre	4.39	4.22
Phosphorus	2.56	2.70
Lysine	0.62	0.93
Methionine	0.21	0.29

4.2.3 Experimental Data

The following parameters were measured:

4.2.3.1 Sow feed intake, bodyweight, back fat thickness and condition score

The weekly feed intake was determined by subtracting the amount of uneaten food from the feed portion given weekly. Sow body weight and condition score were taken at the start of the experiment (four weeks before parturition), at transfer to the farrowing accommodation and at weaning. Sows were condition scored according to a standard protocol (DEFRA, 2006) by placing a palm over the dorsal part of the animal and pressing firmly over the lumbar vertebrae. The sows were scored using a condition score ranging from 1 to 5 (poor condition to fatter condition) depending on the level of tissue covering the lower spine and the backfat thickness (P2) was measured with the aid of a machine. The P2 measurement was done three times; at allocation, 110th day gestation and at weaning.

4.2.3.2 Behaviour and vitality data

In each of the two farrowing systems, a video camera was located strategically above the pen and connected to a recorder with the aid of a multiplexer. The behaviour of the sows before, during and after farrowing was recorded for the period from five days before expected farrowing until three days after farrowing. Data from the video were transcribed using Observer Video Pro 6 software (Noldus, Wageningen, Netherlands). The sows were observed using continuous sampling to determine the duration of farrowing for each sow and the latency for individual piglets to stand, reach the teat and suckle.

4.2.3.3 Piglet data

For each litter the total number of piglets born (litter size), total number of piglets born alive and total number of dead piglets were recorded along with the sex of each individual piglet. In addition, individual piglet weight at birth and weaning were taken. The date and cause of death, determined by post mortem examination, for any piglets which died during lactation were recorded. At birth, additional measures of piglet body conformation were taken. Each piglet was ventrally positioned on a flat surface such that a tape rule

could be used to measure the length from the crown (around the mid-brain) to the rump (at the base of the tail). The heart girth measurement was also taken using a flexible tape measure. The Ponderal index and body mass index were subsequently calculated for each piglet using the following formula:

$$\text{Ponderal index} = \frac{\text{birth weight (kg)}}{\text{crown rump length}^3\ (\text{m})}$$

$$\text{Body mass index} = \frac{\text{birth weight (kg)}}{\text{crown rump length}^2\ (\text{m})}$$

4.2.3.4 Statistical Analysis

The data collected were analysed according to the factorial experiment. The factors were: a) farrowing system, with two levels (farrowing crate and PigSAFE pen) and b) diet supplementation with three levels of DHA (0, 0.03% and 0.3%). Data were analysed for the main effects and their interaction using analysis of variance (ANOVA), fitting the general linear model (GLM) command for treatments assuming equal variance. The analysis was performed using the statistical package MINITAB v 15.0. Probability values <0.05 were described as significant. Post hoc comparisons were made using Tukeys test.

4.3 Results

4.3.1 Effect of dietary supplementation with DHA

The main effect of DHA supplementation on sow bodyweight gain in the last month of gestation, weight at transfer to the farrowing house and feed consumed by the sows during gestation and lactation is presented in Table 4.4. There were no significant differences between levels of DHA supplementation for any of these parameters.

Table 4.4 Effect of DHA supplementation on sow weight gain in the last month of gestation, weight at transfer to the farrowing house and feed consumption

	Level of DHA supplementation (%)				
	0	0.03	0.3	SEM	P Value
No of sows	20.0	20.0	20.0		
Mean parity	4.5	4.7	4.9	0.53	0.83
P2 at allocation	24.9	24.1	26.8	1.27	0.30
P2 at farrowing	25.0	24.8	25.8	1.13	0.73
P2 at weaning	21.6	20.3	21.8	0.95	0.46
Weight gain in gestation (kg)	21.9	18.0	19.7	1.37	0.14
Weight pre farrowing (kg)	283.6	273.9	285.8	6.61	0.41
Weight at weaning (kg)	244.2	238.1	255.6	7.64	0.27
Feed total during gestation (kg)	75.07	74.96	74.88	0.96	0.99
Feed total during lactation (kg)	171.73	170.47	169.72	3.80	0.93

Similarly, there was no significant effect of DHA supplementation on mean gestation length or number of piglets born alive, although total number born was numerically more than half a piglet greater in the control treatment (see Table 4.5). However, there was a significant effect of DHA supplementation on the number of stillborn piglets per litter, an effect which was retained when litter size was included as a covariate ($P<0.001$) in the analysis. The number of stillborn piglets was significantly lower in 0.3%DHA sows

followed by 0.03%DHA sows while the control group sows had the highest. The number of liveborn piglets which died in the subsequent three days after farrowing, and total mortality between birth and weaning did not differ between treatments (litter size as a covariate was not significant).

Table 4.5 Effect of DHA supplementation on total litter size at birth, number of piglets born alive, number of stillborn piglets per litter and number of liveborn piglets dying in the subsequent 3 days.

	Level of DHA supplementation (%)				
	0	0.03	0.3	SEM	P Value
Gestation length (days)	115.8	116.0	115.7	0.24	0.79
Litter size	13.60	12.90	12.70	0.73	0.66
Number of piglet born alive	12.40	12.25	12.50	0.67	0.97
Stillborn piglets/litter	1.20 [a]	0.65 [b]	0.20 [c]	0.22	0.01
(with litter size covariate)	(1.13)	(0.67)	(0.25)	(0.21)	(0.014)
Mortality (no in first 3 days)	0.65	1.00	0.80	0.27	0.65
Total mortality of liveborn (no/litter over whole lactation)	0.85	1.05	0.9	0.30	0.89

Values that do not share the same superscript are significantly different within rows

Mean birth interval was not influenced by level of DHA supplementation (See Table 4.6). However, it was observed that total farrowing duration and the piglets' latency to stand, reach the teat and suckle were significantly influenced by feed treatment. Sows offered DHA supplementation had a prolonged farrowing duration relative to the control sows. The 0.3%DHA supplemented sows had a significantly longer farrowing duration than the 0.03% and control sows. However, the opposite trend was observed in latency to stand, locate a teat and suckle of the experimental piglets (Table 4. 6).

Table 4.6 Main effect of DHA supplementation on birth interval, farrowing duration and vitality of piglets

	Level of DHA supplementation (%)				
	0	0.03	0.3	SEM	P Value
Number of sow videos	13	18	14		
Birth interval (min)	11.64	20.23	16.74	3.55	0.20
Farrowing duration (min)	150.30[a]	195.20[b]	216.20[c]	13.67	0.02
Latency to stand (min)	1.92 [a]	1.44 [b]	1.17 [c]	0.09	0.00
Latency to teat (min)	21.55[a]	15.71[b]	11.20[c]	1.35	0.00
Latency to suckle (min)	25.66[a]	19.14[b]	14.83[c]	1.40	0.00

N -This analysis was carried out on 45sows

Supplementation of DHA in the sow diet did not have any significant effect on the weight of the piglets at birth, their heart girth, crown rump length or the corresponding ponderal index or body mass index as shown in Table 4. 7.

Table 4.7. Main effect of DHA supplementation on piglets' birth weight, hearth girth, crown rump length and ponderal index.

	Level of DHA supplementation (%)				
	0	0.03	0.3	SEM	P Value
Birth weight (kg)	1.50	1.50	1.40	0.05	0.47
Hearth girth (cm)	24.5	23.9	24.1	0.31	0.42
Crown rump length (cm)	27.9	27.2	27.4	0.32	0.25
Ponderal index	68.4	72.0	68.5	1.71	0.25
Body mass index	19.0	19.5	18.7	0.44	0.39

Supplementation of DHA in the sows' diet had no significant influence on the average weight of piglets at birth (Table 4.8). However the mean piglet weight at weaning of control piglets and 0.03%DHA were higher than 0.3%DHA group sows.

Table 4.8. Main effect of DHA supplementation on net fostering, and average weight per piglet at birth and weaning.

	Level of DHA supplementation (%)				
	0	0.03	0.3	SEM	P Value
Mean age at weaning(days)	28	28	27	0.10	0.92
Mean piglet weight at birth (kg)	1.49	1.44	1.41	0.06	0.53
Mean piglet weight at weaning (kg)	7.87[a]	7.64 [a]	6.91[b]	0.23	0.01
Net fostering change (piglets/litter)	-0.85	-0.50	-1.00	0.29	0.67
Litter size at weaning (including fostering)	10.70	10.70	10.60	0.18	0.90

Values that do not share the same superscript are significantly different within rows

4.3.2 Effect of Housing systems

Table 4.9 shows that there was no significant effect of farrowing system on sow gestation length, feed consumption or bodyweight at any point in the experiment

Table 4.9. Main effect of housing system on sows weight at gestation, pre-farrowing, weaning and feed consumed by sows during gestation and lactation

	Farrowing Crate	PigSAFE pen	SEM	P Value
Number of sows	30	30		
Mean parity	4.8	4.6	0.43	0.82
Gestation length (days)	115.8	115.8	0.19	0.90
Weight gain in gestation (kg)	19.63	20.17	1.12	0.74
Weight pre farrowing (kg)	284.50	277.80	5.40	0.35
Weight at weaning (kg)	250.50	241.40	6.24	0.31
Feed intake during gestation (kg)	75.37	74.56	0.79	0.47
Feed total during lactation (kg)	172.10	169.20	3.10	0.50
Weight loss in lactation (kg)	33.9	36.4	3.5	0.63

Similarly, there was no significant effect of farrowing system on piglet survival and growth (Table 4.10).

Table 4.10. Effect of housing system on total litter size at birth, number of piglets born alive, number of stillborn piglets per litter, net fostering, number of liveborn piglets dying in the subsequent 3 days and total mortality.

	Farrowing crate	PigSAFE pen	SEM	P Value
Mean age at weaning (days)	28	28	0.01	0.52
Litter size	13.60	12.90	0.73	0.66
Number of piglets born alive	12.97	11.80	0.55	0.14
Stillborn piglets/litter	0.67	0.70	0.18	0.90
Mortality in first 3 days (n)	1.10	0.53	0.22	0.71
Total mortality of liveborn (no/litter over whole lactation)	1.10	0.70	0.24	0.25
Net fostering change (piglets/litter)	-1.27	-0.50	0.51	0.24
Litter size at weaning (including fostering)	10.60	10.77	0.15	0.21
Average weight per piglet at weaning (kg)	7.43	7.52	0.18	0.90

Farrowing system had no significant effect on the weight of the piglets at birth, their heart girth or crown rump length (Table 4.11). However the corresponding ponderal index and body mass index were greater for piglets born in the PigSAFE system.

Table 4.11. Effect of housing system on piglet birth weight, hearth girth, crown rump length, ponderal index and body mass index

	Farrowing crate	PigSAFE pen	SEM	P Value
Birth weight (kg)	1.42	1.50	0.04	0.15
Hearth girth (cm)	24.03	24.30	0.26	0.45
Crown rump length (cm)	27.79	27.24	0.26	0.14
Ponderal index	65.72	73.56	1.40	<0.001
Body mass index	18.16	19.97	0.36	0.001

There was no significant effect of farrowing system on farrowing duration, mean birth interval or any of the piglet latencies to stand, reach the teat or suckle (Table 4.12)

Table 4.12. Main effect of housing system on birth interval, farrowing duration and vitality of piglets

	Farrowing crate	PigSAFE pen	SEM	P Value
Number of sow videos	23	22		
Mean Birth Interval (min)	14.65	17.76	2.75	0.43
Farrowing Duration(min)	203.60	175.50	13.23	0.14
Latency to Stand(min)	1.45	1.56	0.07	0.29
Latency to teat(min)	15.47	16.84	1.10	0.38
Latency to suckle(min)	19.10	20.83	1.20	0.30

4.3.3 Interactions of DHA supplementation with Housing system

There was no interactive effect of Feed and Housing treatment on sows weight gain in the last month of gestation, weight at transfer to the farrowing house or feed consumption during gestation and lactation periods (Table 4.13).

Table 4.13. Interactive effect of Feed and Housing treatment on sows weight gain in the last month of gestation, weight at transfer to the farrowing house and feed consumed by the sows during gestation and lactation

	Farrowing Crate			PigSAFE pen				
DHAlevels (%)	0	0.03	0.3	0	0.03	0.3	SEM	*Pval
Number of sows	10	10	10	10	10	10		
Weight gain in Gestation (kg)	22.80	17.00	19.10	21.10	19.00	20.40	1.94	0.60
Weight pre farrowing (kg)	288.40	286.0	279.0	278.90	261.80	292.6	9.35	0.12
Weight at weaning(kg)	246.2	254.4	251.0	242.2	221.8	260.2	10.81	0.15
Feed intake in gestation (kg)	75.51	75.20	75.41	74.62	74.72	74.34	1.36	0.98
Feed intake in lactation(kg)	170.90	171.20	174.30	172.60	169.80	165.20	5.37	0.59
Gestation length (days)	116.10	115.50	115.90	115.40	116.40	115.60	0.33	0.05

*P value for interaction

There were no significant interactive effect of the Feed and Housing treatment on total litter size at birth, number of piglets born alive, number of stillborn piglets per litter or mortality at any point (Table 4.14). No significant effect was recorded even when litter size was included as a covariate ($P<0.001$) in the analysis.

Table 4.14. Interactive effect of Feed and Housing treatment on total litter size at birth, number of piglets born alive, number of stillborn piglets per litter, number of liveborn piglets dying in the subsequent 3 days and total piglet death.

	Farrowing crate			PigSAFE pen				
DHA levels%	0	0.03	0.3	0	0.03	0.3	SEM	*Pval
Litter size	13.50	14.40	13.00	13.70	11.40	12.40	1.04	0.28
Piglets born alive	12.60	13.50	12.80	12.20	11.00	12.20	0.95	0.48
Still born (SB) Piglet/litter	0.90	0.90	0.20	1.50	0.40	0.20	0.32	0.23
SB with litter size as covariate	0.85	0.73	0.21	1.42	0.61	0.29	0.29	0.49
Mortality(n)	0.58	1.53	1.10	0.67	0.49	0.54	0.38	0.34
Total Death over lactation	0.70	1.60	1.20	1.00	0.50	0.70	0.42	0.18

n- Average number of piglets that died in the first 3 days, *P value for interaction

Table 4.15 shows a DHA supplementation by farrowing system interaction for mean farrowing duration of sows. Sow on the highest DHA treatment had longer farrowing duration only in the crate system, whilst those on the lower DHA inclusion had longer farrowing duration in the PigSAFE system. There was no interaction between level of DHA supplementation and farrowing system for any of the piglet viability indicators, nor for mean weight of the piglets at birth, heart girth, crown rump length or corresponding ponderal/body mass index (see Table 4.16).

Table 4.15 Interactive effect of House treatment on birth interval, farrowing duration and vitality of piglets

	Farrowing crate			PigSAFE pen				
DHA levels%	0	0.03	0.3	0	0.03	0.3	SEM	*Pval
Birth Interval (mins)	9.82	13.57	20.56	13.45	26.90	12.91	4.74	0.09
Farrowing duration(mins)	145.70^{b}	177.1^{ab}	288.0^{a}	154.8^{b}	213.9^{ab}	157.7^{b}	21.35	0.004
Latency to Stand (mins)	2.02	1.26	1.08	1.82	1.63	1.25	0.12	0.09
Latency to teat(mins)	22.56	13.10	10.76	20.54	18.33	11.64	1.90	0.16
Latency to suckle(mins)	26.70	16.55	14.31	24.63	21.74	15.36	1.95	0.19

*P value for interaction, Values that do not share the same superscript are significantly different within rows

Table 4.16 Interactive effect of Feed and Housing treatment on hearth girth, crown rump length, body mass index and ponderal index.

	Farrowing crate			PigSAFE pen				
DHA levels%	0	0.03	0.3	0	0.03	0.3	SEM	*Pval
Heart girth (cm)	24.44	23.26	24.39	24.55	24.61	23.75	0.44	0.08
Crown-rump length (cm)	28.38	26.88	28.11	27.50	27.56	26.67	0.45	0.06
Ponderal index (cm)	65.03	68.07	64.05	71.72	75.94	73.03	2.42	0.89
Body mass index	18.36	18.17	17.96	19.63	20.89	19.40	0.62	0.45

*P value for interaction

There was no interaction between the main treatments for average weight per piglet at birth or weaning, nor on litter size at weaning (Table 4.17).

Table 4.17 Interactive effect of Feed and Housing treatment on average weight per piglet at birth, weaning and litter size at weaning

	Farrowing crate			PigSAFE pen				
DHA levels%	0	0.03	0.3	0	0.03	0.3	SEM	*Pval
Litter size at weaning	10.40	10.50	10.70	11.00	10.90	10.50	0.26	0.29
Average weight of piglet born alive (kg)	1.47	1.29	1.43	1.52	1.59	1.39	0.07	0.06
Average weight of piglet at weaning (kg)	7.86	7.35	7.07	7.88	7.93	6.75	0.32	0.37

*P value for interaction

4.4 Discussion

4.4.1 Effect of farrowing system on sow and piglet performance

The feed intakes in this current study during the last four weeks of gestation and throughout lactation were not significantly different between sows housed in crates and in the alternative farrowing pens. This corroborates what was reported by Pajor (1999) but is in contrast with Farmer et al. (2006) who reported an increase in consumption by sows housed in modified pens compared to sows housed in standard crates during lactation. The increase in feed intake of the sows in the modified pens was suggested to be a compensation for greater milk production (Farmer et al., 2006). The live weight of the sows before farrowing and at weaning in this study were not influenced by housing treatments, as would be expected in the absence of any difference in feed intake, and the lactation weight loss was therefore unaffected by housing type.

An effect of the housing system on litter size was not expected because the sows were introduced into the farrowing accommodation five days before parturition commenced. However, sows in the crate system had numerically larger litters by on average 0.7 piglets. Piglets born in a large litter are more likely to have a lighter birth weight (Pedersen et al., 2011) and this was observed in the farrowing crates (in this study) where Crate piglets had a numerically lower mean birth weight, although the difference was again not statistically significant. Several studies have suggested that an increase in the litter size will lead to a decrease in birth weight and this predisposes the piglets to crushing in the first few days of life (Weary et al., 1996, Weary et al., 1998, Edwards, 2002, Baxter et al., 2009).

The present study shows that there was no marked effect of house type on the number of still born piglets. This is similar to what was reported by Pedersen et al. (2011) but in disagreement with the findings of Cronin et al. (1996) and Pedersen and Jensen (2008) who reported greater stillbirth when gilts farrowing in crates were compared with gilts farrowing in pens. In this current study, the sows used were balanced for parity ranging from gilts to eight parity sows. Some studies, conducted both in the past and more recently, comparing alternative loose pens and farrowing crates found that sows housed in farrowing crates tended to have a longer farrowing duration, thus increasing the risk of stillbirth (Biensen et al., 1996; Cronin et al., 1996; Pedersen and Jensen, 2008; Oliviero et al., 2010). It was shown that the numbers of still born recorded in this study was not

influenced by house type, despite a (non-significant) increase of 28mins in the mean farrowing duration observed in the crates compared to the pens.

The crown rump length in this present study was not influenced by the housing systems but the body mass index and ponderal index, which have been suggested (Baxter et al., 2008) to be more closely associated with stillborn mortality than birth weight on its own, did differ. Ponderal index is a measure which reflects the change in relative weight for length during gestation, giving information about the proportions of each piglet. This study showed that farrowing crate piglets had lower ponderal index and were therefore, lighter, and disproportionately long and thin when compared to PigSAFE piglets. The ponderal index and body mass index results for each farrowing accommodation may be due to the large litter size in the farrowing crate, as the number of days for which the sows were housed in the farrowing accommodation was too short to register any influence on these parameters.

The total pre weaning mortality in the current study was also not influenced by the two house types. This was in contrast with what was reported by many previous studies, in which pre-weaning mortality was significantly lower in crate systems than in loose farrowing systems (Blackshaw et al., 1994; Marchant et al., 2000; Marchant et al., 2001), but similar to what was reported by others (Cronin et al., 2000; Weber, 2000; Weber et al., 2007) who stated that piglet mortality did not differ significantly between farrowing crates and loose pens. The provision of sufficiently large and appropriately designed freedom pens is a prerequisite for good production results (Pajor et al., 1999), and Wechsler and Weber (2007) summarised that there should not be any reason why the piglet mortality in a loose farrowing should surpass that recorded in a farrowing crate.

4.4.2 Effect of DHA supplementation on sow and piglet performance

There was no significant effect of feeding varying levels of omega-3 polyunsaturated fatty acid during the last four weeks of pregnancy and through lactation on sow weight gain in gestation, sow feed intake during gestation and lactation, number of piglets born alive and number of piglets weaned. The induction of farrowing in sows which went beyond predicted date will have masked any possible effects in the current study. It is

perhaps not surprising that, in the current study, there was no effect of DHA supplementation on litter size (i.e. total number born), since the last four weeks of feeding the sows with DHA supplemented diets would not be enough to cause any significant effect on litter size, which would have been fixed much earlier in pregnancy – soon after implantation.

An interesting impact of supplementing omega-3 polyunsaturated fatty acid in the current study was the significant reduction in number of stillborn piglets. There are a number of possible explanations for a reduction in number of stillbirths following DHA supplementation. Litter size could not have been the only reason for the increased stillbirth level in the control piglets because the effect of DHA supplementation was significant even when litter size was used as a covariate. It was reported in a recent study investigating risk factors for stillborn piglets on a commercial pig farm in Belgium that sows with lower backfat (<16mm) tend to have an increased number of stillbirths compared to those with higher backfat (>27mm; Vanderhaegh et al., 2010), but the current study had sows balanced for backfat with mean backfat thickness of more than 19mm.

It is possible that DHA supplementation in this current study might have provided a better placental environment by facilitating a good placenta blood supply and nutrient exchange, as reported in a human study when marine foods (fish) were supplemented in pregnancy (Rogers et al., 2004). This effect was suggested to be attributed to increase in the omega-3 fatty acid content of marine foods which increases the ratio of biologically active prostacyclins to thromboxanes (Anti-thrombic effects) thereby reducing blood viscousity as reported by previous studies (Rogers et al., 2004 Simopoulos, 2009). However, the exact mechanism responsible for the reduction in the number of stillbirths for sows fed DHA supplemented diets is unclear so, further investigation is required.

An increase in farrowing duration would have been a good basis to explain the number of increased stillbirths but in the current study control sows had the shortest farrowing duration and so might have been expected to have the lowest rate of stillborn piglets. Sows fed DHA supplemented diets had a prolonged farrowing duration which might be connected with the effect of increased DHA levels on uterine smooth muscle which makes it less responsive to oxytocin during parturition, which has been reported in rats (Wathes et al., 2007 review). The current study seems to be the first report in pigs

describing an effect of DHA on farrowing duration; hence further investigation should be carried out to verify this finding.

It might have been expected that piglets born following a prolonged farrowing may have decreased vitality indicators because increase in the farrowing duration and birth interval will increase the lactate levels in cord blood at birth. This occurs when piglets are suffering from hypoxia during birth as a result of increase in the farrowing duration or birth interval as pointed out in previous studies (Herpin et al., 1996 Malmkvist et al., 2006). In this present study, the reverse was the case as piglets from sows offered the highest inclusion level of DHA were quicker to stand, get to the udder and suckle. This is similar to a report by an earlier study which reported a reduced latency to suckle when tuna oil was fed to pregnant sows from day 92 to term (Rooke et al., 2001). Further studies on the mechanism involved should be carried out to explain the increased vitality and vigour of piglets from DHA fed sows.

There are very few studies describing the effect of DHA supplementation on piglet vitality, although one study showed that the cognitive performance of rats was enhanced when diets were supplemented with polyunsaturated fatty acid (Wathes et al., 2007 review) while Capper et al. (2006) reported reduced latency to suckle in lambs given 15g/kg Incromega (high in DHA) in maternal diets. So also, Pickard et al (2007) found out that supplementing DHA in ewe diet in late gestation enhanced the lambs' vigour at birth. The enhanced vitality of piglets could also be explained by an increased amount of DHA in the brain lipids which might influence the function of the brain (Crawford 2000). It was reported that DHA crosses the placenta barrier to get to the foetus, and is used by the developing foetus for development of body tissues like the brain and the retina (Rooke, 1998).

In the current study there was no significant effect of DHA supplementation on piglet birth weight. No effects of DHA supplementation on birth weight were observed in previous studies (Rooke et al., 1998; Rooke et al., 2001a; Smits et al., 2011). However, Rooke et al. (2001c) reported decreased piglet birth weights from multiparous sows fed diets supplemented with fish (salmon) oil throughout pregnancy. These authors suggested that the reduction in birth weight of piglets was due to the increased amount of eicosapentaenoic acid (EPA) in the salmon oil, which has been known to inhibit arachidonic acid synthesis (Rooke et al., 2001c; McCowen and Bistrian, 2003) thus

negatively affecting growth of neonates (Carlson et al., 1993). In the current study, the source of DHA used contains a high proportion of DHA relative to EPA.

When litter size was used as a covariate, there was no significant impact of DHA supplementation on piglet birth weight. Baxter et al. (2008) reported the importance of increased crown rump length, ponderal index and body index in achieving high piglet survival as a result of better fetal nutrient supply; the higher the values of these parameters the better the chance of survival, as still birth is reduced. However, in the current study there was no effect of DHA supplementation on crown rump length, body mass index or ponderal index, so this cannot explain the reduced rate of stillbirths following DHA supplementation.

Rooke et al. (2001a) reported that tuna oil supplementation of sow diets during either late gestation or lactation resulted in heavier piglets at birth and weaning compared with sows fed the control diet throughout the study. This is in contrast with results observed in the current study, where piglets from sows fed 0.3% DHA had significantly lower weight at weaning compared to the other two treatments.The increased weaning weight in earlier experiments was suggested by the authors to be a consequence of improved piglet vitality (Rooke et al., 2001b) and vigour at birth (Rooke et al., 2001a; Rooke et al., 2001b). Thus the negative association between supplementation with DHA and piglet weaning weight seen in the current study may be similar to the growth limitation experienced by first year preterm infants fed marine oil which arose from inadequate Arachidonic acid (Carlson et al., 1993).

4.4.3 Interaction between DHA supplementation and farrowing systems

This study was conducted to determine if there is any interactive effect of housing type (farrowing crate vs PigSAFE pen) and supplementation of omega-3 polyunsaturated fatty acid (DHA from algal biomass) in varying quantities in the gestation and lactation diet on sow reproductive performance and survival of piglets. Overall, there were no significant interactive effects on survival or performance parameters, and few significant main effects of the housing system. The interactive effect of the housing system and the supplementation of polyunsaturated fatty acid were not significant for any of the parameters measured. It might be that the good design and management of the PigSAFE system meant that even weaker piglets were still at low risk compared to the situation in

less good pen designs. Piglets were born close to the creep area and able to access warmth quickly. Sows have the possibility to nest build, so may be less restless.

4.5. Conclusions

In summary, maternal diet supplementation with DHA appears to have an influence on piglet survival at birth. Further studies should be carried out in large-scale production herds with highly prolific sows, comparing piglet mortality in crate and pen sows by postmortem examination to differentiate stillborn from live-born piglets, to arrive at a final conclusion on the exact risk of stillbirth and the effect of housing types (Pedersen et al., 2011). The present study has shown that inclusion of omega-3 polyunsaturated fatty acid supplement increased farrowing duration, but reduced stillbirth and also reduced the latency of liveborn piglets to stand, reach the udder and suckle (improved vitality) even after a long farrowing duration. However, it was also observed that DHA inclusion reduced weaning weight of piglets which is in contrast with previous other studies. The mechanism which brings about the improved survival of piglets, even after prolonged farrowing duration should be further studied. More studies should also be carried out on the reason why DHA fed piglets have reduced weaning weight. More investigation must be done to determine the amount of omega-3 polyunsaturated fatty acid supplement to be used, especially during lactation, and to also determine the length of time it must be used for optimum production.

Chapter 5

Effects of maternal supplementation with essential fatty acid (Docosahexanoic acid) on neonatal piglet metabolism and vitality

5.1 Introduction

It has been documented that losses due to piglet mortality are still a source of concern, with 3 to 8% of losses due to stillbirths and generally greater than 10% mortality recorded after farrowing until weaning (Van der Lende et al,. 2001). In a recent production experiment, the dietary inclusion of DHA (Docosaheaxanoic acid) in sows' diet has been suggested to reduce the incidence of stillbirth (Adeleye et al., 2011) where stillbirth rate was observed to be 1.2 pigs per litter in control sows while sows fed 15g of algal biomass (high in DHA)/kg of feed averaged only 0.2 pigs per litter. The factors which are responsible for the enhanced viability of the piglets from sows fed DHA, and the mechanisms mediating these factors, are still poorly understood. Stillbirth occurrence in pig herds has been associated with longer farrowing durations, as a result of intrapartum hypoxia (Edwards, 2002), but video records of the sows in the production experiment eliminated this as an explanation for the observed result.

It is therefore necessary to consider other possible effects arising from the inclusion of DHA in maternal diets including improved placental nutrient transfer or blood flow, influencing blood glucose and lactate levels at birth and piglet vitality. A better understanding of neonatal and maternal physiology in relation to placental transfer of nutrients and regulation of the parturition process as a result of DHA inclusion is important. The hypothesis of this study is that increase in the farrowing duration as DHA supplementation increases (Chapter 4) will increase the blood lactate and blood glucose levels. Hence, the aim of this study was to determine the effect of DHA supplementation of sow diet on new born piglet vitality measures and survival.

5.2 Materials and Methods

5.2.1 Experimental treatments

Three treatments were compared (identical with those used in Chapter 4) in which sows were fed home mixed basal diets (see Tables 5.1 and 5.2), which were supplemented with 0, 0.03 and 0.3% DHA, delivered by 0, 1.5g/kg and 15g/kg algal biomass. The calculated analysis of the sow diets is shown in Table 5.3.

Table 5.1. Dietary composition for the treatment groups for the gestation phase

Components	Control (%)	Diet 1(%)	Diet 2(%)
Barley	86.0	86.0	86.0
Soya	10.0	10.0	10.0
Soya oil	1.0	1.0	1.0
*PS/310 SI PE	3.1	3.1	3.1
Alga Biomass g/kg	0.0	0.15	1.5
Total	100.10	100.25	101.60

*Vitamin A- 403,225iu/kg, Vitamin D3- 64,516iu/kg, Vitamin E- 1,612iu/kg (alpha-tocopherol acetate), Copper- 645.16mg/kg (Cupric Sulphate), Selenium- 9.68mg/kg (Sodium Selenite), Phosphorus- 2.56%, Sodium- 4.58%, Selenium- 1.61mg/kg (Alkasel R379), Calcium- 26.00%.

Table 5.2. Dietary composition for the treatment groups for the lactation phase

Components	Control (%)	Diet 1(%)	Diet 2(%)
Barley	74.0	74.0	74.0
Soya	14.0	14.0	14.0
Soya oil	2.0	2.0	2.0
Sunlustre	5.0	5.0	5.0
Dical	2.0	2.0	2.0
*SI	2.7	2.7	2.7
Alga Biomass g/kg	0.0	0.15	1.5
Total	99.7	99.85	101.20

* Vitamin A- 462,979iu/kg, Vitamin D3- 74,076iu/kg, Vitamin E- 1,852iu/kg (alpha-tocopherol acetate), Copper- 740.76mg/kg (Cupric Sulphate), Selenium- 11.11mg/kg (Sodium Selenite), Phosphorus- 2.70%, Sodium- 5.10%, Selenium- 1.85mg/kg (Alkasel R379), Calcium- 25.50%.

Table 5.3. Calculated Analyses of sow diets

Nutrient Supplied %	Dry Sow	Lactating Sow
Dry matter	87.67	88.25
Protein	13.82	17.93
Oil	2.47	4.43
Fibre	4.39	4.22
TDN	72.59	75.64
Calcium	0.92	0.95
Lysine	0.62	0.93
Methionine	0.21	0.29

5.2.2 Animals and Management

18 crossbred sows (Landrace x Large White) with a mean parity of 4.0 (sem 0.46) were allocated according to parity and previous litter size records in six replicates over time. The pregnant sows were group-housed in kennelled, straw-based accommodation with individual feeding stalls. During the last four weeks of pregnancy, sows were fed 3kg daily, at 07.00h, of a cereal/soyabean diet in a single feed, with the appropriate level of supplement separately weighed and added to the daily ration. After farrowing, they were fed twice daily 07.00 and 16.00hours and water was provided *ad-libitum*. The level of feed increased daily after farrowing according to appetite. Feed refusals were weighed and feed delivery was adjusted to the sows' appetite on a daily basis from the first day of lactation.

The sows were moved from the gestation accommodation in group pens into the farrowing crate accommodation 5 days before the expected delivery date. Wood shavings were spread on the floor of the pen, and the creep was bedded with shavings and well lighted to warm the creep area before farrowing occurred. The temperature of the building was recorded with the use of a digital thermometer and hygrometer, which measured both the temperature and relative humidity, in the morning and evenings.

The backfat thickness and body condition score of the sows was taken at allocation, immediately after housing and 14days after farrowing. Sows were condition scored according to a standard protocol (DEFRA, 2006) by placing a palm over the dorsal part of the animal and pressing firmly over the lumbar vertebrae. The sows were scored using a condition score ranging from 1 to 5 (poor condition to fatter condition) depending on the level of tissue covering the spine.

General management was standardised across all treatments and farrowing was allowed to occur naturally with the intervention of the staff only when considered necessary to reduce stillbirth risk (when 30 minutes had passed since the birth of the previous piglet). The behaviour of sows and piglets was video recorded from 5days before farrowing till 3days after farrowing to be able to determine the latency of each piglet to get to the teats and latency to suckle.

5.2.3 Measurements during parturition

All farrowings were attended and, immediately after birth, the time of birth was recorded and a vitality score was given to each newborn piglet. This score (modified from Baxter et al., 2008) was based on activity during the first 15 seconds after birth:

V0: Still birth/Resuscitated,
V1: Piglet remains static in the same position as born, but is breathing
V2-: Piglet rolls onto belly but no other movement
V2+: Piglet rolls onto belly, head moves, but do not attempt to stand,
V3: Piglet moves and attempt to stand.

The piglet was then picked up for blood sample collection from the umbilical cord. The blood glucose (Acucheck meter, Boots Pharmaceuticals) and blood lactate (Lactate Pro meter, FaCT Canada consulting company) levels were determined immediately. A further blood sample was taken into a 5ml heparinised tube, and later centrifuged to separate the plasma which was then frozen at -20^{o}C for subsequent analysis. The rectal temperature was taken using a digital thermometer (BNIB8617A, Boots Pharmaceuticals). The crown rump length and the birth weight were recorded and the piglet then returned to its birth position. Two hours later, each piglet's weight and rectal temperature were taken for a second time.

5.2.4 Post-parturition measurements

Following expulsion, the placenta was collected and vascularisation was scored according to the following scale (Baxter et al., 2008):

Placenta Vascular score 1- Placenta appears white, thin and fragile and easily torn. There is very little evidence of blood within the major blood vessels or capillaries, which are sparse across the placenta.
Placenta Vascular score 2- Placenta appears pale, pink and fragile and easily torn. There is some evidence of blood within the major blood vessels but not the capillaries, which are sparse across the placenta.
Placenta Vascular score 3- Placenta appears red, bright and is less fragile, resisting tearing. There is evidence of blood within the major blood vessels and capillaries, which are diffuse across the placenta.
Placenta Vascular score 4- Placenta appears deep red, robust and thick resisting tearing. Blood is evident in the major blood vessels and capillaries, which are diffuse across the placenta.

The placentae were collected and dissected no later than 24hrs after expulsion. Each individual placenta was washed; the amniotic fluid and amnion were removed. The width and the length of the placenta were measured with the aid of a tape rule. A 5cm x 5cm quadrant was placed on the upper part and the lower part of the exposed placenta and all areolae visible within each quadrant were counted. With respect to the surface area, the total number of the areola was calculated as well as areola density (areola per cm^2). Placental efficiency was also calculated (total piglet birth weight/total placenta weight).

The weight of each piglet was measured again at 24 hours and 14 days after farrowing. Blood samples were taken from the anterior vena cava into 2ml vacutainer tubes from piglets at 48h and 14 days of age. A colostrum sample was taken from each sow by hand milking a number of different teats before first suckling, and milk samples were taken at 48hrs, 10days and 14days after farrowing. The samples were frozen at -20^oC for subsequent analysis.

Cross fostering was carried out, not later than 48hrs after birth, where necessary to equalise litter sizes, and litter of origin and destination were recorded. When necessary,

milk supplement was given to litters with too many piglets and inadequate teats available for suckling, and this was again recorded.

5.2.5 Behaviour Measurement

The results on the piglets' behaviour immediately after birth were obtained by viewing the video tapes recorded during parturition. A video machine connected to a multiplexer and time code generator was used. The time of birth of each piglet was recorded. So also the time lag between the first 15seconds (when the vitality score is taken) and when the piglets were returned was recorded. This was termed the Processing time. The processing time was excluded from the time it took each piglet to get to the teat and suckle.

5.2.6 Plasma fatty acid analysis

Blood samples were centrifuged to separate the plasma which was then frozen at -20^{o}C before being analysed. Fatty acids were extracted from supplements and plasma samples using a lipid isolation method as done by Sukhija & Palmquist, (1988) in which fats were extracted into a methanol/toluene solution containing an internal standard (C:17). Fatty acids were methylated using acetyl chloride at 100^{o}C for 1hour. The supernatant was then separated after centrifugation at 1000G. The supernatant was also further dried by liquid nitrogen to enable the fatty acid to peak in the Gas liquid chromatography. Fatty acid profiles were obtained using Gas liquid chromatography, using a 30m BPX70 capillary column (SGE Europe Ltd. Milton Keynes, UK) on a Hewlett Packard 5890 Series 2. The initial temperature of the column was 100^{o}C where it was held for 2mins before being raised to 260^{o}C where it was held for further 1min, and then returned to the initial temperature. Fatty acid concentrations were determined with reference to the internal standard concentration, expressed as a percentage of total fatty acid (see Appendix).

5.2.7 IgG determination

The immunoglobulin concentrations in piglet plasma collected from blood sampled at 48 hours postpartum and 14 days after parturition were measured using a Horiba Pentra 400 automated spectrum photometer with Horiba ABX IgG kits.

5.2.8 Statistical Analysis

The data collected were analysed in a Completely Randomized Design using a general linear model (GLM) ANOVA assuming equal variance. The litter means was the unit of analysis except where individual piglets were used in correlation analyses. The factors or predictors affecting survival of piglets at birth were analysed using both multiple linear regression and binary logistic regression. The analyses were performed using MINITAB v 16.0. Probability values <0.05 were described as significant.

5.3 Results

5.3.1 Sow traits

The effect of DHA supplementation on weight gain in the last month of gestation, sow entry weight before farrowing and weight change two weeks after farrowing are presented in Table 5.4, together with the body condition scores of sows at entry, at two weeks after farrowing and feed consumed by the sows during gestation and lactation period. There were no significant differences in these sow parameters between the DHA treatments.

Table 5. 4. Effect of DHA supplementation on sows feed intake, weight loss and gestation length

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
Feed in Gestation (kg)	76.2	76.2	76.2	5.04	1.00
Feed in Lactation (kg)	63.8	64.3	62.3	9.72	0.99
Sow Gestation Length (days)	116.2	115.8	116.3	0.68	0.87
Sow entry weight (kg)	285.7	283.7	286.3	8.52	0.97
Sow Weight at 14 days (kg)	244.7	246.70	251.0	9.32	0.88
Sow Weight change (kg)	41.0	37.0	35.0	5.63	0.75
Condition score at entry	3.7	3.7	3.7	0.18	0.93
Condition score at 14days	2.9	3.0	2.9	0.16	0.92
Condition score change	0.7	0.7	0.8	0.18	0.75

5.3.2 Farrowing traits

Neither the Birth interval nor the Cumulative farrowing duration was significantly influenced by the feed treatments (Table 5.5). The total number of piglets born alive and stillborn were also not affected significantly by DHA supplementation despite a marked trend in the treatment means.

5.3.3 Mortality

A total of 247 piglets were born out of which 11 (4.5%) died in total before weaning. Stillbirth rate was 3.6%, while 9 live born piglets died in the first three days after farrowing. The total live born mortality to 14 days was 3.6%. The live born deaths and total pre-weaning deaths per litter showed no significant difference between feed treatments, as shown in Table 5.5.

Table 5.5. Effect of DHA supplementation on farrowing duration, birth interval, piglets born alive, dead piglets and litter size

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
Birth Interval (mins)	20.63	20.02	28.56	7.75	0.69
Farrowing Duration (mins)	259.3	216.8	391.8	81.45	0.31
*Farrowing Duration (mins)	259.3	216.8	259.4	29.05	0.52
Litter size	14.83	12.83	13.50	1.02	0.46
Born alive	13.83	12.50	13.33	1.01	0.65
Still Birth (no/litter)	1.00	0.33	0.17	0.21	0.34
Still Birth (with Litter size as covariate)	0.92	0.40	0.18	0.34	0.34
Live born deaths@ 3days (with Litter size as covariate)	0.78	0.21	0.51	0.29	0.44
Total Preweaning deaths (with Litter size as covariate)	0.90	0.42	0.52	0.31	0.20

* One piglet born dead 24h after farrowing and placental expulsion were apparently completed was not included

5.3.6 Vitality Score

The vitality score of the piglets is shown in table 5.6. The vitality scores of piglets, expressed as number/litter and their corresponding percentages, indicate a numerical trend in the number (and percentage) of piglets that are still born or resuscitated; piglets from 0.3%DHA treatment had the lowest while the piglets from the control group had the highest prevalence. Control litters had numerically more piglets in low vitality categories and fewer in high vitality categories, but treatment differences were only significant for the V2+ category (piglets that move the head and the body but do not stand). The piglets in 0.03%DHA group had the highest number and percentage while the control grouped piglets had the lowest. When combining these scores within litter, the mean vitality score was significantly higher in litters from DHA supplemented sows.

Table 5.6. Effect of DHA supplementationon piglet vitality parameters

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
V0 no/litter (percent)	0.90 (6.1)	0.42 (2.6)	0.35 (2.5)	0.35	0.27
V1 no/litter (percent)	1.56 (10.0)	0.09 (0.7)	1.18 (11.6)	0.54	0.44
V2- no/litter (percent)	4.64 (33.3)	3.33 (23.2)	3.87 (29.6)	0.64	0.24
V2+ no/litter (percent)	5.72 [b] (43.2)	8.18[a] (59.5)	6.60 [b] (47.7)	0.94	0.02
V3 no/litter (percent)	0.61 (5.7)	1.58 (13.8)	1.15 (8.2)	0.68	0.54
$V2^{+}$ +V3 no/litter (percent)	6.33 (47.2)	9.66 (74.7)	7.67 (56.2)	1.03	0.25
Mean Vitality Score (coded 1-5scale)	3.28	3.85	3.56	0.10	<0.001

*V0 – Still birth/Resuscitated, V1- Piglet remain static in the same position, V2- - Piglet rest on belly but other parts doesn't move, V2+- Piglet rest on belly, head moves, belly moves but not stand, V3- Piglet move and attempt to stand.
All date analysed with litter size as covariate.

Table 5.7 shows that there was no significant difference across treatments in the latency to show landmark behaviours, although the 0.03%DHA treatment was numerically quicker on average to get to the udder and suckle compared to other treatments.

Table 5.7. Effect of DHA supplementationon piglets' latency to get to teat and latency to suckle

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
Latency to teat(mins)	20.50	12.88	16.57	3.66	0.37
Latency to suckle (min)	23.83	15.42	19.50	3.62	0.30
Latency to teat(mins) ¶	19.08	12.96	17.91	3.70	0.47
Latency to suckle (mins)¶	22.66	15.49	20.60	3.75	0.39
Processing time (mins)	4.82	4.64	5.02	0.24	0.55

Litter means were used for analysis. ¶litter size as covariate

5.3.7 Piglet Performance

There was no significant difference between treatments in the birth weight and corresponding weights taken at 2hrs and 24hrs after birth. So also the crown rump length at birth showed no significant treatment effect including the numbers of piglets weaned (Table 5.8).

Table 5.8. Effect of DHA supplementationon piglet birth weight and weaning weights

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
Birth weight@0hrs (kg) ¶	1.49	1.64	1.47	0.07	0.31
Crown Rump length (cm)	30.76	30.47	28.76	1.17	0.53
Weight@2hrs (kg) ¶	1.50	1.69	1.50	0.68	0.31
Weight@24hrs (kg) ¶	1.57	1.76	1.58	0.06	0.22
Weight increase@ 2hrs (kg) ¶	0.02	0.06	0.03	0.02	0.80
Weight increase@ 24hrs (kg) ¶	0.09	0.12	0.11	0.03	0.79
Weight@ 14days (kg) ¶	4.87	5.33	4.96	0.70	0.89
Weight increase 24h to 14d (kg)	3.32	3.55	3.37	0.66	0.97
Weaning number	12.33	11.83	11.83	0.48	0.71
Net fostering	-0.67	0.17	-0.50	0.48	0.74

¶litter size as covariate

5.3.8 Neonatal physiology and placental characteristics

There was no effect of feed treatment on the blood glucose, blood lactose and rectal temperature of piglets as shown in table 5.9. The placenta vascularisation score was also not significantly different (Table 5.10) but there was a significant difference between DHA supplementation treatments on the area of the placenta. The placentae of piglets from the control group were smaller while those of the 0.3%DHA were the largest (Table 5.10). There was no significant difference between feed treatments in the placenta efficiency, total areola and areola density, although a numerical trend was again observed.

Table 5.9. Effect of DHA supplementationon piglet cord blood glucose, blood lactate and rectal temperatures

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	P value
Blood glucose (mmol/l)	2.79	2.93	2.83	0.22	0.82
Blood lactate (mmol/l)	4.83	4.68	5.62	0.28	0.25
Rectal temp 0hrs (Celsius)	37.78	38.22	37.55	0.41	0.78
Rectal temp 2hrs(Celsius)	37.35	37.66	37.50	0.28	0.85
Temperature change in 2h	-0.43	-0.56	-0.05	0.48	0.73

Analysed with litter size as covariate**.**

Table 5.10. Effect of DHA supplementation on placenta traits

	Level of DHA Supplementation %				
	0	0.03	0.3	SEM	Pvalue
Mean Placenta Vasc. Score (1-4 scale)	2.67	3.87	3.12	1.15	0.26
Placenta area(m^2)	0.16	0.17	0.18	0.01	0.03
Placenta weight (kg)	0.33	0.35	0.32	0.04	0.80
Placenta efficiency	4.68	4.84	4.88	0.43	0.94
Areola density (no/cm^2)	0.68	0.86	0.88	0.11	0.42

Analysed with litter size as covariate.

There was no significant effect of feed treatment on the blood glucose and lactate levels of piglets using the litter means as observed in table 5.11. However, using individual piglet data and the time since start of farrowing as a covariate, there was a significant difference in the blood lactate levels between the treatments, with piglets from the 0.3% DHA inclusion having higher levels (table 5.11).

Table 5.11. Effect of DHA inclusions on blood glucose and lactate levels of individual piglets

	Level of DHA Supplementation %				
Parameters/Treatments	0	0.03	0.3	SEM	Pvalue
Blood Glucose (mmol/l)	2.67	2.93	2.76	0.11	0.22
Blood Lactate (mmol/l)	4.92	4.61	5.60	0.29	0.07
*Blood Lactate (mmol/l) (cumulative farrowing duration as covariate)	4.83	4.58	5.68	0.22	0.002

Table 5.12 shows the relationship between different survival traits. Increased farrowing duration increased both blood glucose and blood lactate, which were significantly positively correlated. It was observed that there was a negative correlation between rectal temperature at birth and blood glucose and blood lactate levels. The crown rump length had a significant positive correlation with birth interval, farrowing duration and blood glucose, but these were not reflected in relationships of farrowing interval with ponderal index or body mass index.

Table 5.12. Correlation coefficient (upper figure) and the corresponding P values (lower figure) between different piglet traits

	Birth wt.h (kg)	**Birth Interval**	**Cumul. Farrowing Duration**	**Blood Glucose**	**Blood Lactate**	**Rectal Temp (0hr)**	**CRL (cm)**
Cumulative Farrowing Duration	-0.237 (0.36)	**0.747** **(<0.001)**					
Blood Glucose	-0.30 (0.23)	0.092 (0.16)	**0.146** **(0.03)**				
Blood Lactate	**-0.49** **(0.04)**	**0.132** **(0.04)**	**0.214** **(<0.001)**	**0.393** **(0.001)**			
Rectal Temp (0hr)	0.128 (0.62)	0.077 (0.24)	0.052 (0.43)	**-0.334** **(<0.001)**	**-0.157** **(0.02)**		
Rectal Temp change (0-2h)	0.133 (0.62)	-0.063 (0.33)	-0.103 (0.11)	0.072 (0.28)	0.025 (0.71)	**-0.40** **(<0.001)**	
Crown rump length (CRL) (cm)	0.399 (0.10)	**0.20** **(0.002)**	**0.343** **(<0.001)**	**0.136** **(0.039)**	-0.084 (0.20)	-0.004 (0.95)	
Ponderal index	0.134 (0.11)	-0.001 (0.99)	-0.023 (0.72)	-0.072 (0.27)	-0.053 (0.42)	0.032 (0.63)	**-0.186** **(0.003)**
Body mass index	0.116 (0.08)	0.027 (0.67)	0.026 (0.69)	-0.044 (0.51)	-0.066 (0.31)	0.034 (0.60)	-0.048 (0.48)

NB- This correlation matrix is based on individual piglet records (N=238)

Table 5.13 shows a logistic regression analysis of how various factors contributed to the survival of the newborn piglets (Stillborn/Alive). The result as depicted below shows that birth interval and birth weight are very important in determining the survival of newborn piglets. The table reveals that the more the increase in the duration of births between one piglet and another, the higher the likelihood of the piglet not surviving. So also, the increase in birth weight, the more the chances of survival.

Table. 5.13 This is a logistic regression (probit function model) that predicts the probability of survival of the new born piglets.

Variable	Mean	Estimated coefficient	SE	T ratio	Marginal Effect	P.Value
Treatment (DHA levels)	0.11	21.646	18.531	1.17	0.000	
Birth Interval (mins)	22.43	-0.016	0.007	-2.247	0.000	<0.001
Crown rump length (cm)	29.20	-0.00003	0.002	-0.014	0.000	
Weight at birth (kg)	1.61	2.097	1.008	2.079	0.000	

Likelihood ratio test= 43.36, % Right predictions = 96.76

Table 5.14 shows The IgG concentration in piglet plasma at 2 and 14 days of age. There were no differences between litters from sows receiving the different DHA supplementation levels.

Table 5.14. The effect of DHA supplementation on plasma immunoglobulin G concentration of piglets at two days and 14 days of age

	Level of DHA supplementation (%)				
	0	**0.03**	**0.3**	**SEM**	**P value**
IgG 2days (g/L)	5.99	5.90	6.14	0.15	0.50
IgG 14days (g/L)	3.38	3.60	3.68	0.16	0.35

5.3.9 Fatty acid concentrations in blood and milk samples

There was a significant effect of DHA supplementation of the maternal diet on the fatty acid composition of the blood plasma taken from the umbilical cord at birth of piglets (Table 5.15). There was a significant increase in the relative concentration of DHA present in the blood plasma in umbilical cord at birth as DHA maternal supplementation increased. The relative concentrations of all other fatty acids except DHA were not significantly affected.

Table 5.15: Effect of DHA supplementation on fatty acid composition (expressed as percentage total fatty acids) of piglet blood plasma from the umbilical cord at birth

	Level of DHA supplementation %			
% total fatty acids	**0**	**0.03**	**0.3**	**SEM**
C9:0	0.285	0.327	0.120	0.135
C10:0	0.253	0.191	0.214	0.041
C12:0	0.564	0.405	0.600	0.084
C14:0	4.209	3.792	4.956	1.009
C14:1	0.876	0.961	1.031	0.133
C15:0	0.805	0.475	0.853	0.266
C16:0	16.330	18.090	17.600	2.360
C18:0	11.800	13.110	12.340	1.668
T9-14	8.093	9.752	8.664	1.232
C9	2.730	3.601	2.817	0.474
C11	0.401	0.394	0.495	0.046
C18:2 n-6 (LA)	2.976	2.812	2.720	0.475
C20:0	0.784	0.903	0.884	0.135
C18:3n-6 (GLA)	0.138	0.170	0.138	0.044
C5C20:1	0.160	0.166	0.188	0.035
C8C20:1	0.528	0.844	0.562	0.142
C18:3n-3 (aLN)	0.512	0.607	0.562	0.086
C20:2	0.613	0.725	0.662	0.100
C22	0.042	0.063	0.154	0.046
C20:3n-6	10.561	9.868	8.032	1.730
C20:3n-3	0.024	0.024	0.036	0.017
C20:4n-6	0.802	1.032	1.230	0.165
C20:5n-3 (EPA)	0.405	0.231	0.610	0.101
C24:1	5.050	4.851	4.611	0.741
C22:3	2.166	2.289	1.981	0.441
C22:4	0.369	0.427	0.338	0.054
C22:5n-3 (DPA)	0.428	0.377	0.363	0.061
C22:6n-3 (**DHA)**	**1.696**[b]	**3.863**[a]	**4.300** [a]	**0.557**
SFA	36.530	38.540	39.140	4.863
MUFA	42.450	38.660	39.510	7.660
PUFA	20.830	22.810	21.340	3.079
n-3	6.883	10.106	9.934	1.161
n-6	14.950	14.440	12.640	2.350
n-3/n-6 ratio	0.523	0.714	0.807	0.065
SCFA	1.777	1.570	1.700	0.430
MCFA	47.650	42.000	46.400	7.363
LCFA	50.380	56.430	51.900	7.150

Where superscripts differ within a row, values are significantly different. **DHA – P=0.02**. SFA- Saturated fatty acid, MUFA- Medium unsaturated fatty acid, PUFA- Poly unsaturated fatty acid, n-3- Omega 3 fatty acid, n-6-Omega 6 fatty acid, SCFA- Short chain fatty acid, MCFA- Medium chain fatty acid, LCFA- Long chain fatty acid.

There was a significant effect of DHA supplementation of maternal diet on the colostrum fatty acid concentration as shown (Table 5.16). The relative concentrations of C20:3 n3 and C22:4 were significantly reduced in colostrum of 0.3%DHA group sows at the commencement of farrowing compared to the control diets and 0.03%DHA sows. On the other hand, the colostrum of 0.3%DHA sows had a higher proportion of EPA and DHA than the control and 0.03%DHA sows at the same period. The percentage of omega-3(n-3) fatty acids and the n-3/n-6 ratio were also significantly higher with increasing DHA supplementation.

The 0.3% DHA supplemented sows also had milk with a significant higher relative concentration of DHA at day 2 of lactation than the other two treatment groups (Table 5.17). There was no other significant difference in the relative concentration of the SFAs, MUFAs and PUFAs in the 48hr milk samples with DHA supplementation.

The 0.3% DHA supplemented sows had milk with significant higher relative EPA and DHA concentration at day 14 of lactation than the other two treatment groups (Table 5.18). There was no other significant difference in the concentration of the SFAs, MUFAs and PUFAs in the 14d milk samples with DHA supplementation

Table 5.16: Effect of DHA supplementation on fatty acid composition (expressed as percentage total fatty acids) of sow colostrum at onset of farrowing

	Level of DHA supplementation %			
	0	**0.03**	**0.3**	**SEM**
C10:0	0.002	0.003	0.003	0.001
C11:0	0.005	0.001	0.001	0.001
C12:0	0.019	0.025	0.017	0.006
C13:0	0.002	0.002	0.001	0.001
C14:0	1.579	2.138	2.160	0.191
C14:1	0.013	0.025	0.020	0.007
C15:0	0.101	0.166	0.150	0.020
C16:0	31.630	32.450	32.300	0.886
T9C16:1	1.409	1.377	1.283	0.099
C9C16:1	3.324	3.692	3.143	0.299
C17:0	0.322	0.353	0.248	0.037
C17:1	0.177	0.181	0.228	0.025
C18:0	8.108	7.520	7.864	0.345
T9-14	0.191	0.185	0.200	0.032
C18:2n-6 (LA)	31.170	32.82	31.77	1.651
C20:0	0.150	0.182	0.157	0.026
C18:3n-6 (GLA)	0.011	0.010	0.084	0.032
C5C20:1	3.055	3.240	2.579	0.369
C8C20:1	0.661	0.661	1.249	0.408
C18:3n-3 (aLN)	0.160	0.149	0.216	0.062
C20:2	0.390	0.401	0.302	0.037
C22	0.042	0.063	0.154	0.046
C20:3 n6	1.583	1.462	1.141	0.129
C20:3 n3	**0.078**[a]	**0.063**[ab]	**0.037**[b]	**0.009**
C20:4 n6	0.056	0.063	0.088	0.018
C20:5n-3 (EPA)	**0.328**[b]	**0.358**[ab]	**0.571**[a]	**0.065**
C24:1	0.089	0.094	0.081	0.008
C22:3	0.025	0.034	0.029	0.006
C22:4	**0.221**[a]	**0.213**[a]	**0.161**[b]	**0.011**
C22:5n-3 (DPA)	0.798	0.761	0.695	0.063
C22:6n-3(DHA)	**0.228**[b]	**0.993**[b]	**2.603**[a]	**0.440**
SFA	41.93	42.85	42.91	1.05
MUFA	10.88	10.62	9.94	0.48
PUFA	38.40	40.69	41.41	2.11
n-3	**48.73**[c]	**54.70**[b]	**58.10**[a]	**10.05**
n-6	33.41	26.10	24.26	8.69
n-3/n-6 ratio	**1.46**[b]	**2.10**[a]	**2.39**[a]	**0.94**
SCFA	3.35	4.03	4.14	0.001
MCFA	38.59	40.42	39.56	0.52
LCFA	53.30	54.64	55.54	0.69

Where superscripts differ within a row, values are significantly different. **C20:3 n3- P=0.01, EPA- P<0.01, C22:4- P=0.03, DHA – P<0.01, n-3 – P=0.023, n-3/n-6 – P=0.01.**

SFA- Saturated fatty acid, MUFA- Medium unsaturated fatty acid, PUFA- Poly unsaturated fatty acid, n-3- Omega 3 fatty acid, n-6-Omega 6 fatty acid, SCFA- Short chain fatty acid, MCFA- Medium chain fatty acid, LCFA- Long chain fatty acid.

Table 5.17: Effect of DHA supplementation on fatty acid composition (expressed as percentage total fatty acids) of sow milk at day 2 of lactation

	Level of DHA Supplementation %			
	0	**0.03**	**0.3**	**SEM**
C10:0	0.043	0.062	0.053	0.024
C11:0	0.003	0.006	0.021	0.009
C12:0	0.102	0.129	0.104	0.037
C13:0	0.002	0.002	0.422	0.205
C14:0	2.302	2.680	2.263	0.469
C14:1	0.051	0.074	0.088	0.027
C15:0	0.079	0.084	4.954	2.382
C16:0	30.560	33.740	20.500	4.227
T9C16:1	0.887	0.893	2.345	0.509
C9C16:1	6.151	6.889	4.387	1.262
C17:0	0.234	0.2412	0.185	0.028
C17:1	1.252	1.243	1.100	0.142
C18:0	6.847	5.585	4.856	1.652
T9-14	8.207	16.022	15.982	9.058
C9	40.24	32.760	28.580	8.186
C18: 2n-3 (LA)	18.040	14.450	13.740	4.430
C20:0	0.129	0.143	0.157	0.040
C18: 3n-6 (GLA)	0.434	0.997	0.351	0.435
C5C20:1	2.104	1.839	2.157	0.364
C8C20:1	0.518	0.420	0.534	0.095
C18: 3n-3 (aLN)	0.126	0.184	0.122	0.024
C20:2	0.169	0.146	0.199	0.028
C22	0.084	0.129	0.085	0.033
C20:3 n6	0.794	0.538	0.652	0.146
C20:3 n3	0.049	0.037	0.032	0.013
C20:4 n6	0.047	0.038	0.054	0.007
C20: 5n-3EPA	0.195	0.217	0.265	0.021
C24:1	0.057	0.071	0.068	0.006
C22:3	0.017	0.019	0.031	0.003
C22:4	0.131	0.131	0.125	0.011
C22: 5n-3(DPA)	0.405	0.387	0.376	0.045
C22:6n-3 (DHA)	**0.527[b]**	**0.451[b]**	**1.515[a]**	**1.010**
SFA	40.31	42.69	34.78	4.72
MUFA	19.55	27.73	25.20	9.34
PUFA	21.43	18.31	19.05	3.96
n-3	53.25	48.61	47.90	5.00
n-6	19.40	15.70	16.30	4.36
n-3/n-6 ratio	6.51	9.69	8.76	4.23
SCFA	1.01	1.02	1.01	0.01
MCFA	41.99	46.32	38.01	3.74
LCFA	48.32	54.64	51.98	6.93

Where superscripts differ within a row, values are significantly different. **DHA – P<0.001**

SFA- Saturated fatty acid, MUFA- Medium unsaturated fatty acid, PUFA- Poly unsaturated fatty acid, n-3- Omega 3 fatty acid, n-6-Omega 6 fatty acid, SCFA- Short chain fatty acid, MCFA- Medium chain fatty acid, LCFA- Long chain fatty acid.

Table 5.18: Effect of DHA supplementation on fatty acid composition (expressed as percentage total fatty acids) of sow milk at 14 days of lactation

	Level of DHA supplementation %			
	0	**0.03**	**0.3**	**SEM**
C10:0	0.207	0.199	0.155	0.049
C11:0	0.016	0.016	0.022	0.010
C12:0	0.298	0.293	0.243	0.061
C13:0	0.004	0.003	0.304	0.232
C14:0	4.387	4.458	3.958	0.794
C14:1	0.168	0.186	0.183	0.043
C15:0	0.069	0.076	3.586	2.697
C16:0	41.600	44.580	32.840	7.278
t9C16:1	0.422	0.402	1.645	0.642
c9C16:1	10.693	11.578	8.987	2.208
C17:0	0.172	0.207	0.192	0.026
C17:1	1.489	0.253	2.181	1.180
C18:0	5.486	7.463	5.395	1.297
t9-14	9.272	11.700	11.444	7.499
C18: 2n-6 (LA)	17.350	21.610	15.830	4.032
C20:0	0.142	0.174	0.149	0.035
C18: 3n-6 (GLA)	0.491	0.558	0.280	0.396
c5C20:1	2.194	1.182	2.331	0.476
c8C20:1	0.400	1.221	0.435	0.317
C18: 3n-3 (aLN)	0.120	0.249	0.112	0.047
C20:2	0.116	0.110	0.155	0.022
C22	0.086	0.130	0.079	0.031
C20:3 n6	0.316	0.247	0.308	0.117
C20:3 n3	0.047	0.040	0.033	0.005
C20:4 n6	0.037	0.062	0.059	0.017
C18: 3n-3 (EPA)	**0.123^{b}**	**0.137^{ab}**	**0.231^{a}**	**0.029**
C24:1	0.055	0.072	0.058	0.014
C22:3	0.015	0.036	0.016	0.007
C22:4	0.103	0.095	0.115	0.018
C22: 5n-3 (DPA)	0.290	0.255	0.339	0.042
C22: 6n-3 (DHA)	**0.098^{c}**	**0.354^{b}**	**1.513^{a}**	**0.470**
SFA	54.41	57.51	59.20	0.77
MUFA	14.75	15.01	16.65	0.71
PUFA	23.69	24.48	25.65	0.66
n-3	53.22	51.15	49.35	0.67
n-6	22.78	22.48	23.21	0.90
n-3/n-6	2.38	2.31	2.18	0.85
SCFA	0.05	0.05	0.05	0.90
MCFA	58.80	60.05	60.88	0.80
LCFA	39.01	39.18	40.96	0.60

Where superscripts differ within a row, values are significantly different. **EPA – P=0.01, DHA – P<0.001.** SFA- Saturated fatty acid, MUFA- Medium unsaturated fatty acid, PUFA- Poly unsaturated fatty acid, n-3- Omega 3 fatty acid, n-6-Omega 6 fatty acid, SCFA- Short chain fatty acid, MCFA- Medium chain fatty acid, LCFA- Long chain fatty acid.

5.4 Discussion

Overall, this study had a much lower percentage pre weaning mortality than previously reported in earlier studies (Fritsche et al 1993, Baidoo et al., 2003, Rooke et al., 2000, 2001b and 2001c). The difference in still birth rate observed between treatments was non-significant which was in contrast with the earlier study (Production experiment, chapter 4) and is probably due to the low number of animals in this more detailed experiment. However, there was a similar trend for increased DHA supplementation to result in a decrease in stillborn piglets (Figure 5.1).

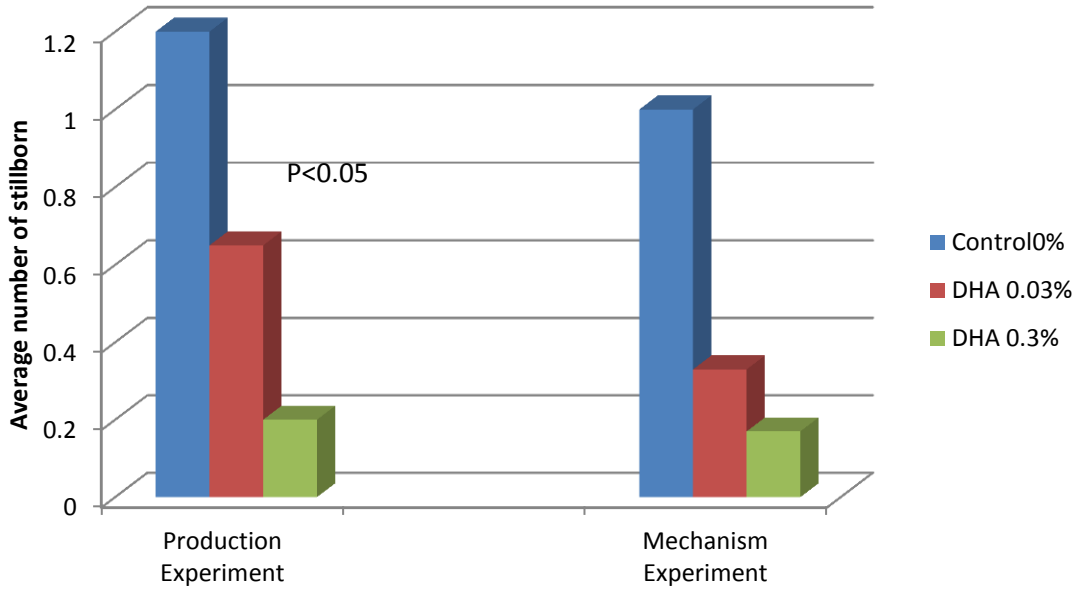

Figure 5.1 Number of stillborn piglets per litter in the production and mechanism experiments (Chapters 4 and 5).

In the present study, there was no significant increase in the farrowing duration across the treatment groups such as was reported by Adeleye et al (2011; chapter 4) in a production experiment where farrowing duration increased as DHA supplementation increased. Prolonged farrowing not only kills piglets during birth, but has also been reported to be a cause of reduced viability which makes piglets prone to starve to death or be crushed by the sow (Alonso-Spilsbury et al., 2007, Baxter et al., 2008, Shankar et al., 2009). Taken together, the results suggest that DHA supplementation positively enhances the survival of piglets, no matter how long the birth interval, possibly owing to the fact that DHA facilitates better placental blood flow, so that nutrient and blood gas exchange might be less restricted. A reduction of arterial thrombosis with the supplementation of fish oil has been reported in humans (Hornstra, 2001). Maternal – foetal blood flow was suggested to

be maintained with improved uterus and placenta vascularisation aiding the increase in blood flow and uterine growth when n-3 fatty acid was supplemented in humans, as reviewed by Allen and Harris (2001).

The birth interval and the cumulative farrowing duration are traits of importance in piglet survival which are key in determining the number of piglets born dead or alive (Baxter et al., 2008). An explanation of the mechanism involved in the observed effect of DHA on farrowing duration in the previous experiment still remains unclear, especially with the current dearth of information on the subject matter. The role of oxytocin during farrowing has been well established, as it plays a major role in myometrial contractility during labour. It was suggested that the higher the levels of oxytocin, the better for fast expulsion of piglets (van Dijk et al., 2005) which means that anything that negatively interferes with this mechanism will be detrimental to the sow and piglets. Polyunsaturated fatty acids (PUFA) are a precursor of prostaglandins (PG) which are of three types; 1-, 2-series, generated from n-6 PUFAs and Arachidonic acid (AA), and 3-series PGs, derived from eicosapentaenoic acid (EPA), which all compete for the same enzyme substrate for synthesis (Lands, 1992). As a result, the type of PUFA ingested will determine the types of PG synthesized and the physiological responses which will arise afterwards (Abayasekara and Wathes, 1999), since the 2-series PGs are more biologically active.

It has been reported in a rat study that high inclusion of any of the n-3 PUFAs will result in the depression of prostaglandin 2 production in the amnion and uterus (Allen and Harris, 2001). The longer farrowing duration of sows in 0.3% DHA group observed in the previous study might be due to reduced contraction of the uterine muscles even in the presence of oxytocin. There is a lack of information on how the uterus responds to dietary supplementation of DHA and relative mixtures of DHA and EPA (Wathes et al., 2007), and no report on the probable effect of polyunsaturated fatty acid on the production of prostaglandins during farrowing, especially PGE2 and PGF2α (Cheng et al., 2004). However, studies are emerging which suggest that DHA dietary supplementation, which has been reported to influence the AA concentration and PG production, might influence the uterine tissues to be less responsive to oxytocin stimulus, as reviewed by Wathes et al. (2007). An effect of DHA on the response of smooth muscle to oxytocin might also have a negative effect on the milk let down, and therefore neonates' growth and performance before weaning. The weaning weights of the piglets in the present study were not significantly reduced, in contrast to the production experiment. Such an effect might also

occur as a result of the increase in the concentration of EPA due to the retro conversion of DHA. The resulting effect of this might be a reduction in Arachidonic acid which is important for growth.

Interestingly, and in spite of the prolonged farrowing duration in the previous study, the result of the vitality scores and early piglet behaviour, as observed in both this study and the previous study, revealed a significant influence of the feed treatment. The vitality of piglets at birth is a measure related to piglet survival, as demonstrated by Baxter et al. (2008). The current pair of studies showed that the piglets from the control litter were less vital immediately after birth, even with a shorter farrowing duration. This is different from what is expected, as previous studies (Fraser et al., 1997, Motas –Rojas et al., 2005, Alonso-Spilsbury et al., 2005) have indicated that piglets with prolonged farrowing duration are less viable at birth. According to the vitality score, taken from Baxter et al. (2008) as amended by Chevaux et al. (2010), 3.6% of the total piglets were still born or resuscitated from the control group compared to lower prevalence in the other treatment groups. This correlates with the still birth litter mean figures. A significant increase in the number of piglets that remained static in the 15 seconds after birth was observed in control group and 0.3%DHA group relative to the 0.03%DHA group. This might be connected with the prolonged farrowing duration experienced by the former two groups, as suggested by Shankar et al. (2008). Chevaux et al. (2010) criticised the vitality score of Baxter et al. (2009) based on the high percentage of piglets similarly recorded in the group V2 (which has piglets rolling onto their belly and/or raising the head but not attempting to stand). Using an amended vitality score, as suggested by Chevaux et al. (2010), in which this was divided into two sub-categories, it was observed that the 0.03% DHA maternal dietary supplementation gave a relatively greater proportion of piglets in the V2+ rather than V2- category.

The improved vitality score of piglets with supplemented DHA in this study might be expected to reduce the latency for key landmark behaviours, such as the time at which they get to the udder and subsequent suckling. However, no significant difference was seen in this study despite a strong numerical trend to this effect, which might be as a result of low sample size and the important contributing factor of individual sow behaviour. This does not correspond to the results from the previous production study (chapter 4) or from an earlier study which also reported significantly reduced latency to suckle of piglets fed n-3 PUFA from tuna oil (Rooke et al., 2001).

The metabolic substrate (blood glucose and blood lactate) levels of newborn piglets have been argued to be a pointer to the survival of the neonate (Herpin et al., 1996). The levels of lactate have been reported to be higher than those of glucose in the individual piglets within a normal litter (Randall, 1997), and the range of blood glucose and blood lactate result obtained in this study is similar to that reported by Malmkvist et al. (2006) and Hernandez et al. (2009). Cord blood lactate levels in this study were very high in the 0.3%DHA litters. Herpin et al. (1996) reported a high level of plasma lactate to reflect anoxia in stillborn piglets. High lactate levels in litters might be associated with increased farrowing duration, as a result of glycogen mobilisation by stressed neonates (Malmkvist et al., 2006). This result is justified by the correlation which exists between the blood lactate and farrowing duration. However, despite their numerically higher lactate levels piglets from the 0.3% DHA treatment did not show impaired vitality. There was no significant effect of the treatments on the cord blood glucose levels. Previous reports (Herpin et al., 1996, Tuchscherer et al., 2000) have found higher glucose concentration in less viable piglets compared to high vitality piglets (looking at behaviour 1 min after birth), suggesting an inability to utilise this metabolic fuel. The positive correlation between cord blood lactate and glucose, and their negative relationship with rectal temperature, supports this suggestion. The thermoregulatory function of the piglets was not influenced by DHA supplementation. The rectal temperatures in the present study were high at birth and within the range for normal piglets, but a decrease in rectal temperature was observed after two hours from birth in all treatments**.**

Many studies have shown that the dietary fatty acid composition influences the concentration of fatty acids found in piglets' tissues, colostrum and milk of sows (Rooke et al, 1998; Rooke et al 2000; Lauridsen and Danielsen, 2004; Lauridsen and Jensen 2007; Samples et al., 2011). The increase in the concentration of DHA, EPA and the ratio of n-3/n-6 in the piglet blood at farrowing and 48hours postpartum was not surprising, as the fatty acid composition of the algae fed to the sows in the last four weeks of pregnancy consisted almost exclusively of DHA. This finding is consistent with a previous study with tuna oil supplementation, which found an increase in plasma DHA in the umbilical cord of piglets at birth (Rooke et al. 1999; 2000) and also observed a significant increase of DHA concentration in plasma samples at birth.

The increase in the omega-3/omega-6 ratio in the plasma samples suggests that DHA can cross the placenta into the foetal circulation in the last four weeks of gestation. This could also be related to the reason why the piglets were seen to be vital, looking at the mean vitality scores, since DHA supplementation is known to be important in brain and nerve tissue development at the third trimester of pregnancy (Crawford, 2000). Though the DHA and EPA were significantly increased, Arachidonic acid seemed not to be significantly affected, although a trend was observed for its reduction as DHA supplementation increased. This is similar to the result reported by Arbuckle and Innis (1993) when fish oil was fed for four days prepartum and fifteen days postpartum. Similarly, omega-3 concentrations in the colostrum samples at birth and later milk samples at day 2 were also higher and this was in line with what was observed by Rooke et al. (1998) when tuna was supplemented in sow diets. The 14 day milk sample had a higher DHA and EPA content with increasing DHA supplementation. An earlier study showed that there was a retro-conversion of DHA to EPA when pregnant women were treated with a protected DHA supplement and this was also observed in humans and rats with DHA supplementation in another *in vivo* study (Brossard *et al.*, 1996; Stark and Holub, 2004).

It has previously been reported that n-3 fatty acid supplementation can increase colostral IgG content (Mateo et al., 2009) and the serum IgG content of piglets at weaning (Rooke et al., 2003). The absence of a significant effect of DHA supplementation on the plasma IgG samples of the piglets at birth and on the 14^{th} day in the current study might be due to the method and kits used which were designed for humans and might not be suitable for detecting considerable amounts of pig IgG.

Newly born piglet survival can be also be viewed to be highly dependent on placental nutrient supply in the uterus. This has been reported to be determined by the placental quality as depicted by placenta mass, surface area and blood flow. A measure of the ability of the placenta to sustain foetal growth is placental efficiency (van Rens et al., 2005), which is the amount of foetal weight supported by a gram of placenta. The placenta area in this study for 0.3%DHA fed sows was significantly higher than for the other groups. Since placental establishment occurs much earlier in pregnancy than the time at which DHA treatments started, this result could be attributed as a chance effect which could have positively affected the survival of piglets in terms of reduced still birth

and increased vitality, as increased placental area could have aided improved blood flow and nutrient transport from the mother to the foetus.

Previous studies (Wilson et al., 1998, van der Lende et al., 2004, van Rens et al., 2005) have found that an efficient placenta is smaller, thicker and more vascularised than the less efficient ones. There was no significant difference observed in the placenta vascularisation.

5.5 Conclusion

Results from this study suggested a similar beneficial impact of supplementing Docosaheaxanoic acid (DHA) from the last week of gestation to 14days lactation as shown in chapter 4 in the reduced number of stillbirth. The colostrums, milk and blood plasma omega-3 fatty acid was also increased with increasing DHA supplementation but no metabolic explanation for the still birth was found.

Chapter 6

Exploratory behaviour and performance of piglets fed novel creep in two housing systems

6.1 Introduction

Creep feeding for improved growth and performance of piglets before and after weaning is important to the pig industry, especially if sow milk supply is reduced for any reason. Creep feed intakes have been reported to be very low during lactation (Kuller et al., 2010) and this might have an effect on weaning performance, hence the need to study ways of stimulating the exploratory behaviour and acceptance of creep feeds by piglets during lactation. One approach to achieve this might be by presenting the feed in a more variable form, using novelty to encourage exploration. Studies on rats fed novel feeds showed that rats ate more when fed different flavoured feeds in a concurrent pattern (Shafat et al., 2009; Myers et al., 2005; Treit et al., 1983). In sheep studies, it was observed that feeding novel foods by varying the colour, texture and/or the flavour of feeds in a concomitant design to growing lambs has been effective in terms of increase in feed intake (Villalba et al., 2012; Treit et al., 1983). It is expected that an increase in creep intake will enhance performance of suckling piglets (Lawlor et al., 2002; Klindt, 2003; Wattanakul et al., 2005).

To enhance weight gain in rats, cafeteria feeding was introduced to stimulate feed intake (Shafat et al., 2009). This system of feeding allows animals to have access to several food items of varied composition, appearance and texture and has led to increase in feed intake and significantly heavier rats at weaning (Rothwell and Stock, 1982). However, this increased intake of feed has also been reported to result in obesity (Shafat et al., 2009). An alternative approach, which might be expected to give greater stimulation of exploratory behaviour because of daily novelty, is the repeated variation in the nature of the available feed on a daily basis.

It has been reported that piglets reared in more extensive lactation environments have higher weaning weights and reduced post weaning growth check because of better feed intake (O'Connell et al., 2005). The extent to which this reflects better milk production by less confined sows or enhanced pre-weaning development of exploratory and ingestive behaviour by the piglets in a more complex environment has received little study.

Table 6.1 Literature on effect of flavours on feeding intake before and after weaning

Reference	Test period	Flavour (s)	Pre-weaning Intake (g/pig/d)	Postweaning Intake (g/pig/d)	Effect of flavour
King, 1979	Day7-weaning (21d). 31days after weaning	Firanor	51.8	78	FI was significant post weaning
		Control- No flavour	43.9	55	
Kornegay et al., 1979	22 days post farrowing	Sugar replacer +Aromatic attractants	-	285	FI was significant post weaning
		Control	-	195	
McLaughlin et al., 1983	Days 7/10- weaning (18d). 35days after weaning	1.Cheese flavour, 2.Composite flavour (sweet, molasses and caramel)	113.48 106.4	360 368	Significant only in week 1 pre-weaning FI and post weaning Weight Gain
		Control	115.08	355	
Langendijk et al.,2007	Days 7-weaning (21d). 10days after weaning	Garlic and Aniseed flavour	309	833	FI was significant post weaning
		Control	233	687	
Sulabo et al., 2010	Day 18-weaning (28d).	Luctarom	525	-	NS
		Control	516	-	
Yan et al., 2011	Day5-weaning (28d). 7days after weaning	1.Cheese 2.Vanilla	*21 19	234 228	FI was significant in pre-weaning period only. Weight Gain was significant post weaning
		Control	17	210	

- Feed intake (FI) , NS- Not significantly improved when compared with the control group

Studies in rats have demonstrated that flavour supplementation increases feed intake during suckling and after weaning (Treit et al., 1983, Hepper 1988). Previous studies have also reported the benefits of introducing creep early to piglets during lactation (Bruininx et al., 2002, Kuller, 2004, Sulabo et al., 2008) and suggested that including flavours in piglet diets could enhance their feed intake during suckling and post weaning performance.

In some flavoured creep studies, it was found out that weaned pigs had preference for sugar replacers mixed with aromatic attractants (Kornegay et al., 1979), Firanor (King, 1979) and garlic and aniseed flavour (Langendijk et al.,2007) with increased consumption recorded only during the post weaning period when compared to the control groups (table 6.10). In some studies, the increased creep consumption during the post weaning period could be as a result of exposure to the flavours via the amniotic fluid during gestation (prenatal learning experience) or the milk during suckling, which gives familiarity with the aroma/taste of the flavour when the creep is presented. Previous studies reported that piglets fed some flavoured diets during the lactation period showed a preference for such flavours when fed after weaning.

The effects of creep feed intake on post weaning performance have been extensively documented (Pajor et al., 1991, Appleby et al., 1992, Fraser et al, 1994, Kuller et al., 2004, Sulabo et al, 2008, Oostindjer et al., 2010). While some studies reported a significant effect of creep feed on post weaning intake and weight gain (Bruininx et al., 2002, Kuller et al., 2004), others have found no effect (Pajor et al., 1991, Appleby et al., 1992, Fraser et al, 1994).

To test this suggestion, this study aimed at investigating the effect of introducing novelty through different types of food flavour. In the past, studies using different flavours have taken two forms; 1) Direct introduction of single (or mixed) flavour into piglet creep diets (McLaughlin et al., 1983, Nofre et al., 2002, Sulabo et al., 2010, Yan et al., 2011) (See Table 6.10); or 2). The supplementation of flavour (single or mixed) into sow diets and later into piglet diets; flavour imprinting (Campbell, 1976, King 1979, Langendijk et al., 2007).

It was hypothesized that the sequential feeding of flavoured creep will improve feed intake and weight during lactation and post-weaning period. Therefore, the aim of this current study is to investigate the effect of increasing creep feed variety by use of different sequential flavours on intake, growth and health of piglets (pre and post weaning) in two housing systems with different degrees of complexity and freedom for the sow.

6.2 Materials and Methods

6.2.1 Experimental Animals and Design

34 sows (Large White and Landrace crossbred) were used for this experiment, which had a 2x2 factorial design. At 5 days before farrowing, the sows were randomly allocated to one of two housing treatments as follows;

a) Farrowing crate

b) PigSAFE system (loose farrowing pen)

On day 10 of lactation, litters in each system were further divided into two groups based on litter size and mean piglet weight, and allocated to one of two creep feed treatments;

1) Novel creep - This was the same base creep feed as (2) with addition of one of 5 different flavouring agents given sequentially on different days as follows:

   Apricot flavour, Red fruit flavour, Toffee flavour, Apple flavour and Butterscotch flavour. All the flavours were supplied by Inroads International Company, Shropshire, United Kingdom.

2) Commercial creep - same creep feed without additional flavouring given throughout lactation, using the same presentation method as for (1)

6.2.2 Feeding and litter management

The sows were fed two standard commercial feeds; one from day 0 of gestation to transfer to farrowing accommodation, and another from this point throughout lactation. Piglets were weighed before commencing creep feeding on day 10 of lactation. The

flavours were added at the rate of 500g/t, according to manufacturer's advice, by mixing the appropriate amount (0.5g) to treat 1kg of feed with 30g of water and spraying this onto the creep feed, after which it was air dried before feeding. Control creep feed was sprayed with water alone to correct for any effects of wetting and drying. The flavoured creeps were fed in a sequential order, which differed from one batch to another (Table 6.1).

Table 6.2 Feeding order of the different flavoured creep feeds

Farrowing batch 1	Farrowing batch 2	Farrowing batch 3
Toffee	Apricot	Red Fruit
Apricot	Red fruit	Butterscotch
Red fruit	Butterscotch	Apple
Butterscotch	Apple	Toffee
Apple	Toffee	Apricot

For the first 5 days (10^{th} – 15^{th} day), a small measured amount of creep (15g, pre-weighed into labelled bags for each litter per day) was fed daily on the floor of the creep resting area. During this period, refusals could not be determined because piglets were floor fed to stimulate investigation and ingestion of the feed. On day 15, creep feeders were introduced into the crates and pens with the amount of daily creep fed doubled (30g/litter). As lactation progressed the amount of creep was increased daily, with small amounts (60g, pre-weighed into labelled bags for each litter per day) added as it was cleared up (checked at least 3 times/day), and any residual removed and weighed at the start of the next day. The creep troughs in the PigSAFE system were placed in the creep area, while the feeding troughs were placed just outside the creep in the farrowing crate system. This was because, whereas in the conventional system the sows were restricted in the crates, the sows in the loose pens could reach and eat the creep feed, or disturb feeding piglets, at all locations apart from the creep area. Litters were fed to appetite in this way as their creep intake developed. From day 20, creep feed was available ad-libitum from the feeder, and the amount consumed was recorded by weighing the amount offered at the start of each day and the amount remaining on the following morning. Litters assigned to experimental diets continued to be fed different types of flavoured

creep every day in a sequential manner, with the order randomised across litters and recorded.

All routine management procedures were carried out according to a standardised protocol for all litters. Piglets were weaned in the fourth week (approx 28d of age) and moved as litter groups to weaner accommodation with fully-slatted flooring in all-in all-out controlled environment rooms. They were offered the standard commercial creep feeds ad libitum according to the normal farm routine and their feed intake and growth monitored for the first 2 weeks after weaning. The health conditions of the litter were also monitored.

The piglet feeds used in the experiment were standard commercial diets supplied by A-One Feeds, Thirsk (Table 6.2). Flat deck 1 was used as the creep feed during lactation and was provided at a quantity of 1kg per pig after weaning. The second diet, Flat Deck 150, was then phased in to provide a further 2kg per pig before the third diet, Turbowean, was phased in and fed until the end of the experiment.

Table 6.3 Composition of creep feed diets fed during lactation to 2weeks post weaning.

	Flat Deck 1 (%)	Flat Deck 150 (%)	Turbowean (%)
Phosphorus	0.70	0.68	0.64
Sodium	0.30	0.30	0.20
Lysine	1.70	1.55	1.45
Protein	22.50	21.00	21.50
Crude fibre	2.50	3.00	21.00
Calcium	0.75	0.74	0.75
Ash	6.00	5.50	5.00
Oil and fat	8.50	6.50	6.25
Methionine	0.63	0.63	0.57
DE (MJ/kg)	16.50	16.00	15.80

6.3 Measurements

6.3.1 Production data

Litter size at day 10 of lactation and subsequent mortality and veterinary treatments were recorded. The creep feed offered and uneaten residuals were recorded daily. Individual piglets in each litter were weighed at day 10, 15, 22 and weaning (at approx. day 28). After weaning, feed intake was recorded for the first and second week post-weaning. Piglets were weighed at 7 and 14 days post-weaning. The litter weight gain and feed conversion ratio were calculated.

6.3.2 Behaviour studies

With the aid of cameras connected to a multiplexer and a VCR unit, the creep feeding behaviour of litters was recorded for the first 5 days after introduction of the feed hopper. The frequency of visits to the creep feeder was recorded for selected periods.

6.3.3 Statistics

All data collected were subjected to a two way analysis of variance (ANOVA) using the GLM procedure in Minitab 16 statistical software.

6.4 Results

There was no significant effect of housing type on the amount of creep consumed and the weekly weights of the piglets during lactation (Table 6.3).

Table 6.4 Main effect of housing type on feed intake and weight of piglets from day 10 of lactation to weaning.

	Farrowing crate	PigSAFE pen	SEM	P value
Number of piglets/litter	10.73	10.67	0.18	0.81
Weaning age (days)	27.95	28.25	0.37	0.53
Total feed intake/pig (g)				
15-22days	19.70	19.72	0.02	1.00
22days-weaning	48.18	70.65	14.24	0.21
10days-weaning	74.90	97.42	19.76	0.37
Total feed consumed/litter during lactation	792.7	1052.6	209.7	0.33
Weight/pig (kg)				
Initial weight (day 10)	2.93	3.03	0.18	0.35
15days	4.55	4.74	0.34	0.65
22days	5.45	5.96	0.46	0.38
Average weaning weight	7.33	8.12	0.44	0.25

Table 6.4 shows that there was no significant effect of flavoured feed treatment on the weekly weights of the piglets. However, there was a significant increase in the amount of creep feed consumed by the piglets fed flavoured feeds during lactation.

Table 6.5 Main effect of flavour diversity on feed intake and weight of piglets from day 10 of lactation to weaning.

	Control	Flavour	SEM	P value
Number of piglets/litter	10.74	10.65	0.18	0.72
Weaning age (days)	28.09	28.11	0.33	0.96
Total feed intake/pig (g)				
15-22days	8.46	30.94	22.77	0.01
22days-weaning	38.55	80.28	42.52	0.03
10days-weaning	54.04	118.28	17.37	0.01
Weight/pig (kg)				
Initial weight (10 days)	2.94	2.92	0.16	0.93
15days	4.62	4.67	0.29	0.91
22days	5.80	5.61	0.40	0.74
Average weaning weight	7.70	7.74	0.39	0.87

There was no interaction between the effect of flavour and housing system on the amount of creep consumed and the corresponding weekly weights (Table 6.5).

Table 6.6 Interactive effect of flavour treatment and housing system on feed intake and weight of piglets from day 10 of lactation to weaning.

	Farrowing crate		PigSAFE pen			
	Control	Flavour	Control	Flavour	SEM	P value
Number of piglets/litter	10.82	10.64	10.67	10.67	0.29	0.72
Weaning age (days)	28.18	27.73	28.00	28.11	0.52	0.31
Total feed intake/pig (g)						
15-22days	9.30	30.10	7.67	31.77	9.27	0.84
22days-weaning	33.06	63.29	44.04	97.26	20.13	0.52
10days-weaning	49.33	100.48	58.76	136.08	27.95	0.60
Weight/pig (kg)						
Initial weight	2.80	2.85	3.08	2.99	0.25	0.74
15days	4.44	4.65	4.80	4.68	0.48	0.69
22days	5.23	5.66	6.36	5.52	0.65	0.29
Average weaning weight	7.17	7.49	8.24	8.00	0.63	0.47

The mean intake of each of the different flavoured creep feeds offered to piglets during the lactation period was analysed with litter included as a random factor and correcting for the various orders in which these feeds were given (Table 6.6). There was a significant effect of the individual litter on creep feed consumption ($P<0.001$). In

addition, there was also a significant difference between flavours in the amount eaten by the piglets. The piglets consumed creep flavoured with butterscotch significantly more than red fruit flavoured creep.

Table 6.7 Effect of flavour and order of presentation on piglet creep feed intake from 10 days to weaning

Creep flavour	Intake/pig (g)	Order of presentation	Intake/pig(g)
Toffee	20.46 [ab]	First	19.20
Apricot	15.01 [ab]	Second	26.00
Butterscotch	35.14 [a]	Third	23.57
Apple	24.47 [ab]	Fourth	17.85
Red fruit	14.99 [b]	Fifth	23.45
SEM	3.89		3.89
P Value	0.004		0.55

Values that do not share a letter are significantly different

There was no significant effect of lactation housing system on the quantity of feed consumed in the first 2 weeks after weaning or the weekly post weaning weights of the piglets (Table 6.7).

Table 6.8 Main effect of lactation housing system on feed intake, weight of piglets and feed conversion ratio from weaning to two weeks post weaning.

	Farrowing crate	**PigSAFE pen**	**SEM**	**P value**
Average feed intake/pig (kg)				
0-2weeks after weaning	3.93	3.96	0.23	0.92
Weight/pig (kg)				
1week post weaning average weight	8.87	9.42	0.42	0.30
2weeks post weaning average weight	12.16	12.47	0.47	0.59
Weight gain in the first week	1.54	1.31	0.21	0.38
Weight gain in the 2weeks post weaning	4.83	4.35	0.38	0.32
Feed Conversion Ratio	0.85	1.01	0.08	0.10

Table 6.8 shows that there was no significant effect of the flavoured creep treatment on the feed intake or the weekly weights of the piglets after weaning, although a tendency for improved weight of flavour pigs was seen at the end of week 2. However, there was a significant increase in the average weight gain over the two weeks after weaning of piglets fed flavoured creep during lactation.

Table 6.9 Main effect of the flavoured creep treatment on feed intake, weight of piglets and feed conversion ratio from weaning to two weeks post weaning.

	Control	Flavour	SEM	Pvalue
Average feed intake/pig (kg)				
0-2weeks after weaning	3.71	4.18	0.20	0.11
Weight/pig (kg)				
1week post weaning average weight	9.09	9.20	0.37	0.84
2weeks post weaning average weight	11.77	12.86	0.41	0.07
Weight gain in the first week	1.39	1.46	0.18	0.79
Weight gain in the 2weeks post weaning	4.07	5.11	0.33	0.03
Feed Conversion Ratio	1.01	0.85	0.07	0.11

There was no interaction in the effect of flavoured creep treatment and lactation housing system on the amount of creep consumed and the corresponding weekly post weaning weights (Table 6.9).

Table 6.10 Interactive effect of flavoured creep treatment and lactation housing system on feed intake, weight of piglets and feed conversion ratio from weaning to two weeks post weaning.

	Farrowing crate		**PigSAFE pen**			
	Control	Flavour	Control	Flavour	SEM	Pvalue
Average feed intake/pig (kg)						
2weeks after weaning	3.64	4.22	3.77	4.15	0.32	0.72
Weight/pig (kg)						
1week post weaning average weight	8.55	9.19	9.63	9.21	0.60	0.32
2weeks post weaning average weight	11.39	12.92	12.15	12.79	0.66	0.45
Weight gain in the first week	1.38	1.70	1.40	1.21	0.30	0.33
Weight gain in the 2weeks post weaning	4.22	5.43	3.91	4.79	0.53	0.73
Feed Conversion Ratio	0.89	0.81	1.13	0.90	0.11	0.43

6.5 Discussion

This current study did not find any effect of lactation housing system on the weaning weight of the piglets. This is in contrast with earlier studies which reported that piglets housed in pens had a higher weaning weight than those in crates (Cronin and Smith 1992, Biensen et al., 1996). Biensen et al. (1996) attributed the reduced weaning weight of piglets in crates to a restriction in the quality of sow- piglet interaction due to space constraints. There is a dearth of information on the comparative amount of creep consumed in crates and loose farrowing pens.

Past studies have centred on the supplementation of flavour treatments consistently over time to a given litter, while the current study sequentially fed different flavoured creeps to the piglets. McLaughlin et al. (1983) reported an increase in feed intake only during week 1 of lactation, whereas the present study showed a continued increase of creep feed intake throughout lactation. The reason for this effect could be the sequential feeding of the piglets such that the piglets were eager to receive new creep feed every day because of the novel aroma or taste. Kornegay (1979) found no effect of feeding flavoured creep to piglets in conventional farrowing crates during lactation and triple deck cage housing systems in the three weeks after weaning. He suggested that it could likely be the absence of choice of different flavoured feeds for the piglets.

Sulabo et al. (2010) explained that the reason for the non-effect of feeding flavoured creep on pre weaning performance of piglets in their study was likely to be age-related differences or individual piglet variations in the way each piglet encountered the creep feed, whereas in this current study a minimum time of close familiarization of piglets to the flavoured creep feed (by floor feeding for five days before the introduction of the feeders) could have triggered an increase in the feed consumption by the piglets.

The increase in pre weaning feed intake did not lead to an increased pre weaning weight gain The total creep food energy consumption during lactation (MJ DE) in this study varied from 0.9MJ (control) to 1.9MJ (flavoured diet) digestible energy intake per piglet. This additional intake of 1MJ of energy would be expected to equate to only about 50g of extra live weight gain, which would be difficult to detect with statistical reliability.

When considering the different creep flavours fed in this current experiment, there was a significant increase in intake of creep feed mixed with butterscotch flavour compared to other flavours. The reason why the piglets chose to consume more of butterscotch flavoured creep could not be clearly explained and no previous reports for this flavour have been found. It could be that butterscotch flavour had a strong taste or smell making it more palatable and attractive compared to other creep feeds. More studies need to be carried out to ascertain this effect on feed intake, as it was suggested by Kornegay (1979) that piglets offered feed mixed with dietary sweeteners or aromatic compounds could have increased feed intake and performance because these ingredients will attract the piglets to eat more during lactation.

Piglets fed cheese and vanilla flavour (McLaughlin et al., 1983, Yan et al., 2011) both pre-weaning and post weaning ate more creep and had increased body weight gain. This current study, in contrast, shows residual effects of flavoured feed pre-weaning when piglets were offered a standard diet after weaning. This suggests that flavoured creep feeding could stimulate the exploratory foraging behaviour of piglets making them more willing to find and eat solid food after weaning and thus enhancing their post weaning growth.

Similar to earlier flavour conditioning studies which reported increased feed intake and weight in the post weaning period (Kornegay et al., 1979, Langendijk et al., 2007), this study found a significant beneficial effect of the flavour treatment on the weight gain of piglets over the two weeks after weaning, even though their post weaning average feed intake was not significantly increased. However, a numerical difference in mean intake of 13% was recorded, which might have become statistically significant with greater replication.

Post-weaning performance of piglets from outdoor systems was found to be better compared to commercial indoor rearing of pigs according to Cox and Cooper (2001). The increase in feed intake and growth of piglets housed in outdoor pens during the pre-weaning period was reported to be due to the enriched environment of the piglets, which facilitates early exposure of pigs to solid food and early development of the gut (Oostindjer et al., 2010). In the current experiment there was no difference in the post weaning performance of piglets from the two housing systems and this could be due to

absence of enrichment in the loose housed pens, making the two farrowing conditions look to the piglets to be similar (barren) as described by Oostindjer et al. (2010).

6.5 Conclusion

Sequential feeding of different flavoured creep feeds to piglets during lactation increased their solid food intake prior to weaning and increased weight gain during the first two weeks after weaning. The sequential style of feeding the flavours is a novel approach which may be more effective than continuous presentation of a single flavour. The apparent preference for butterscotch flavoured creep feed could still be further verified. There was no effect of lactation housing system on the quantity of creep consumed and or the weight gain during the pre-weaning and post weaning period. It may be that the pen system used in this study, despite giving greater freedom to the sow, was not perceived by the piglets as being a significantly more enriched environment.

Chapter 7

General Discussion

With the existence of non-confinement systems for farrowing and lactation, which have been designed to improve sow welfare without compromising piglet welfare (Edwards, 2008), employing additional strategies, methods or skills in order to further reduce piglet mortality is inevitable. Piglet survival and welfare are dependent on the interaction of multiple factors (Edwards, 2002).

To address the welfare and economic challenge posed by piglet mortality, this study investigated both environmental and nutritional strategies of enhancing piglet survival as suggested by Edwards (2002). Initially aspects of an environmental strategy were addressed by investigating the effect of two different space allocations on survival of piglets in loose housing pens with support features (Chapter 3). The extent to which sows could be conditioned to farrow piglets in a safe position by using pen design features was also studied. Since pigs in loose housing systems may need to be more robust, one strategy for preparing the piglets for this environment by maternal dietary supplementation of long chain omega-3 acid (DHA) in varying quantity to enhance piglet vitality and viability was investigated (Chapter 4). Following the unexpected results on stillbirth reduction obtained during the production experiment (Chapter 4), a physiological study aimed at understanding the underlying mechanisms responsible for the responses of piglets to DHA supplementation was carried out (Chapter 5). Finally, in view of the reduced weaning weight seen in DHA supplemented piglets in the production experiment, a new method/procedure of improving creep feed intake of suckling piglets was investigated (Chapter 6). Tackling the problem of piglet mortality is an on-going concern and the overall results of this study have no doubt contributed to the existing body of knowledge in this area.

7.1 Environmental Strategy: Effect of pen sizes/space

Increase in pen size was found to increase pre weaning mortality due to crushing, though the significant effect of pen size could not be statistically demonstrated in the study of behaviour (Chapter 3), using a subset of sows from a larger trial. The final result from the complete experiment reported an increase in the death of piglets before weaning in the large space pens (Baxter et al., 2011). The behaviour of sows leading to crushing in the two pen sizes investigated was found to be different, and was associated with the nest space allocation in the different pen sizes. The death of piglets in the large space pens, which was attributed to the rolling movement and the sit to lie transitional movement of the sows, clearly demonstrates the hazard of excessive nest space.

This study found out that designing too much nesting space for the sow around farrowing might predispose the piglets to being crushed because of the greater number of unsupported posture changes by the sow. The farrowing crate was introduced to prevent such posture changes, but does not give much scope for the behavioural needs of the sows, thus leading to a significant welfare problem as reported by Hotzel (2004). These above mentioned risky movements were also reported in a study by Weary et al. (1996), who found out that rolling movements of the sow immediately after farrowing, which are facilitated by the amount of space they are given, were responsible for the death of the majority of piglets. The stand to lie transitional movements in the small pens, where sows are unable to perform the full sequence of pre-lying piglet gathering behaviours, also shows that these pens pose some risks, similar to those for sows housed in crates, for the crushing of piglets during such posture change. More studies should be carried out to find out the optimum space needed for the sows before, around and after parturition.

The intent of the PigSAFE pen design was to encourage the sow to farrow in a location which resulted in delivery of the piglets near to the heated creep area, reducing the risk of early hypothermia and crushing. This aim was achieved, with the majority of the sows in the two pens farrowing in such a location – facing the nest entrance. This study (Chapter 3) suggested that the reason for choosing this could be due to either the natural instinct of the sows to face the nest entrance and potential danger, or to the presence of strategically placed pen features such as the sloping wall designed to ease lying behaviour.

It has been suggested that the use of pen features such as bars (Andersen et al., 2007) and sloped walls (Damn et al., 2006) could reduce piglet mortality because of their importance in aiding the sows to complete the lying down process which has been reported to be dangerous (Wechsler and Hegglin, 1997). Though the sloped walls were mostly used by sows in both pen sizes while changing posture during and after giving birth, the use of this support did not always prevent crushing, especially in the small space pens in this study. At the end of this study, it could be deduced that an optimum nest space area for the sow and modifying the existing pen features will enhance piglet survival in loose farrowing pens like PigSAFE. The length of the creep protection bars could be shortened and the lower end bent inwards at an angle above the floor to reduce the numbers of piglets crushed beside the creep bars (Chapter 3). However, the newly born piglets should also be better prepared for the new challenge of an extra-uterine life in an open pen with the mother. To ensure this, experiments aimed at improving the vitality and vigour of new born piglets to cope with the mismatch in size and weight of the free-moving sow were carried out.

7.2 Nutritional Strategy: Supplementation of DHA

Maternal supplementation of omega-3 fatty acid using different fish oils in pigs has been extensively documented (Chapter 2). It was previously observed that fish oil (salmon) supplementation extended the gestation length of sows and improved survival despite reduced new born piglet birth weight (Rooke et al., 2001). Studies on human and rat species have also reported the increased gestation length as a result of feeding omega-3 fatty acid (Olsen et al., 1990, Smuts et al., 2003). In contrast to Rooke's study, the production and mechanism study (Chapters 4 and 5) did not observe an increase in gestation length and reduced birth weight when sows were fed varying quantity of alga biomass. This suggests that feeding different sources of omega-3 fatty acid could result to different effects on the sows. Fish oil (salmon) is known to have a high ratio of EPA to DHA and this has been reported to be responsible for the suppression of arachidonic acid which is necessary for synthesis of prostaglandin required during parturition (Rooke et al., 2001c). The reduction in arachidonic acid was also suggested to have been responsible for the reduced birth weight reported in the study (Reese, 2003).

Though the gestation length was not increased, an unexpected result seen in the sows fed algal biomass was a prolonged farrowing duration (Chapter 4) suggesting an effect of DHA on the farrowing process. The prolonged farrowing duration observed in this study is difficult to explain because no previous study has reported the effect of DHA or any omega -3 fatty acid supplementation on the progress of farrowing. The farrowing duration increased with increasing DHA supplementation, indicating the existence of a link between the DHA supplementation and tissues, processes or hormones associated with farrowing. The mechanism experiment (chapter 5) could not clearly explain the reason why the farrowing duration was prolonged in DHA fed sows, since prostaglandin concentrations were not examined to determine whether the inclusion of DHA affected the PGF2α hormone during farrowing.

It is somewhat surprising that stillbirth was significantly reduced in DHA litters, since a higher number of stillborns would be expected as a result of the increased farrowing duration recorded in DHA fed sows (Chapter 4). A similar still birth trend was shown in the mechanism experiment (Chapter 5), but is difficult to explain as measures on neonatal piglet physiology did not show any significant differences in degree of hypoxia. Stillbirths have been reported to constitute a major cause of piglet death in the first three days after birth (Chapter 2), so reducing stillbirth by 0.2/litter will greatly increase the number of piglets weaned and finished, thus positively impacting on farmers' profitability.

Stillbirth has been linked to increased farrowing duration, placental insufficiency and temperature stress in the last trimester of pregnancy (Leenhouwers, 2003) but this study showed that, even in spite of prolonged farrowing, supplementing DHA could positively enhance survival. It can be suggested that the survival of piglets with extended parturition can be attributed to the better sufficiency of placental blood flow, which keeps them alive till they are expelled, though erythrocyte counts and haemoglobin concentrations were not investigated. Reduced haemoglobin concentration and erythrocyte counts have been reported in stillborn piglets when compared with born alive piglets (Svendsen et al., 1991, Svetina et al., 2006).

The vitality of piglets from sows fed DHA in this study (Chapters 4 and 5) was improved in the face of prolonged farrowing duration. Brain tissues were not examined in this study, which would have further shown if the improved piglet vitality and vigour immediately after birth was linked to increased brain DHA concentration, as reported by Rooke et al. (2001c). However, the blood plasma samples at birth in this study showed an increase in DHA concentration, and this has been shown to correlate to brain concentration (Rooke et al, 2001). Hence there is a high probability that DHA concentration in the brain tissues of the new born piglets would have been increased significantly and might account for the reduced latency to stand, get to the teat and suckle (Chapter 4 and 5).

Weaning weight of piglets is an important factor which influences growth and feed efficiency of piglets during the post-weaning period (Tokach et al, 1992). Because of this, pig farmers put significant effort into making sure that weaning weight is improved. One unanticipated finding was that supplementation of DHA in the production experiment resulted in a significantly reduced weaning weight, contrary to the result from a similar study as reported by Edwards (2009). A trial comparing the effect of maternal sea weed and fish oil supplementation on piglet growth reported no improvement of piglet growth performance during the lactation period (Leonard et al., 2010). This result may be explained by the fact that milk DHA was retro-converted to EPA during the later stages of lactation (Chapter 4). This could elicit the suppression of arachidonic acid thereby impairing growth and weaning weight of the piglets. Another possible explanation could involve an effect of DHA on smooth muscle contractility, as suggested by farrowing duration, which might impair milk letdown.

The optimum amount of DHA to be supplemented during lactation needs to be further investigated as the highest inclusion rate of DHA resulted in the lowest weaning weight. This current study has shown that DHA supplementation in the last four weeks of pregnancy reduced still birth and improved piglet vitality. Perhaps if the DHA was discontinued during lactation, the retro conversion of DHA to EPA would not have happened thereby leading to a better growth rate until weaning. To improve the weaning weight in conjunction with DHA supplementation, the timing and quantity of supplementation should be further investigated.

7.2.1 Creep Feeding

In a bid to increase weaning weight of piglets, strategies such as creep feeding have been used (Chapter 6). Supplementing creep during suckling was found to increase growth rate in the post weaning period (English, 1980) as documented by Pluske et al. (2003). According to a review by Pluske et al. (1995), dry creep feed intake during lactation is usually very small and unlikely to have any positive effect on piglets weaning weight. Previous studies have also reported no significance of creep feeding throughout lactation (Chapter 6). The age of the piglets has been a major factor contributing to the low intake of creep feed (Sulabo et al., 2010).

In order to influence the palatability of the diet to improve feed intake, several studies have investigated different flavours in different concentrations (Chapter 6). A few flavour imprinting and flavour conditioning studies have reported an increase in feed intake after weaning though not during lactation (Chapter 6). The novel approach to feeding piglets which was used in this thesis showed that suckling piglets can be made to consume more creep by stimulating their exploratory behaviour. This suggests that maturity or age influences on pre weaning consumption can be overcome by the introduction of novelty into feeding creep to suckling piglets.

The consumption response of the piglets to the different flavoured creep cannot be explained in clear terms. The addition of flavour could have some effect on the chemical properties of the creep feed, affecting the preference of the piglets for them. The lack of a significant residual effect of flavoured creep on post weaning consumption could then be due to the non-addition of the flavour during this period, which could elicit a detrimental effect on the attractiveness for the piglets. The weaning weight of the piglets in this study (Chapter 6) was not improved even with a significantly improved consumption of flavoured creep during lactation. This effect could be as a result of the limited number of replicates studied; the amount of additional creep feed energy needed for a measurable improvement in weight gain during lactation was not attained as described by King (1979). However, despite the lack of significance in weaning weight and post weaning feed intake, a reliable improvement in post weaning growth was measured, indicating a production benefit from this novel approach.

7.3 Further Study

This current study has shown that environmental and nutritional strategies could enhance the survival and growth of piglets' pre and post weaning. However, more investigation should be carried out on defining the optimum space needed for sows in loose farrowing systems which will positively cater for the welfare of the sows and reduce piglet mortality. The PigSAFE pens with its features (bars and sloping walls) should be reviewed in the future to enhance piglet survival, although performance in this system was no worse than that in farrowing crates in this study (Chapters 4 and 5). Investigating the effect of reducing the length and adjusting the angle of the creep bars and sloped walls could be worthwhile.

The two DHA experiments suggest that the foetal development of piglets and their subsequent survival is influenced by the supplementation of DHA in the maternal diet. Previous studies using fish oil reported an increased piglet brain DHA concentration and reduced latency to suckle, as reviewed in chapter 2. Studies on inclusion of algal biomass compared with fish oil could assist in understanding to what extent DHA from alga biomass and/or fish oil is beneficial. The quantity and timing of DHA supplementation should be an ongoing investigation, as time constraints did not permit us to carry out further work on this study. Discontinuation of DHA supplementation immediately after farrowing should be investigated to see if the weaning weight of piglets would be improved. Further physiological studies looking at the mechanism of the effect of DHA on farrowing duration and still birth should be carried out. Supplementation of DHA should also be carried out on a larger commercial scale to see if the result obtained in this study could be replicated on other farms.

The effect of creep feed novelty on feed intake and post weaning performance should be replicated on a larger scale, and the animals monitored throughout their life to investigate long term effects. Further studies to explain the preference of piglets for particular flavours should also be carried out; in particular a commercial scale experiment to be able to affirm the preference for butterscotch flavour. The supplementation of liquid diets (milk replacers) could also be investigated, since this has been reported to increase weaning weight at 28 days by 1.62 kg (Kim et al., 2001).

7.4 Conclusion

The available information after this research suggests that maternal dietary supplementation with DHA can improve piglet survival by reducing stillbirth and enhancing vitality and viability in the first few days of life, though weaning weight was reduced. However, further work needs to be done to investigate the physiological mechanisms that brought about these effects. This study discovered a new method of improving creep feed intake of lactating piglets with benefits to post weaning performance. The advantage of feeding flavoured creep sequentially in order to increase weaning weight could be further explored by carrying out studies on more litters and following the pigs through to slaughter.

References

Abayasekara, D. R. E. and Wathes, D. C. (1999) 'Effects of altering dietary fatty acid composition on prostaglandin synthesis and fertility'. *Prostaglandins, Leukotrienes and Essential Fatty Acids*, 61, pp 275-287.

Adeleye, O.O., Brett, M., Blomfield, D., Guy, J.H and Edwards, S.A 2011. Effect of essential fatty acid supplementation of sow diets on piglet survival in two farrowing systems, Proceedings of the 62nd Annual Conference of the European Federation of Animal Science, Stavanger, Aug 30, 2011, Pg 210.

Alexander, G. (1984) Constraints to Lamb Survival. In: Lindsay, D.R., Pearse, D.T. (Eds), Reproduction in Sheep, Australian Academy of Science and Australian Wool Corporation, Canberra, pp. 199-209.

Algers B and Jensen P. (1990) 'Thermal microclimate in winter farrowing nests of free-ranging domestic pigs'. *Livestock Production Science*, 25, pp 177–181.

Algers, B. (1994) Health, behaviour and welfare of outdoor pigs. Pig News Information, 15, pp. 113–115.

Algers, B., Madej, A., Rojanasthien, S., and Uvna¨s-Moberg, K. (1991) Quantitative relationships between suckling-induced teat stimulation and the release of prolactin, gastrin, somatostatin, insulin, glucagon and vasoactive intestinal polypeptide in sows. Veterinary Research Communication, 15, pp. 395–407.

Allen, K. G. D. and Harris, M. A. (2001) The Role of n-3 Fatty Acids in Gestation and Parturition. Experimental Biology and Medicine, 226, pp. 498-506.

Alonso-Spilsbury M., Ramirez-Necoechea R., Gonzalez- Lozano M., Mota-Rojas D., and Trujillo-Ortega, M. E. (2007) 'Piglet survival in early lactation: a review'. *Journal of Animal and Veterinary Advances*, 6, pp.76–86.

Alonso-Spilsbury, M., Mota-Rojas, D., Villanueva-García, D., Martínez-Burnes, J., Orozco, H., Ramírez-Necoechea, R., Mayagoitia, A. L. and Trujillo, M. E. (2005)

‘Perinatal asphyxia pathophysiology in pig and human: A review’, *Animal Reproduction Science*, 90, (1-2), pp. 1-30.

Andersen, I. L., Berg, S. and Bøe, K. E. (2005) ‘Crushing of piglets by the mother sow (Sus scrofa)--purely accidental or a poor mother?’, *Applied Animal Behaviour Science*, 93, (3-4), pp. 229-243.

Andersen, I. L., Tajet, G. M., Haukvik, I. A., Kongsrud,S and BÃ¸ K. E. (2007) "Relationship between postnatal piglet mortality, environmental factors and management around farrowing in herds with loose-housed, lactating sows". *Acta Agriculturae Scandinavica, Section A - Animal Science*, 57, pp. 38-45.

Appleby, M.C., Pajor, E.A. and Fraser, D. (1992). Individual variation in feeding and growth of piglets: effects of increased access to creep food. *Animal Production*, 55, 147-152.

Arango, J., Misztal, I., Tsuruta, S., Culbertson, M., Holl, J. W., and Herring, W. (2006) ‘Genetic study of individual preweaning mortality and birth weight in Large White piglets using threshold-linear models’, *Livestock Science*, 101, (1-3), pp. 208-218.

Arbuckle, L. D. and Innis. S. M. (1993) ‘Docohexaenoic acid is transferred through maternal diet to milk and to tissues of naturally milk fed piglets’. *Journal of Nutrition*, 123:1668-1675.

Arey, D. S., A. M. Petchey, and V. R. Fowler, (1992) "The peri-parturient behaviour of sows housed in pairs," *Applied Animal Behaviour Science*, 34, pp. 49-59.

Baidoo, S. K., Azunaya, G and A. Fallad-Rad. (2003). ‘Effects of feeding flaxseeds on the production traits of sows’. *Journal of Animal Science*, 81(1), pp. 320.

Barb, C. R., Estienne, M. J., Kraeling, R. R., Marple, R. R. X., Rampacek, G. B., Rahe, C. H and Sartin, J. L, (1991) ‘Endocrine changes in sows exposed to elevated ambient temperature during lactation’. *Domestic Animal Endocrinology* 8, pp 117.

Bate, L. A., Kreukniet, M. B. and Hacker, R. R. (1985) 'The relationship between serum testosterone levels, sex and teat-seeking ability in new born piglets'. *Canadian Journal of Animal Science*, 65, pp.627-630.

Bauchart, D. (1993) 'Lipid absorption and transport in ruminants', *Journal of Dairy Science*, 76, pp. 3864-3881.

Bauer, R. W., Gaser, B., Rosel, E., Kluge H T., and Zwiener, U. (1998) 'Cardiovascular function and brain metabolites in normal weight and intra uterine growth restricted newborn piglets- effect of mild hypoxia', *Experimental Toxicology Pathology* 50, pp. 294-300.

Baxter S. H. (1984) Intensive pig production: environmental management and design. London, Granada.

Baxter, E. M., Adeleye, O. O., Jack M, Ison S. and Edwards, S. A. (2011) The influence of space and temperature on sow farrowing location and piglet survival in an indoor free-farrowing system: the PigSAFE pen. Proceedings Australian Society of Animal Science, pp. 236.

Baxter, E. M., Jarvis, S., D'Eath, R. B., Ross, D. W., Robson, S. K., Farish, M., Nevison, I. M., Lawrence, A. B. and Edwards, S. A. (2008) 'Investigating the behavioural and physiological indicators of neonatal survival in pig', *Theriogenology*, 69, (6), pp. 773-783.

Baxter, E. M., Jarvis, S., Sherwood, L., Robson, S. K., Ormandy, E., Farish, M., Smurthwaite, K. M., Roehe, R., Lawrence, A. B. and Edwards, S. A. (2009) 'Indicators of piglet survival in an outdoor farrowing system', *Livestock Science* 124, (1-3), pp. 266-276.

Baxter, E. M., Jarvis, Susan., Sherwood, Lorna., Farish, Marianne., Roehe, Rainer and Lawrence, A. B., Edwards, Sandra. A. (2011) 'Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow', *Applied Animal Behaviour Science* 130, (1-2), pp. 28-41.

Behrens, P. W. and Kyle, D. J. (1996) 'Microalgae as a source of fatty acids', *Journal of Food Lipids*, 3, pp. 259–272.

Bereskin, B., Shelby, C. E. and Cox, D. F. (1973). Some factors affecting pig survival. *Journal of Animal Science*, 36, pp. 821–827.

Biensen, N. J., Haussmann, M. F., Lay, D. C., Christian, Jr., L. L. and Ford, S. P. (1999) 'The relationships between placental and pig birth weights and growth traits', *Animal Science*, 68, pp. 709–715.

Biensen, N. J., Wilson M. E., and Ford, S. P. (1996) 'Differential mechanisms regulating Meishan (M) and Yorkshire (Y) fetal growth'. *Journal of Animal Science*, 74 (Suppl. 1):215 (Abstr.).

Biensen, N. J., Wilson, M. E. and Ford, S. P. (1998) 'The impact of either a Meishan or Yorkshire uterus on Meishan or Yorkshire fetal and placental development to days 70, 90, and 110 of gestation', *Journal of Animal Scence,* 76, pp 2169–2176.

Birberg-Thornberg, U., Karlsson, T., Gustafsson, P. A. and Duchén, K. (2006) 'Nutrition and theory of mind--The role of polyunsaturated fatty acids (PUFA) in the development of theory of mind, *Prostaglandins, Leukotrienes and Essential Fatty Acids*, 75, (1), pp. 33-41.

Blackshaw, J. K., Blackshaw, A.W., Thomas, F. J., Newman, F.W., (1994) 'Comparison of behavioural patterns of sows and litters in a farrowing crate and a farrowing pen'. *Applied Animal Behaviour Science*, 39, 281–295.

Bland, I.M., Rooke, J.A. , Bland, V.C., Sinclair, A.G. and Edwards, S.A. (2003) 'Appearance of immunoglobulin G in the plasma of piglets following intake of colostrum, with or without a delay in sucking'. *Animal Science*, 77:277-286.

BPEX (British Pig Executive) (2004). An industry update on farrowing systems. Milton Keynes, UK.

Brazle, A. E., Johnson, B. J., Webel, S. K., Rathbun, T. J. and Davis, D. L. (2009) 'Omega-3 fatty acids in the gravid pig uterus as affected by maternal supplementation with omega-3 fatty acids', *Journal Animal Science*, 87, pp. 994-1002.

Brossard, N., Croset, M., Pachiaudi, C., Riou, J. P., Tayot, J. L and Lagarde M. 1996. Retroconversion and metabolism of [13C]22:6n−3 in humans and rats after intake of a single dose of [13C]22:6n−3-triacylglycerols. *American Journal of Clinical Nutrition*, 64:577–86.

Brown, N. A, Goulding, E. H. and Fabro, S. (1979) Ethanol embryo-toxicity: direct effects on mammalian embryos in vitro. *Science,* 206, 573–575.

Bruininx, E.M.A.M., Binnendijk, G.P., van der Peet Schwering, C.M.C., Schrama, J.W., den, H. L. A., Everts, H. and Beynen, A.C. (2002). 'Effect of creep feed consumption on individual feed intake characteristics and performance of group-housed weanling pigs'. *Journal of Animal Science*, 80, pp. 1413-1418.

Buhi, W.C., Ducsay, C. A., Bazer, F. W. and Roberts, R. M. (1982) 'Iron transfer between the purple phosphatase uteroferrin and transferrin and its possible role in iron metabolism of the fetal pig', *Journal of Biology Chemistry*, 257, pp. 1712- 1723.

Burr, G. O. and Burr, M. M., (1929) 'A new deficiency disease produced by the rigid exclusion of fat from the diet ', *Journal of Biological Chemistry*, 82, pp. 345-367.

Butler, J. E., Sun, J., Wertz, N. and Sinkora, M. (2006) 'Antibody repertoire development in swine', *Developmental & Comparative Immunology*, 30, (1-2), pp. 199-221.

Caceres, L., Bilkei, G., McGil, M. and Pena, F. J. (2001) 'The effect of levamisole on the preweaning performance of lightweight born piglets'. *Medical Veterinary*, 18: 435-438.

Callaway, T. R, Morrow, J. L, Johnson, A. K, Dailey J. W, Wallace, F. M, Wagstrom, E. A, McGlone, J. J, Lewis, A. R, Dowd, S. E, Poole, T. L, Edrington, T. S, Anderson, R. C, Genovese, K. J, Byrd, J. A, Harvey, R. B and Nisbet, D. J (2005) 'Environmental

prevalence and persistence of Salmonella spp. in outdoor swine wallows'. *Foodborne Pathogens and Disease,* 2, 263–273.

Campbell, R.G. (1976). 'A note on the use of a feed flavour to stimulate the feed intake of weaner pigs'. *Animal Production*, 23, pp. 417-419.

Capper, J. L, Wilkinson R. G, Kasapidou E, Pattinson SE, Mackenzie AM and Sinclair, L.A (2005) 'The effect of dietary vitamin E and long-chain polyunsaturated fatty acid supplementation of pregnant and lactating eweson placental and mammary transfer of vitamin E to the lamb', *The British Journal of Nutrition*, 93, pp.549–557.

Capper, J. L, Wilkinson R. G, Mackenzie A. M and Sinclair L. A (2006) 'Polyunsaturated fatty acid supplementation during pregnancy alters neonatal behaviour in sheep', *The Journal of Nutrition*, 136, pp. 397–403.

Carlson S.E, Werkman S.H, Peepples J. M, Cooke R. J. and E. A. Tolley (1993) Arachidonic acid status correlates with first year growth in preterm infants. Applied Biological Sciences, Proceedings of the National Academy of Science. USA, 90, pp. 1073-1077.

Cariolet, R., Le Diguerher, G., Julou, P., Rose, N., 'Ecobichon, P., Bougeard S. and Madec, F. (2004). Survival and growth rate of suckling piglets in the SPF herd of AFSSA at Ploufragan'. *Journal of Research in Pigs in France,* 36, pp. 435-442.

Cheng, Z., Elmes, M., Kirkup, S. E., Abayasekara, D. R. E and Wathes, D. C. (2004) Alteration of prostaglandin production and agonist responsiveness by n-6 polyunsaturated fatty acids in endometrial cells from late gestation ewes. *Journal of Endocrinolog,y* 182, pp. 249–256.

Chevaux, E., A. Sacy, Y. Le Treut, and G. Martineau. (2010) IntraUterine Growth Retardation (IUGR): Morphological and behavioural description. Proceedings of the 21st IPVS Congress, Vancouver, Canada. pp610-611.

Coalson, J. A. and Lecce, J. G. (1973) 'Influence of nursing intervals on changes in serum protein (immunoglobulins) in neonatal pigs'. *Journal of Animal Science,* 36, pp. 381-385.

Collins, E. R., Kornegay, E. T., Bonnette, E. D., (1987) 'The effects of two confinement systems on the performance of nursing sows and their litters'. *Applied Animal Behaviour Science,* 17, pp. 51–59.

Cordoba, R., Pkiyach, S, Rooke, J. A., Edwards, S. A, Penny, P. C and Pike, I. (2000) 'The effect of feeding salmon oil during pregnancy on causes of piglet deaths prior to weaning'. Proceedings of the British Society of Animal Science, pp. 105.

Cox, L and Cooper, J., (2001) 'Observations on the pre- and post-weaning behaviour of piglets reared in commercial indoor and outdoor environments'. *Journal of Animal Science,* 72, pp.75–86.

Crawford, M. A. (2000) 'Placental delivery of arachidonic and docosahexaenoic acids: implications for the lipid nutrition of preterm infants'. *The American Journal of Clinical Nutrition,* 71, pp. 275-284.

Crawford, M. A, Bloom, M, Cunnane S., Holmsen, H., Ghebremeskel, K., Parkington, J, Schimdt. W, Sinclair, A. J. and Leigh, B. C. (2001) Docosahexaenoic acid and cerebral evolution. In Fatty Acids and Lipids – New Findings, ed Hamazaki T, Okuyama H., *World Review Nutrition Diet,* Basel, Krager, 88, pp. 6-17.

Cronin G. M, Dunsmore, B. and Leeson E. (1998) 'The effects of farrowing nest size and width on sow and piglet behaviour and piglet survival', *Applied Animal Behaviour Science,* 60, pp 331–345.

Cronin, G. M and Smith, J. A. 1992. "Effects of accommodation type and straw bedding around parturition and during lactation on the behaviour of primiparous sows and survival and growth of piglets to weaning," *Applied Animal Behaviour Science*, vol. 33, pp. 191-208.

Cronin, G. M. and van Amerongen, G. (1991) ‘The effects of modifying the farrowing environment on sow behaviour and survival and growth of piglets’. *Applied Animal Behaviour Science,* 30: 287–298.

Cronin, G. M., Lefebure, B and McClintock, S. (2000) ‘A comparison of piglet production and survival in the Werribee Farrowing Pen and conventional farrowing crates at a commercial farm’, *Australian Journal of Experimental Agriculture,* 40, pp. 17-23.

Cronin, G. M., Simpson, G. J and Hemsworth, P. H. (1996) ‘The effects of the gestation and 1 farrowing environments on sow and piglet behaviour and piglet survival and growth in 2 early lactation’, *Applied Animal Behaviour Science,* 46, (3-4), pp 175-192.

Cunningham, P. J., England, M. E., Young, L. D. and Zimmerman, D. R. (1979) ‘Selection for ovulation rate in swine: correlated response in litter size and weight’, *Journal of Animal Science,* 48, pp. 509-516.

Curtis, S. E. (1974) ‘Responses of the piglet to perinatal stressors’, *Journal of Animal Science,* 38: 1031–1036.

Damgaard L. H., Rydhmer L., Lovendahl P, Grandinson K., (2003) ‘Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling’, *Journal of Animal Science,* 81(3), pp. 604-610.

Damm, B. I, Pedersen, L. J, Marchant-Forde, J. N and Gilbert, C. L (2003) 'Does feed-back from a nest affect periparturient behaviour, heart rate and circulatory cortisol and oxytocin in gilts?,' *Applied Animal Behaviour Science* 83, (1), pp. 55-76.

Damm, B. I., Forkman, B. and Pedersen, L. J. (2005a) 'Lying down and rolling behaviour in sows in relation to piglet crushing', *Applied Animal Behaviour Science,* 90, (1), pp. 3-20.

Damm, B. I., Pedersen, L. J., Heiskanen, T. and Nielsen, N. P. (2005b) 'Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth', *Applied Animal Behaviour Science,* 92, (1-2), pp. 45-60.

Damm, B. I., V. Moustsen, E. Jørgensen, L. J. Pedersen, T. Heiskanen, and Forkman, B. (2006) "Sow preferences for walls to lean against when lying down," *Applied Animal Behaviour Science*, 99, pp. 53-63.

Dantzer, V. (1982) Transfer tubules in the porcine placenta. Anatomy, 22:144–149.

Dawson, L. E. R and Edgar, H. (2005) 'Effect of source and level of fish oil for ewes in late pregnancy on subsequent performance', Proceedings of the British Society of Animal Science, pp. 141.

DEFRA (2006) Livestock: Pigs. Facts and Figures Http://www. defra.org.uk/ farms/pigs

De Passille, A. M. B. and Rushen, J. (1989) 'Suckling and teat disputes by neonatal piglets', *Applied Animal Behaviour Science*, 22, (1), pp. 23-38.

De Passille, A. M. B., Rushen, J, Harstock, T.G (1988) 'Ontogeny of Teat fidelity in pigs and its relation to competition at suckling', *Canadian Journal of Animal Science*, 68, pp. 325-338.

De Passillé, A. M. B., Rushen, J., Foxcroft, G. R., Aherne, F. and Schaefer, A. (1993) 'Performance of young pigs: relationship with periparturient progesterone, prolactin and insulin of sows'. *Journal of Animal Science*, 71: 179-184.

Devillers N, Van Milgen J, Prunier A, Le Dividich, J. (2004) 'Estimation of colostrums intake in the neonatal pig'. *Journal of Animal Science*. 78: 305-313.

Dewhurst R. J., Shingfield K. J., Lee M. R. F. and Scolan N. D. (2006) 'Increasing the concentrations of beneficial polyunsaturated fatty acids in milk produced by dairy cows in high-forage systems', *Animal Feed Science and Technology*, 131, pp. 168-206.

Dwyer, C. M., Calvert, S.K., Farish, M., Donbavand J. and Pickup H.E. (2005) 'Breed, litter and parity effects on placental weight and placentome number, and consequences for the neonatal behaviour of the lamb', *Theriogenology*, 63, pp. 1092-1110.

Dwyer, C. M., Calvert, S.K., Farish, M., Cotham, S., Donbavand, J., Chirnside, J. and Pickup, H.E. (2003) 'Breed and parity differences in ovine placentation: implications for placental efficiency and lamb vigour', Proceeding of the British Society of Animal Science York, pp. 5.

Dyck, G. W., and Swierstra, E. E., (1987) 'Causes of piglet death from birth to weaning'. *Canandian Journal of Animal Science,* 67 (2) 543-547.

Edwards S. A. (2008) On-farm animal welfare audits. Proceeding 8th London Swine Conference. London, Ontario, 1-2 April 2008. Ed JM Murphy, CFM de Lange. 145-155.
Edwards, S. A and Fraser, D. (1997) 'Housing systems for farrowing and lactation', *The Pig Journal,* 39, pp. 77-89.

Edwards, S. A. (2002) 'Perinatal mortality in the pig: environmental or physiological solutions', *Livestock Production Science*, 78, (1), pp. 3-12.

Edwards, S. A. (2005) 'Enhancing sow performance and welfare by choice of dietary energy substrates', *Biotechnology in Animal Husbandry*, 21, 149-154.

Edwards, S. A. (2007) 'Experimental welfare assessment and on-farm application', *Animal Welfare*, 16, 111–115.

Edwards, S. A. (2009) Report of Newcastle University. (Unpublished)

Edwards, S.A and Baxter, E.M. (2010). The PigSAFE project: developing an alternative to the farrowing crate. Interim briefing note - February 2010. University of Newcastle and SAC, Edinburgh. 5pp.

Edwards, S. A. and Zanella, A. (1996) Pig production in outdoor systems in Europe: production, welfare and environmental considerations. *A Hora Veterinaria*, 92, 86–93.

Edwards, S. and Rooke, J. (1999) Effects of management during the suckling period on post-weaning performance of pigs. Proceeding of the 50th EAAP Annual Meeting, Zurich, Switzerland, p. 8.

EFSA, (2007) ‘Scientific report on animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets’, *EFSA Journal*, 572, 1–100.

English P. R. and Smith W. J. (1975) ‘Some causes of death in neonatal piglets’, *Veterinary Annals,* 15, 95- 104.

English, P. R., Morrison, V., (1984) Causes and prevention of piglet mortality. Pig News Information 5, 369–376.

English, P. R., Smith, W. J. and Maclean¸ A. (1977) The Sow: Improving Her Efficiency. pp 186–218. Farming Press, LTD, Ipswitch, U.K.

English, P.R. and Wilkinson, V. (1982) In: Control of Pig Reproduction, pp. 479–506. Edited by Cole D.J.A and Foxcroft, G.R., Butterworth Scientific, London.

Estienne, M. J., Harper, A. F. and Estienne, C. E. (2006) ‘Effects of dietary supplementation with omega-3 polyunsaturated fatty acids on some reproductive characteristics in gilts’, *Reproductive Biology*, 6 (3), pp. 231-241.

Farmer, C., Devillers, N., Widowski, T and Massa, D. (2006) "Impacts of a modified farrowing pen design on sow and litter performances and air quality during two seasons," *Livestock Science*, 104, pp. 303-312.

Farmer, C., Petit, H. V., Weiler, H. and Capuco, A. V. (2009) ‘Effects of dietary supplementation with different forms of flax in late-gestation and lactation on fatty acid profiles in sows and their piglets’. *Journal of Animal Science*, 87, pp. 2600–2613.

FIN 2006. Annual review of the feed grade fish stocks used to produce fish meal and fish oil for the UK market. Accesed 18/4/2011. Fishmeal Information Network.

Ford, S. P. (1997) Embryonic and fetal development in different genotypes in pigs. Journal of Reproductive Fertility, 52(Suppl.):165–176.

Foxcroft, G. R., Dixon, W. T., Novak, S., Putman, C. T. , Town, S. C. and Vinsky, M. D. A. (2006) 'The biological basis for prenatal programming of postnatal performance', *Journal Animal Science,* 84, pp. 105-112.

Franklin, S. T., Martin, K. R., Baer, R. J., Schingoethe, D. J and Hippen A. R. (1999) 'Dietary marine algae (Schizochytrium sp.) increases concentrations of conjugated linoleic, docosahexaenoic and transvaccenic acids in milk of dairy cows', *Journal of Nutrition,* 129, pp. 2048–2052.

Fraser A. F, and Broom D. M. (1997) Farm animal behaviour and welfare. 3rd ed. Oxon (U.K.): CAB International, pp. 437.

Fraser D. (1990) 'Behavioural perspectives on piglet survival'. *Journal of Reproduction and Fertility Supplement*, 40, pp 355-370.

Fraser, D., Feddes, J.R. and Pajor, E.A., (1994) 'The relationship between creep feeding behavior of piglets and adaptation to weaning: effect of diet quality'. *Canadian Journal of Animal Science,* 74, pp. 1–6.

Fraser, D., Phillips, P. A. and Thompson, B. K. (1997) 'Farrowing behaviour and stillbirth in two environments: An evaluation of the restraint-stillbirth hypothesis', *Applied Animal Behaviour Science,* 55, (1-2), pp. 51-66.

Friess, A. E., Sinowatz, F., Skolek-Winnisch, R. and Träutner, W. (1981) 'The placenta of the pig', *Anatomy and Embryology,* 163, (1), pp. 43-53.

Fritsche K. L, Huang, S-C and Cassity, N. A. (1993) 'Enrichment of omega-3 fatty acids in suckling pigs by maternal dietary fish oil supplementation', *Journal of Animal Science,* 71, 184, pp. 1–1847.

Gluckman, P. D , H. M. (ed.) (2005) The fetal matrix: evolution, development and disease. Cambridge University Press.

Goodridge, J., Ingalls, J. R and Crow, G. H. (2001) 'Transfer of omega-3 linolenic acid and linoleic acid to milk fat from flaxseed or linola protected with formaldehyde', *Canadian Journal Animal Science*, 81, pp. 525-532.

Grandinson K., Lund M. S., Rydhmer, L. and Strandberg E. (2002) Genetic parameters for the piglet mortality traits crushing, stillbirth and total mortality and their relation to birth weight. *Acta Scandinavia, A. Animal Science*, 52, pp 167-173.

Grandinson, K., Rydhmer, L., Strandberg, E. and Thodberg, K. (2003) 'Genetic analysis of on-farm tests of maternal behaviour in sows', *Livestock Production Science,* 83, (2-3), pp. 141-151.

Gunnarsson S, J. Pickova, Högberg, A., Neil, M., Wichman, A., Wigren, I., Uvnäs-Moberg, K., and L. Rydhmer, (2009) "Influence of sow dietary fatty acid composition on the behaviour of the piglets," *Livestock Science*, (123) pp. 306-313.

Gu, Z., Y. Gao, B. Lin, Z. Zhong, Z. Liu, C. Wang, and B. Li. (2011) Impacts of a freedom farrowing pen design on sow behaviours and performance," *Preventive Veterinary Medicine,* 102, pp. 296-303.

Hanenberg, E. H., A. T., Knol, E. F and Merks, J. W. M., (2001) 'Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs', *Livestock Production Science,* 69, pp. 179–186.

Haskell, M. J. and Hutson, G. D., (1996) The pre-farrowing behaviour of sows with access to straw and space for locomotion, *Applied Animal Behaviour Science*, 49, 375–387.

Hemsworth, P. H., Pedersen, V., Cox, M., Cronin, G. M. and Coleman, G. J. (1999) 'A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets', *Applied Animal Behaviour Science,* 65, (1), pp. 43-52.

Herpin, P, Damon, M. and Le Dividich, J. (2002) 'Development of thermoregulation and neonatal survival in pigs', *Livestock Production Science*, 78, 25–45.

Herpin, P. and Le Dividich, J. (1995) Thermoregulation and the Environment. In: The Neonatal Pig Development and Survival (Ed. by M.A. Varley). CAB International.

Herpin, P., Damon, M. and Le Dividich, J. (2002) 'Development of thermoregulation and neonatal survival in pigs', *Livestock Production Science*, 78, (1), pp. 25-45.

Herpin, P., Hulin, J.C., Le Dividich, J., and Fillaut, M. (2001) 'Effect of oxygen inhalation at birth on the reduction of early postnatal mortality in pigs', *Journal of Animal Science*, 79, 5–10.

Herpin, P., Le Dividich, J., Hulin, J.C., Fillaut, M., de Marco, F. and Bertin, R. (1996) 'Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs', *Journal of Animal Science*, 74, 2067–2075.

Hepper P.G (1988) Adaptive fetal learning: Prenatal exposure to garlic affects postnatal preferences. *Animal Behaviour*, 36, pp. 935–936.

Herskin, M. S., Jensen, K. H. and Thodberg, K. (1998) 'Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows', *Applied Animal Behaviour Science*, 58, (3-4), pp. 241-254.

Hohenshell, L. M., Minick, J. A., Lay, D. C., Jr and S. P. Ford. (1996) Maternal behavior potentially affecting offspring survivability: a comparison between Meishan and Yorkshire × Landrace (YL) sows. 1996 Swine Research Reports, Iowa State University, Ames. pp 65–66.

Holman R. T, Johnson S.B, and Hatch T. F. (1982) 'A case of human linolenic acid deficiency involving neurological abnormalities', *American Journal of Clinical Nutrition*, 35, pp. 617–623.

Hornstra, G. (2001) 'Influence of dietary fat type on arterial thrombosis tendency', The *Journal of Nutrition, Health & Aging*, 5, pp. 160-6.

Hötzel, M. J., L. C. Pinheiro Machado F°, F. M. Wolf, and O. A. D. Costa. (2004) 'Behaviour of sows and piglets reared in intensive outdoor or indoor systems'. *Applied Animal Behaviour Science*, 86, pp. 27-39.

Ikemoto A., Ohishi M., Sato Y., Hata N., Misawa Y., Fujii, Y. and Okuyama, H. (2001) Reversibility of n-3 fatty acid deficiency-induced alterations of learning behavior in the rat: level of n-6 fatty acids as another critical factor. *Journal of Lipid Research,* **42**, pp. 1655–1663.

Innis S.M (2000) 'Essential fatty acids in infant nutrition: lessons and limitations from animal studies in relation to studies on infant fatty acid requirements', *American Journal of Clinical Nutrition,* **71**(suppl 1), pp. 238–244.

Innis, S. M. and Mersmann, D. G. B. a. H. J. (2005) 'Chapter 10 Essential fatty acid metabolism during early development', in Biology of Growing Animals. Volume 3 *Elsevier*, pp. 235-274.

Jarvis, S., McLean, K. A., Calvert, S. K., Deans, L. A., Chirnside, J. and Lawrence, A. B. (1999) 'The responsiveness of sows to their piglets in relation to the length of parturition and the involvement of endogenous opioids', *Applied Animal Behaviour Science*, 63, (3), pp. 195-207.

Jarvis, S., Van der Vegt, B. J., Lawrence, A. B., McLean, K. A., Deans, L. A., Chirnside, J. and Calvert, S. K. (2001) 'The effect of parity and environmental restriction on behavioural and physiological responses of pre-parturient pigs', *Applied Animal Behaviour Science*, 71, (3), pp. 203-216.

Jarvis, S., D'Eath, R.B. and Fujita, K. (2005) Consistency of piglet crushing by sows. *Animal Welfare*, 14(1), pp. 43-51.

Jensen P. (2002) The Ethology of Domestic Animals: An Introductory Text ,Wallingford, U.K.: CABI Publishing, p. 159-162.

Jensen, P. (1986) 'Observations on the maternal behaviour of free-ranging domestic pigs', *Applied Animal Behaviour Science*, 16: 131-142.

Jensen, P. (1988) ‘Maternal behaviour and mother-young interactions during lactation in free-ranging domestic pigs’, *Applied Animal Behaviour Science*, 20: 297-308.

Jensen, P. (1989) Nest site choice and nest building of free ranging domestic pigs due to farrow, *Applied Animal Behaviour Science*, 22, pp. 13-21.

Jensen, P. (1993) ‘Nest building in domestic sows: the role of external stimuli’, *Animal Behaviour*, 45, pp. 351-358.

Jensen, P. and Recén, B. (1989) 'When to wean -- Observations from free-ranging domestic pigs', *Applied Animal Behaviour Science*, 23, (1-2), pp. 49-60.

Jensen, P. and Toates, F. M., (1993) Who needs 'behavioural needs'? Motivational aspects of the needs of animals. *Applied Animal Behaviour Science*, 37, 161-181.

Jensen, P., Stangel, G. and Algers, B. (1991) 'Nursing and suckling behaviour of semi-naturally kept pigs during the first 10 days postpartum', *Applied Animal Behaviour Science*, 31, (3-4), pp. 195-209.

Jeon, J. H., Kim, D. J., Han, J. H., Yeon, S. C., Bahng, S. H., Myeong, B. S. and Chang, H. H. (2005) 'Use of a crush-reducing device to decrease crushing of suckling piglets by sows', *Journal of Animal Science*, 83, pp. 1397-1402.

Johnson, A. K. and Marchant-Forde, J. N. (2009) Welfare of pigs in the farrowing environment. In: Marchant-Forde, J.N. (Editor). The Welfare of Pigs. Springer Science. Business Media B.V., Dordrecht, The Netherlands, pp 141-188.

Johnson, A. K., Morrow, J. L., Dailey, J. W. and McGlone, J. J. (2007) 'Preweaning mortality in loose-housed lactating sows: Behavioural and performance differences between sows who crush or do not crush piglets', *Applied Animal Behaviour Science*, 105, (1-3), pp. 59-74.

Johnson, R. K., Zimmerman, D. R. and Kittok, R. J. (1984) ‘Selection for components of reproduction in swine, *Livestock Production Science*, 11: 541–558.

Kennelly, J.J., (1996) 'The fatty acid composition of milk fat as influenced by feeding oilseeds'. *Animal Feed Science and Technology*, 60, pp. 137-152.

Kerr, J. C., and Cameron N. D. (1995) Reproductive performance of pigs selected for components of efficient lean growth. *Animal Science*. 60, pp 281–290.

Kim, J.H., Heo, K.N., Odle, J., Han, I.K. and Harrell, R.J. (2001). Liquid diets accelerate the growth of easily weaned pigs and the effects are maintained to market weight. Journal of *Animal Science*, 79, 427–434.

King, M. W. 1996. The Medical Biochemistry page. Themedicalbiochemistrypage.org URL accessed on 16/3/2011.

King, R. H. (1979). 'The effect of adding a feed flavour to the diets of young pigs before and after weaning'. *Australian Journal of Experimental Agricultural Animal Husbandry*, 19, pp. 695–697.

Kitessa, S. M., Peake D, Bencini R and Williams A. J. (2003) 'Fish oil metabolism in ruminants. III. Transfer of n-3 polyunsaturated fatty acids (PUFA) from tuna oil into sheep's milk', *Animal Feed Science Technology*, 108, pp. 1–14.

Klemcke H. G. (1995) 'Placenta metabolism of cortisol at Mid and Late gestation in swine', *Biology of Reproduction*, 53, pp 1293-1300.

Klindt, J. (2003) 'Influence of litter size and creep feeding on pre-weaning gain and influence of pre-weaning growth on growth to slaughter in barrows'. *Journal of Animal Science*, 81, pp. 2434-2439.

Knight, J. W., Bazer, F. W., Thatcher, W. W., Franke, D. E. and Wallace, H. D. (1977) 'Conceptus development in intact and unilaterally hysterectomized-ovariectomized gilts: Interrelations among hormonal status, placental development, fetal fluids, and fetal growth', *Journal of Animal Science*, 44, pp 620–637.

Knol, E. F. (2001) Genetic aspects of piglet survival. Doctoral thesis. Wageningen University, Wageningen, Holland.

Knol, E. F., Ducro, B. J., van Arendonk, J. A. M. and van der Lende, T. (2002a) 'Direct, maternal and nurse sow genetic effects on farrowing-, pre-weaning- and total piglet survival', *Livestock Production Science*, 73, (2-3), pp. 153-164.

Knol, E. F., Leenhouwers, J. I. and van der Lende, T. (2002b) 'Genetic aspects of piglet survival', *Livestock Production Science*, 78, (1), pp. 47-55.

Kornegay, F.T., Tinsley, S.F. and Bryant, K.L. (1979) 'Evaluation of rearing systems and feed flavours for pigs weaned at two and three weeks of age'. Journal of Animal *Science*, 48, pp. 999-1006.

Kuller, W.I., Soede, N.M.G., Van Beers-Schreurs, H.M., Langendijk, P., Taverne, M.A.M., Verheijden, J.H.M and Kemp, B. (2004). 'Intermittent suckling: Effects on piglet and sow performance before and after weaning'. *Journal of Animal Science*, 82, pp. 405-413.

Kuller, W. I., Tobias, T. J. and van Nes, A. (2010) 'Creep feed intake in unweaned piglets is increased by exploration stimulating feeder', *Livestock Science*. 129, (1â€“3), pp. 228-231.

Kurlak, L.O and T.J. Stephenson. 1999. Plausible explanations for effects of long chain polyunsaturated fatty acids (LCPUFA) on neonates. *Arch.Dis.Child Fetal Neonatal*, 1999; 80:148–154

Kurtz, H., Zechner, U., Orth A and Fundele, R (1999) 'Lack of correlation between placenta and offspring size in mouse interspecific crosses', *Anatomy Embryology*, 200, pp. 335–343.

Lands, W. E. M. (1992) 'Biochemistry and physiology of n-3 fatty acids'. *FASEB Journal*, 6, pp. 2530–2536.

Langendijk, P., J. E. Bolhuis, and B. F. A. Laurenssen (2007). Effects of pre- and post-natal exposure to garlic and aniseed flavour on pre- and post-weaning feed intake in pigs. *Livestock Science*.108, pp.284–287.

Lauridsen, C and Jensen, S. K. (2007) 'Lipid composition of lactational diets influences the fatty acid profile of the progeny before and after suckling'. *Animal*, 1, pp.952–962.

Lauridsen, C., and Danielsen. V. (2004) Lactational dietary fat levels and sources influence milk composition and performance of sows and their progeny. Livestock *Production Science*, 91, pp. 95–105.

Lauritzen, L., Hansen, H. S and Jorgensen, M. H. (2001) 'The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina'. *Lipid Research*, 40, pp. 1-94.

Lawlor, P. G., Lynch, P. B., Caffrey, P. J and O'Doherty, J. V. (2002). 'Effect of pre- and post-weaning management on subsequent pig performance to slaughter and carcass quality'. *Animal Science*, 75, pp. 245-256.

Lawrence, A. B., Petherick, J. C., McLean, K. A., Deans, L. A., Chirnside, J., Gaughan, A., Clutton, E. and Terlouw, E. M. C. (1994) 'The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows', *Applied Animal Behaviour Science*, 39, (3-4), pp. 313-330.

Lay D. C., Matteri R. L., Carroll J. A., Fangman T.J and Safranski T. J (2002) 'Preweaning survival in swine', *Journal of Animal Science*, 80, pp. 74-86.

Le Dividich, Rooke, J. J. and Herpin, P. (2005) 'Nutritional and immunological importance of colostrum for the new-born pig', *Journal of Agricultural Science*, 143, pp. 469-485.

Lee, G. J., Ritchie, M., Thomson, M., Macdonald, A. A., Blasco, A., Santacreu, M. A., Argente, M. J. and C. S. Haley (1995) 'Uterine capacity and prenatal survival in Meishan and Large White pigs', *Animal Science*, 60, pp. 471–479.

Leenhouwers, J. I., Knol, E. F., de Groot, P. N., Vos, H., and van der Lende, T., (2002) 'Fetal development in the pig in relation to genetic merit for piglet survival', *Journal of Animal Science,* 80, pp. 1759–1770.

Leenhouwers, J. I., van der Lende, T and Knol, E. F. (1999) 'Analysis of stillbirth in different lines of pig'. *Livestock Production Science,* 57, pp. 243–253.

Leeson, S., and Caston, L. Getting the omega into the egg. Feeding flaxseed to hens boosts human health. Agri-Food Res. December, (1996) Vol. 19. No.3. Ontario Ministry of Agriculture. pp. 6-8.

Leonard, S. G., Sweeney, T., Bahar, B., Lynch, B. P and O'Doherty, J. V (2010) 'Effect of maternal fish oil and seaweed extract supplementation on colostrum and milk composition, humoral immune response, and performance of suckled piglets'. *Journal of Animal Science,* 88 (29), pp. 88-97.

Lensink, B. J., Leruste, H., De Bretagne, T. and Bizeray-Filoche, D. (2009) 'Sow behaviour towards humans during standard management procedures and their relationship to piglet survival', *Applied Animal Behaviour Science,* 119, (3-4), pp. 151-157.

Leskanich, C. O and Noble, R. C (1999) 'The comparative roles of polyunsaturated fatty acids in pig neonatal development'. *British Journal of Nutrition,* 81, pp. 87–106.

Levant, B, Radel J. D, Carlson, S. E. 2004. Decreased brain docosahexaenoic acid during development alters dopamine-related behaviors in adult rats that are differentially affected by dietary remediation. *Behaviour Brain Research*, 152, pp. 49-57.

Litten, J. C., Drury, P.C., Corson, A. M. , Lean I. J. and Clarke, L. (2003) 'The influence of piglet birth weight on physical and behavioural development in early life', *Biology Neonate,* 84, pp. 311-318.

Lou, Z. and Hurnik, J. F. (1994) 'An ellipsoid farrowing crate: its ergonomical design and effects on pig productivity', *Journal of Animal Science*, 72, pp. 2610-2616.

Lucia, J., Jr., M. N. Corrêa, J. C. Deschamps, I. Bianchi, M. A. Donin, A. C. Machado, W. Meincke, and J. E. M. Matheus. (2002) 'Risk factors for stillbirths in two swine farms in the south of Brazil. *Preventive Veterinary Medicine*, 53, pp. 285–292.

Lund, M. S., Puonti, M., Rydhmer, L., and Jensen, J., (2002) 'Relationship between litter size and perinatal and pre-weaning survival in pigs', *Animal Science*, 74, 217–222.

Malmkvist, J., Pedersen, L. J., Damgaard, B. M., Thodberg, K., Jørgensen, E. and Labouriau, R. (2006) 'Does floor heating around parturition affect the vitality of piglets born to loose housed sows?', *Applied Animal Behaviour Science*, 99, (1-2), pp. 88-105.

Malmkvist, J., Pedersen, L. J., Damgaard, B. M., Thodberg, K., Jørgensen, E. and Labouriau, R. (2006) 'Does floor heating around parturition affect the vitality of piglets born to loose housed sows?', *Applied Animal Behaviour Science*, 99, (1-2), pp. 88-105.

Marchant Forde, J. N. (2002) 'Piglet- and stockperson-directed sow aggression after farrowing and the relationship with a pre-farrowing, human approach test', *Applied Animal Behaviour Science*, 75, (2), pp. 115-132.

Marchant, J. N and Broom, D. M. (1996) "Factors affecting posture changing in loose-housed and confined gestating sows," *Animal Science*, 63, pp. 477-485.

Marchant, J. N., Rudd, A. R., Mendl, M. T., Broom, D. M., Meredith, M. J., Corning, S. Simmins, P. J. (2000) Timing and causes of piglet mortality in alternative and conventional farrowing systems. *Veterinary Record*, 147: 209-214.

Marchant, J. N., Broom, D. M., and Corning, S. (2001) 'The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system'. *Animal Science*, 72, pp.19–28.

Marchant, J. N., Whittaker, X. and Broom, D. M. (2001) 'Vocalisations of the adult female domestic pig during a standard human approach test and their relationships with behavioural and heart rate measures'. *Applied Animal Behaviour Science*, 72, (1), pp. 23-39.

Mateo, R. D., Carroll, J. A., Hyun, Y., Smith, S. and Kim, S. W. (2009)"Effect of dietary supplementation of n-3 fatty acids and elevated concentrations of dietary protein on the performance of sows". *Journal of Animal Science*, 87, pp. 948-959,

Mateo, R. D., G. Wu, J. A. Carroll, I. Shinzato and S. W. Kim. (2006) 'Dietary L-arginine supplementation improves pregnancy outcome in gilts'. *Journal of Animal Science*, 84 (Suppl. 2), pp. 7-8.

Mattos, R., C. R. Staples and W. W. Thatcher. (2000) 'Effects of dietary fatty acids on reproduction in ruminants'. *Review of Reproduction*, 5, pp. 38-45.

MCowen, K. C. and Bistrian, B. B. (2003) 'Immunonutrition: Problematic or problem solving'. *American Journal of Clinical Nutrition*, 77, pp. 761- 770.

McGlone, J. J. and Blecha, F. (1987) 'An examination of behavioural, immunological and productive traits in four management systems for sows and piglets', *Applied Animal Behaviour Science*, 18, pp. 269-286.

McGlone, J. J., and Hicks, T. A. (2000) 'Farrowing hut design and sow genotype (Camborough-15 vs 25% Meishan) effects on outdoor sow and litter productivity'. *Journal of Animal Science*, 78, pp. 2832–2835.

McLaughlin, C. L., C. A. Baile, L. L. Buckholtz, and S. K. Freeman (1983). 'Preferred flavours and performance of weaning pigs'. *Journal of Animal Science*, 56, pp. 1287–1293.

McNamara, R. K and Carlson, S. E. (2006) 'Role of omega-3 fatty acids in brain and function: potential implications for the pathogenesis and prevention of psychopathology'. *Prostaglandins, Leukoterienes and Essential Fatty Acids*, 75, pp. 329–49.

Mellor, D. J. and Stafford, K. J. (2004) 'Animal welfare implications of neonatal mortality and morbidity in farm animals'. *The Veterinary Journal*, 168, (2), pp. 118-133.

Mellor, D. J. and Stafford, K. J. (2004) 'Animal welfare implications of neonatal mortality and morbidity in farm animals'. *The Veterinary Journal*, 168, (2), pp. 118-133.

Merlot, E, Couret D, and Otten, W. (2008) ‘Prenatal stress, fetal imprinting and immunity’. *Brain Behaviour Immunology*, 22:42–51.

Mesa H, Safranski T. J, Fischer K. A, Cammack K. M and Lamberson W. R. (2005) ‘Selection for placental efficiency in swine: Genetic parameters and trends’. *Journal of Animal Science,* 83, 983-991.

Milligan, B. N., Dewey, C. E. and de Grau, A. F. (2002) 'Neonatal-piglet weight variation and its relation to pre-weaning mortality and weight gain on commercial farms'. *Preventive Veterinary Medicine*, 56, (2), pp. 119-127.

MLC, (2004) The Pig Yearbook (2004) Meat and Livestock Commission, Milton Keynes, UK.

MLC, (2007) The Pig Yearbook (2007) Meat and Livestock Commission, Milton Keynes, UK.

Moeller, S. (2000) Genetic, parity effects on productivity traits. National Hog Farmer Blueprint (D. Miller, ed). April, No. 30:22-28.

Morrow-Tesch J and McGlone J. J. (1990) ‘Sources of maternal odors and the development of odor preferences in baby pigs’, *Journal of Animal Science,* 68, 3563–3571.

Mount L. E (1967) ‘The heat loss from new-born pigs to the floor’, Research in *Veterinary Science*, 8, 175-187.

Muskiet, F. A. J., Fokkema, M. R., Schaafsma, A., Boersma, E. R. and M. A. Crawford (2004) ‘Is decahexaenoic acid (DHA) essential?: Lessons from DHA status regulation, our ancient diet, edpidemiology and randomized controlled trials’, *Journal of Nutrition,* 134, pp. 183-186.

Myers, K. P., Ferris, J. and Sclafani, A. (2005) 'Flavor preferences conditioned by postingestive effects of nutrients in preweanling rats', *Physiology and amp; Behavior*, 84, (3), pp. 407-419.

Nash, D. M., R. M. G. Hamilton and H. W. Hulan. (1995) 'The effect of dietary herring meal on the omega-3 fatty acid content of plasma and egg yolk lipids of laying hens', *Canadian Journal of Animal Science*, 75, pp. 247-253.

National Research Council (NRC), (1998) Nutrient requirements of swine, 10th revised edition, pp. 1–189. National Academy Press, Washington.

Neuringer, M., Anderson, G. J. and Connor, W. E. (1988) 'The essentiality of n-3 fatty acids for the development and function of the retina and brain'. Annual Review Nutrition, 8, pp. 517-541.

Ng, K. F and Innis, S. M. (2003) 'Behavioral responses are altered in piglets with decreased frontal cortex docosahexaenoic acid'. *Journal of Nutrition,* 133, pp.3222–3227.

Nofre, C., Glaser, D., Tinti, J. M and Wanner, M. (2002) 'Gustatory responses of pigs to sixty compounds tasting sweet to humans'. *Journal of Animal Physiology and Animal Nutrition*, 86, pp. 90- 96.

O'Connell, N. E., Beattie, V. E., Sneddon, I. A., Breuer, K., Mercer, J. T., Rance, K. A., Sutcliffe, M. E. M and Edwards, S. A. (2005) 'Influence of individual predisposition, maternal experience and lactation environment on the responses of pigs to weaning at two different ages'. *Applied Animal Behaviour Science*, 90, pp. 219–232.

Okai D. B, Wyllie D, Aherne A. H and Ewan R. C (1978) 'Glycogen reserves in the fetal and newborn pig'. *Journal of Animal Science*, 46, pp. 391–401.

Oliviero, C., Heinonen, M., Valros, A and Peltoniemi, O. (2010) 'Environmental and sow-related factors affecting the duration of farrowing'. *Animal Reproduction Science*, 119, pp. 85-91.

Olmos-Hernandez, A., Trujillo-Ortega, M. E., Alonso-Spilsbury, M., Ramirez-Necoechea, R and Mota-Rojas, D. (2008) 'Foetal monitoring, uterine dynamics and reproductive performance in spontaneous farrowing sows'. *Journal of Applied Animal Research*, 33, pp. 181–185.

Olsen, S. F., Olsen, J and Frische, G. (1990) 'Does fish consumption during pregnancy increase fetal growth? A study of the size of the newborn, placental weight and gestational age in relation to fish consumption during pregnancy'. International Journal of Epidemiology, 19, pp. 971–977.

Oostindjer M, Bolhuis JE, Van den Brand H, Kemp B (2010) 'Prenatal flavor exposure affects growth, health and behavior of newly weaned piglets'. *Physiology and Behaviour*, 99, pp. 579–586.

Pajor, E.A., Fraser, D. and Kramer, D.L. (1991) 'Consumption of solid food by suckling pigs: individual variation and relation to weight gain'. *Applied Animal Behaviour Science*, 32, pp. 139-155.

Pajor, E. A., Weary, D. M., Fraser, D and Kramer, D. L. (1999) "Alternative housing for sows and litters: 1. Effects of sow-controlled housing on responses to weaning," *Applied Animal Behaviour Science*, 65, pp. 105-121.

Papadopoulos, G. A., Maes, D. G. D., Van Weyenberg, S., van Kempen, T. A. T. G., Buyse, J., and Janssens, G. P. J., (2009) "Peripartal feeding strategy with different n-6: n-3 ratios in sows: effects on sows' performance, inflammatory and periparturient metabolic parameters," *British Journal of Nutrition*, 101, pp. 348-357.

Papadopoulos, G., Goulas, C., Apostolaki, E and Abril, R. (2002) 'Effects of dietary supplements of algae, containing polyunsaturated fatty acids, on milk yield and the composition of milk products in dairy ewes', *Journal of Dairy Research*., 69, pp. 357-365.

Parfet R., K. A. and Gonyou, H. W. (1990) 'Directing the teat-seeking behaviour of newborn piglets: use of sloped floors and curved corners in the design of farrowing units', *Applied Animal Behaviour Science*, 25:71-84.

Pedersen, L. J., Damm, B. I., Marchant-Forde, J. N. and Jensen, K. H. (2003) 'Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24 h after farrowing onset', *Applied Animal Behaviour Science*, 83, (2), pp. 109-124.

Pedersen, L. J., Damm, B. I., Marchant-Forde, J. N. and Jensen, K. H. (2003) 'Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24 h after farrowing onset', *Applied Animal Behaviour Science*, 83, (2), pp. 109-124.

Pedersen, L. J., Jorgensen, E., Heiskanen, T., and Damm, B. I. (2006) 'Early piglet mortality in loose-housed sows and piglet behaviour and to the progress of parturition', *Applied Animal Behaviour Science,* 96, pp. 215–232.

Pedersen, B. P., L. J., Jørgensen G and I. L. Andersen. (2011) 'Neonatal piglet traits of importance for survival in crates and indoor pens'. *Journal of Animal Science,* 89, pp. 1207-1218, 2011.

Pedersen, L. J and T. Jensen. (2008) "Effects of late introduction of sows to two farrowing environments on the progress of farrowing and maternal behavior," *Journal of Animal Science,* 86, pp. 2730-2737.

Pedersen, L. J., E. Jorgensen, T. Heiskanen, and B. I. Damm. (2006) 'Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition'. *Applied Animal Behaviour Science,* 96, pp. 215–232.

Perez-Rigau, A., Lindemann, M. D., Kornegay, E. T., Harper, A. F. and Watkins, B. A. (1995). 'Role of dietary lipids on fetal tissue fatty acid composition and fetal survival in swine at 42 days of gestation', *Journal of Animal Science*, 73, pp. 1372- 1380.

Perry, J. S. (1954) 'Fecundity and embryonic mortality in pigs', *Journal of Embryology and Experimental Morphology*, 2, pp. 308–322.

Petersen, V., Recén, B. and Vestergaard, K. (1990) 'Behaviour of sows and piglets during farrowing under free-range conditions', *Applied Animal Behaviour Science*, 26, (1-2), pp. 169-179.

Petersen, V., Recén, B. and Vestergaard, K. (1990) 'Behaviour of sows and piglets during farrowing under free-range conditions', *Applied Animal Behaviour Science*, 26, (1-2), pp. 169-179.

Pettigrew. J. E., Jr. (1981) 'Supplemental dietary fat for peripheral sows': A review; *Journal of Animal Science*, 53, pp. 107.

Phillips, P. A and Fraser, D. (1993) 'Developments in farrowing housing for sows and litters', Pig News and Information 14, 51–55.

Pickard, R. M, Beard A. P, Gentle K., Scott-Baird E., and Edwards, S. A. (2006) Lamb viability is improved by supplementing Docosahexaenoic acid for a specific time period during late gestation. Proceedings of the British Society of Animal Science, pp. 6.

Pickard, R. M, Beard A. P, Seal C. J, and Edwards, S. A. (2008) 'Neonatal lamb vigour is improved by feeding docosahexaenoic acid during late gestation', *Animal*, 2: pp. 1186-1192.

Pluske, J. R., Williams, I. H and Aherne, F. X. 1995. Nutrition of the neonatal pig. The Neonatal Pig: Development and Survival. M. A. Varley, ed. CAB Int., Wallingford, UK.

Pluske, J. R., Black, B., Pethick, D. W., Mulland, B. P and Hampson, D. J. (2003). Effects of different sources and levels of dietary fibre in diets on performance, digesta characteristics and antibiotic treatment of pigs after weaning. *Animal Feed Science Technology*, 107, pp129 - 142.

Primefact, (2006) Alternative farrowing accommodation in the pork industry, Primefact 61 Pig Magazine. www.dpi.nsw.gov.au/primefacts.

Pope, W. F. (1991) Embryonic mortality in swine. Pages 53-78 in Embryonic mortality in Domestic Species. H. D. Geisert. ed. CRC Press. Boca Baton. FL.

Quesnel, H, Brossard, L, Valancogne, A. and Quiniou N (2008) ‘Influence of some sow characteristics on within-litter variation of piglet birth weight’, *Animal*, 2, 1842-1849.

Quigley, J. D., III, and Drewry, J. J. (1998) ‘Nutrient and immunity transfer from cow to calf pre- and post-calving’, *Journal of Dairy Science*, 81, pp. 2779–2790.

Quiniou, N., Dagorn, J. and Gaudra, D. (2002) 'Variation of pigletsâ€™ birth weight and consequences on subsequent performance', *Journal of Animal Science*, 78, (1), pp. 63-70.

Randall, G. C. B. (1972) ‘Observations on parturition in the sow. I. Factors associated with the delivery of the piglets and their subsequent behaviour’, *Veterinary Record*, 90, pp. 178–182.

Randall, G. C. B. (1982) ‘Changes in fetal and maternal blood at the end of pregnancy and during parturition in the pig’, *Research Veterinary Science*, 32, pp. 278-282.

Randall, G. C. (1979) ‘Studies on the effect of acute asphyxia on the fetal pig in utero’. *Biology of Neonate*, 36, pp. 63–69.

Raz, A., Kamin-Belsky, N., Przedecki, F., Obukowicz, M. G. (1997) ‘Fish oil inhibits Δ 6 desaturase activity in vivo: Utility in a dietary paradigm to obtain mice depleted of arachidonic acid’. *Journal of Nutritional Biochemistry*, 8, pp. 558-565.

Reese, 2004. Nebraska Swine Report 2004: 12–13.

Reese, D. 2003. Omega-3 Fatty Acids and Swine Reproduction – A Review. Nebraska Swine Reports, paper 66. http://digitalcommons.unl.edu/coopext_swine/66.

Rigau, A. P., Lindemann, M. D., Kornegay, E. T., Harper, A. F and Watkins, B. A. (1995) ‘Role of dietary lipids on fetal tissue fatty acid composition and fetal survival in swine at 42 days of gestation’. *Journal of Animal Science*, 73, pp. 1372–1380.

Reynolds, L. P. and Redmer D. A. (1995) ‘Utero-placental vascular development and placental function’, *Journal of Animal Science*, 73, pp. 1839-1851.

Roehe, R. (1999) ‘Genetic determination of individual birthweight and its association with sows’ productivity traits using Bayesian analysis’, *Journal of Animal Science,* 77, 330–343.

Roehe, R. and Kalm, E. (2000) ‘Estimation of genetic and environmental risk factors associated with preweaning mortality in piglets using generalized linear mixed models’, *Animal Science,* 70, pp. 227-240.

Roehe, R., Shrestha, N. P., Mekkawy, W., Baxter, E. M., Knap, P. W., Smurthwaite, K. M., Jarvis, S., Lawrence, A. B. and Edwards, S. A. (2009) 'Genetic analyses of piglet survival and individual birth weight on first generation data of a selection experiment for piglet survival under outdoor conditions', Livestock Science, 121, (2-3), pp. 173-181.

Rooke, J. A. and Bland, I. M. (2002) 'The acquisition of passive immunity in the new-born piglet', Livestock Production Science, 78, (1), pp. 13-23.

Rooke, J. A., Bland, I. M and Edwards, S. A. (1999) ‘Relationships between fatty acid status of the sow and that of umbilical cord, plasma and tissues of newborn piglets when sows were fed on diets containing tuna oil of soybean oil in late pregnancy’, *British Journal of Nutrition,* 82:213–221.

Rooke, J. A., Bland, I. M. and Edwards, S. A**. (**1998) ‘Effect of feeding tuna oil or soyabean oil as supplements to sows in late pregnancy on piglet tissue composition and viability’, *British Journal of Nutrition,* 80, pp. 273-280.

Rooke, J. A., Shanks, M. and Edwards, S. A. (2000) Effect of offering maize, linseed or tuna oils throughout pregnancy and lactation on sow and piglet tissue composition and piglet performance’, *Animal Science,* 71, pp. 289-299.

Rooke, J. A., Sinclair, S. A., Edwards, Cordoba, R., Pkiyachi, S., Penny, P. C., Penny, Finch, A. M. and Horgan, G. W. (2001c) ‘The effect of feeding salmon oil to sows throughout pregnancy on pre-weaning mortality of piglets’, *Journal of Animal Science,* 73, pp. 489-500.

Rooke, J. A., Sinclair, A. G. and Edwards, S. A. (2001b) 'Feeding tuna oil to the sow at different times during pregnancy has different effects on piglet long-chain polyunsaturated fatty acid composition at birth and subsequent growth', *British Journal of Nutrition*, 86, pp. 21- 30.

Rooke, J. A., Sinclair, A. G. and Ewen, M. (2001a) 'Changes in piglet composition at birth in response to increasing maternal intake of long chain n-3 polyunsaturated fatty acids are nonlinear', *British Journal of Nutrition*, 86, pp.461-470.

Rossi, R., G. Pastorelli, S. Cannata, and C. Corino, (2010) "Recent advances in the use of fatty acids as supplements in pig diets: A review," *Animal Feed Science and Technology*, 162, pp. 1-11.

Rothschild, M. F. and Bidanel, J. P. (1998) Biology and genetics of reproduction. In The genetics of the pig (ed. M. F. Rothschild and A. Ruvinsky), pp. 313-343. CAB International, Oxon.

Rothwell N J and Stock M. J (1982) 'Effects of feeding as palatable 'cafeteria' diet on energy balance in young and adult lean (+/?) Zucker rats'. *British Journal of Nutrition*, 47, pp 461-471.

Rothwell N J, and Stock M. J (1988) 'The cafeteria diet as a tool for studies of thermogenesis'. *Journal of Nutrition*, 118(8), pp. 925-928.

Rountree, W., Morrow, M. and Davies, P. (1997) Observational studies of shoulder ulcers in sows. Pp. 261-264. Quebec City, Quebec, American Association for Swine Practitioners.

Salmon, H. (1987) 'The intestinal and mammary immune system in pigs', *Veterinary Immunology and Immunopathology*, 17, (1-4), pp. 367-388.

Schmid, H. 1993. Ethological design of a practicable farrowing pen. In (M. Nichelmann, H.K. Wierenga and S. Braun, Eds.) Proceedings of the International Congress on Applied Ethology. Berlin. KTBL, Darmstadt, Germany. Pp. 238.

Seckl, J. R. (2004) ‘Prenatal glucocorticoids and long-term programming’, *European Journal of Endocrinology*., 151, pp. 49-62.

Serenius, T., Sevon-Aimonen, M.L., Kause, E.A., Mantysaari, E.A., Maki-Tanila, A., (2004) ‘Selectionpotential of different prolificacy traits in the Finnish Landrace and LargeWhite populations’, *Acta Agricultural. Scandanivia., A Animal Science,* 54, pp. 36–43.

Shafat, A., Murray, B. and Rumsey, D. (2009) 'Energy density in cafeteria diet induced hyperphagia in the rat', *Appetite*, 52, (1), pp. 34-38.

Shankar, B. P., Madhusudhan, H. S. and Harish, D. B. (2009) ‘Preweaning mortality in pig-causes and management’, *Veterinary World*, 2, pp. 236–239.

Sibley, C., Glazier, J.and D’Souza, S. (1997) ‘Placental transporter activity and expression in relation to fetal growth’, *Experimental Physiology*, 82: 389–402.

Siewerdt, F., and Cardellino R. A. (1996) ‘Genetic parameters of piglet mortality from birth to 21 days of age in the Landrace breed’, *Rev. Soc. Bras. Zootec*. 25, pp. 902–909.

Simopoulos, A.P., 2009. Omega-6/omega-3 essential fatty acids: biological effects. *World Revision of Nutrition Diet,* 99, pp. 1–16.

Sinclair, A. J and Crawford, M. A. (1972) ‘The accumulation of arachidonate and docosahexaenoate in the developing brain’, *Journal of Neurochemists,* 19, pp. 1753 – 1758.

Sinkora, M. and Butler, J. E. (2009) 'The ontogeny of the porcine immune system', *Developmental and Comparative Immunology*, 33, (3), pp. 273-283.

Skorupski, M, (2001) A report on the ‘Use of Farrowing crate during farrowing and lactation’: A literature review for the New Zealand Pork Industry. New Zealand Pork Industry Board, pp. 2-23.

Smits,R. J., Luxford, B. G., Mitchell, M and Nottle, M. B. (2011) "Sow litter size is increased in the subsequent parity when lactating sows are fed diets containing omega 3 fatty acids from fish oil," *Journal of Animal Science*, May 24, 2011.

Smuts, C. M., Huang, M., Mundy, D., Plasse, T., Major, S and Carlson, S. E. (2003) A randomized trial of docosahexaenoic acid supplementation during the third trimester of pregnancy. *Obstetrics and Gynaecology*, 101, pp. 469–79.

Spencer J. D., Boyd R. D., Cabrera R., Allee G. L. (2003) 'Early weaning to reduce tissue mobilization in lactating sows and milk supplementation to enhance weight during extreme heat stress', *Journal of Animal Science*, 81, pp. 2041–2052.

Spencer, J. D., Wilson, L., Webel, S. K., Moser, R. L. and Webel, D. M. (2004) 'Effect of feeding protected n-3 polyunsaturated fatty acids (Fertilium™) on litter size in gilts', *Journal of Animal Science*, 82 (Suppl. 1) pp. 211.

Spicer, E. M., Driesen, S. J., Fahy, V. A., Horton, B. J., Sims, L. D., Jones, R. T., Cutler, R. S. and Prime, R. W. (1986) *Australian Veterinary Journal*, 63, pp 71.

Spicer, E.M., Fahy, V.A., Cutler, R. S., (1990) Management of the farrowing sow. In: Gardner, J. ,A .A., Dunkin, A.C., Lloyd, L.C. (Eds.), Pig Production in Australia. Butterworths, Sydney, pp. 252–256.

Spinka, M., Illmann, G., De Jonge, F., Andersson, M., Schuurman, T., Jensen, P., (2000) 'Dimensions of maternal behaviour characteristics in domestic and wild x domestic crossbred sows', *Applied Animal. Behavour Science*, 70, pp99–114.

Spotter, A. and Distl, O. (2006) 'Genetic approaches to the improvement of fertility traits in the pig', *The Veterinary Journal*, 172, (2), pp. 234-247.

Stark, K. D and Holub, B. J. (2004) Differential eicosapentaenoic acid elevations and altered cardiovascular disease risk factor responses after supplementation with docosahexaenoic acid in postmenopausal women receiving and not receiving hormone replacement therapy. *American Journal of Clinical Nutrition*, 79, pp. 765–73.

Su, G., Sorensen, D. and Lund, M. S., (2006) Analysis of variance components for piglet survival using threshold modl. Proceeding of the 8thWorld Congress of Genetics Applied Livestock Production, Belo Horizonte, Brazil. CD-ROM, Communication No. 06-01.

Sukhija, P. S. and D. L. Palmquist (1988) 'Rapid method for determination of total faty acid content and composition of feedstuffs and feces', *Journal of Agricultural Food Chemistry*, 36: pp.1202- 1206.

Sulabo, R. C., M. D. Tokach, E. J. Wiedmann, J. Y. Jacela, J. L. Nelssen, S. S. Dritz, J. M. DeRouchey and R. D. Goodband (2008) Effects of varying creep feeding duration on preweaning performance and the proportion of pigs consuming creep feed. *Journal of Animal Science*, 85(Suppl. 2):198 (Abstr.).

Sulabo, R.C., Tokach, M.D., DeRouchey, J. M., Dritz, S.S., Goodband, R.D. and Nelssen, J.L. (2010). Influence of feed flavours and nursery diet complexity on pre-weaning and nursery pig performance. *Journal of Animal Science*, 88, pp. 3918-3926.

Svendsen, J., Bengtsson, A. C. and Svendsen, L. S. (1986) 'Occurrence and causes of traumatic injuries in neonatal pigs', Pig News Information. 7, 161-170.

Svendsen, J., and Svendsen, L. S. (1997) 'Intensive (commercial) systems for breeding sows and piglets to weaning', *Livestock Production Science*, 49, pp. 165–179.

Svendsen, L. S., Westrom, B. R., Svendsen, J., Olsson, A and Karlsson, B. W. (1991) 'Blood serum characteristic of newborn pigs: Comparison of unaffected pigs with pigs belonging to five mortality groups'. *Acta Veterinary Scandinavia,* 32, pp. 287-299.

Svetina, A., Andreanszky, T., Jerkovic, I and Antoncic, M. (1994) 'Haematology and some blood chemical values in postnatal anaemia of the pig'. *Veterinary Arhiv,* 64, pp. 77-87.

Tlaskalova-Hogenova, H., Mandel, L., Trebichavsky, I., Kovaru, F., Barot, R. and Sterzl, J. (1994) 'Development of immune responses in early pig ontogeny', *Veterinary Immunology and Immunopathology,* 43, (1-3), pp. 135-142.

Thodberg, K., Jensen, K.H and M. S. Herskin. (2002) "Nursing behaviour, postpartum activity and reactivity in sows: Effects of farrowing environment, previous experience and temperament," *Applied Animal Behaviour Science*, 77, pp. 53-76, 2002.

Tokach, M. D., Goodband, R. D., Nelssen, J. L. and Kats, L. J. 1992. Influence of weaning weight and growth during the first week postweaning on subsequent pig performance. Proceedings of Kansas State University swine day, pp. 15-17.

Treit, D., Spetch, M. L. and Deutsch, J. A. (1983) 'Variety in the flavor of food enhances eating in the rat: A controlled demonstration', *Physiology and Amp; Behaviour*, 30, (2), pp. 207-211.

Trujillo-Ortega M.E., Mota-Rojas D., Olmos-Hernandez A., Alonso-Spilsbury M., Gonzalez M., Orozco H., Ramirez-Necoechea R., Nava-Ocampo A. (2007) 'A study of piglets born by spontaneous parturition under uncontrolled conditions: could this be a naturalistic model for the study of intrapartum asphyxia?', *Acta Biomedica* 78, pp. 29–35.

Tuchscherer, M., Puppe, B., Tuchscherer, A. and Tiemann, U. (2000) 'Early identification of neonates at risk: Traits of newborn piglets with respect to survival', *Theriogenology*, 54, (3), pp. 371-388.

Tyler, J. W., Cullor, J. S., Thurmond, M. C., Douglas, V. L. and Parker, K. M. (1990) 'Immunological factors related to survival and performance in neonatal swine', *Journal of Veterinary Research*, 51: 1400-1406.

Uauy, R., Hoffman D. R., Peirano P, Birch D. G and E.E. Birch (2001) Essential fatty acids in visual and brain development. *Lipids*, 36:885–95.

Uauy, R., Mena P., and Rojas C. (2000) 'Essential fatty acid in early life: structural and functional role'. Proceedings of the Nutrition Society. University of Glasgow, pp. 371-388.

Uruakpa, F. O., Ismond, M. A. H. and Akobundu, E. N. T. (2002) 'Colostrum and its benefits: A Review', *Nutrition Research*, 22, (6), pp. 755-767.

Vallet, J. L and Freking, B. A., (2007) ‘Differences in placental structure during gestation associated with large and small pig fetuses’, *Journal of Animal Science*, 85, pp 3267–3275.

Valros, A., Rundgren, M., Spinka, M., Saloniemi, H. and Algers, B. (2003) 'Sow activity level, frequency of standing-to-lying posture changes and anti-crushing behaviour--within sow-repeatability and interactions with nursing behaviour and piglet performance', *Applied Animal Behaviour Science*, 83, (1), pp. 29-40.

Van der Lende, T., E.F. Knol and J.I. Leenhouwers. (2001) ‘Prenatal development as a predisposing factor for perinatal losses in pigs’. *Reproduction*, 58 (Suppl), pp. 247-261.

Van Dijk, A.J., van Rens, B.T.T.M., van der Lende, T., Taverne, M.A.M., (2005) Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. *Theriogenology*, 64, pp. 1573-1590.

Vanderhaeghe, C., Dewulf, J., De Vliegher, S., Papadopoulos, G.A., de Kruif, A and Maes, D. (2010) ‘Longitudinal field study to assess sow level risk factors associated with stillborn piglets’. *Animal Reproduction Science*, 120, pp. 78-83.

Van Rens BTTM and van der Lende, T. (2004) ‘Parturition in gilts: duration of farrowing, birth intervalsm and placenta expulsion in relation to maternal, piglet and placental traits’, *Theriogenology*, 62, pp. 331- 352.

Van Rens BTTM, De Koning, G., Bergsma, R. and Van Der Lende T. (2005) ‘Pre-weaning piglet mortality in relation to placental efficiency’, *Journal of Animal Science*, 83, pp. 144-151.

Varley, M. A. (1995). The Neonatal Pig: Development and Survival. CAB International, Wallingford.

Varley, M. A., Wilkinson, R.G. and Maitland, A. (1987) ‘Artificial rearing of baby piglets: the effect of colostrum on survival and plasma concentrations of IgG’, *British Veterinary Journal*, 143, pp. 369-378.

Vermunt, J. J., Stafford, K. J., Thompson, K. G. (1995) 'Observations on colostral intake in newborn dairy calves. New Zealand', *Veterinary Journal*, 43, pp. 205-206.

Vieuille, C., Berger, F., Le Pape, G. and Bellanger, D. (2003) 'Sow behaviour involved in the crushing of piglets in outdoor farrowing huts--a brief report', *Applied Animal Behaviour Science*, 80, (2), pp. 109-115.

Villalba, J. J., Catanese, F., Provenza, F. D. and Distel, R. A. (2012) 'Relationships between early experience to dietary diversity, acceptance of novel flavors, and open field behavior in sheep', *Physiology and Amp; Behaviour*, 105, (2), pp. 181-187.

Wathes, C., Whittemore, C. T., (2006) Environmental management of pigs. In: Kyriazakis, I., Whittemore, C.T. (Eds.), Whittemore's Science and Practice of Pig Production. Blackwell Publishing, Oxford, UK , pp. 253–472.

Wathes, D. C., Abayasekara, D. R. and Aitken, R. J. (2007) 'Polyunsaturated fatty acids in male and female reproduction', *Biology of Reproduction*, 77, pp. 190-201.

Wattanakul, W., C. A. Bulman, H. L.Edge, and S. A. Edwards. (2005) 'The effect of creep feed presentation method on feeding behaviour, intake and performance of suckling piglets'. *Applied Animal Behaviour Science.* 92, pp. 27-36.

Weary, D. M., Pajor, E. A., Fraser, D. and Honkanen, A.-M. (1996) 'Sow body movements that crush piglets: a comparison between two types of farrowing accommodation', *Applied Animal Behaviour Science*, 49, (2), pp. 149-158.

Weary, D. M., Phillips, P. A., Pajor, E. A., Fraser, D. and Thompson, B. K. (1998) 'Crushing of piglets by sows: effects of litter features, pen features and sow behaviour', *Applied Animal Behaviour Science*, 61, (2), pp. 103-111.

Webel, S. K., Otto, E. R., Webel, D. M., Moser, R. L., Spencer, J. D. and Orr, D. E. (2003) 'Effect of protected n-3 polyunsaturated fatty acids (Fertilium™) on litter size in sows', *Journal of Animal Science*, 81 (Suppl. 1), pp. 18.

Webel, S. K., E. R. Otto-Tice, R. L. Moser, and D. E. Orr. 2004) 'Effect of feeding duration of protected n-3 polyunsaturated fatty acids (FertiliumTM) on litter size and embryo survival in sows'. *Journal of Animal Science*, 82(Suppl. 1), pp. 212.

Weber, R. 2000. Alternative housing systems for farrowing and lactating sows. In (H.J. Blokhuis, E.D. Ekkel and B. Wechsler, Eds.). Improving health and welfare in animal production. EAAP Publication 102. Wageningen Pers, Wageningen, Netherlands. pp 109-115.

Weber, R., Keil, N. M., Fehr, M and Horat, R. (2009) 'Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livestock Science, 124, pp. 216-222.

Weber, R., Keil, N. M., Fehr, M., Horat, R., (2007) 'Piglet mortality on farms using farrowing systems with or without crates'. *Animal Welfare*, 16, pp. 277-279.

Wechsler, B., and Hegglin, D. (1997) 'Individual differences in the behaviour of sows at the nest-site and the crushing of piglets', *Applied Animal Behaviour Science*, 51, pp. 39–49.

Welch, A. R and Baxter, M. R., (1986) 'Responses of newborn piglets to thermal and tactile 8 properties of their environment', *Applied Animal Behaviour Science*, 15, pp. 203-215.

Weschler, B and Weber, R. (2007) 'Loose farrowing systems: challenges and solutions', Animal Welfare, 16(3), pp. 295-307.

Whittemore, C. T, Hazzeldine, M. J and Close, W. H (2003) Nutrient requirement standards for pigs. A report of the British Society of Animal Science nutritional standards working group: pigs. Pig News and Information 23, pp. 67–74.

Wilson, M. E., Biensen, N. J. and Ford, S. P. (1999) Novel insight into the control of litter size in the pig, using placental efficiency as a selection tool', *Journal of Animal Science*, 77, pp. 1654–1658.

Wilson, M. E., Biensen, N. J., Youngs, C. R. and Ford, S. P. (1998) 'Development of Meishan and Yorkshire littermate conceptuses in either a Meishan or Yorkshire uterine environment to day 90 of gestation and to term', *Biology of. Reproduction*, 58, pp. 905–910.

Woods, V.B and A.M. Fearon. (2009) 'Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs: A review'. *Livestock Science,* 126 (1), pp.1-20.

Wu, G., Bazer, F. W., Wallace, J. M. and Spencer, T. E. (2006) 'BOARD-INVITED REVIEW: Intrauterine growth retardation: Implications for the animal sciences', *Journal of Animal Science,* 84, (9), pp. 2316-2337.

Yan, L., Meng, Q. W. and Kim, I. H. (2011) Creep Feed: Effects of Feed Flavor Supplementation on Pre- and Post-weaning Performance and Behaviour of Piglet and Sow. Asian-Australia. *Journal of Animal Science,* 24(6), pp. 851-856.

Yehuda, S., Rabinovitz, S., Carasso, R. L., Mostofsky, D. I., (2002) 'The role of polyunsaturated fatty acids in restoring the aging neuronal membrane', *Neurobiology Aging,* 23, pp. 843-853.

Zaleski, H. M., and R. R. Hacker. (1993) 'Variables related to the progress of parturition and probability of stillbirth in swine'. *Canadian Veterinary Journal*, 34, pp. 109–113.

Zimmerman, D. R and Cunningham P. J. (1975) 'Selection for ovulation rate in swine. Procedures and ovulation response', *Journal of Animal Science,* 40, pp. 61.

Appendices

Appendix 1: Fatty acid analysis of plasma samples

1. Frozen plasma samples thawed overnight in the fridge (4 degree celcius) and vortexed
2. Weight 0.5g of each sample into a soveril tube Five hundred microlitres of internal fatty acid standard (C:17, Sigma-Aldrich) solution (0.3g C:17 in 100ml Toluene) was added using a Gilson pipette to each soveril tube and vortexed (30seconds)
3. A methanol:toluene (1:4) solution (1.7ml) was then added using a positive displacement transfer pipette before vortexing each soveril tube again (30seconds)
4. 250µl of Acetyl chloride was slowly added using a capillary pipette
5. Samples were vortexed again (30seconds) and placed in a hot block at 100 degree celcius for 1hour
6. Samples are removed from hot block and left to cool for 20minutes before adding 5mls of KCL solution (25g of KCL dissolved in 500ml distilled water, 5% KCL).
7. Tubes were gently shaken before centrifugation at 1000G for 5minutes
8. The supernatant (400 µl) was then removed from each tube using a Gilson pipette and transferred into a brown glass vial with a glass insert
9. Vials were refrigerated (4 degree celcius) until gas chromatography was performed

Method extracted from Sukhija and Palmquist (1988).

Appendix 2: Fatty acid analysis of Milk and Colostrum samples

Milk lyophilization

- Transfer milk sample into 7ml bijou labelled containers, half-full, and freeze upright so that frozen milk remains on the bottom part of the container
- Replace the lids with parafilm and penetrate each parafilm 2-3 times with a needle
- Freeze-dry until ready
- Rinse with lids with hot and then distilled water and dry overnight
- When samples are completely lyophilized, replace the parafilm with the clean lids and keep in -20oC.

Sample preparation

- Label test tubes and the correspondent GC vials, using a permanent marker
- Weigh 130mg lyophilized milk in the tubes
- Add 2ml hexane, using a positive displacement pipette, and vortex
- Add 2ml 0.5M sodium methylate, using a positive displacement pipette, vortex
- Place tubes on the hot block on 50oC for 15min
- Remove from hot block and allow to reach room temperature
- Add 75µl 12N HCl, using a positive displacement pipette, vortex gently, and leave in room temperature for 15 min
- Add 3 ml hexane, using a positive displacement pipette and vortex
- Add 3 ml deionised water, using a positive displacement pipette, and vortex
- Centrifuge at 1,160xg for 5min at 5oC
- Collect the upper layer into a GC vial, using an 1ml Gilson pipette (400µl)

Gas Chromatography

Samples were analysed on a Shimadzu GC-2014 gas chromatography usin helium as the carrier gas using a 30m BPX70 capillary column (SGE Europe Ltd. Milton Keynes, UK). The initial temperature of the column was 100oC, for 2minutes and later raised to 260oC and held for further 1minutes. The temperature was later reduced to 100oC. Sample fatty acids were identified using the external lipid standards, and concentrations were determined with reference to the internal standard concentration.

Column: Varian CP-SIL 88, 100m x 0.25mm ID x 0.20µm FT

Injector temperature: 255oC

Injection volume: 2.0µl

Injection Mode: Split

Flow Control Mode: Linear Velocity

Pressure: 212.0 kPa

Total Flow: 52.9 ml/min

Column Flow: 1.00 ml/min

Linear Velocity: 17.6 cm/sec

Purge Flow: 2.0 ml/min

Split Ratio: 50.0