Journal of
Advanced Veterinary Research
Volume 2 (2012) 218-231 **Review Article**

Stillbirth in Pigs

Mudasir Bashir Gugjoo, Raja Aijaz Ahmad*, Shahnawaz Ahmad Bhat, Mohammad Yaqoob Wani
Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

(Recieved 11 February 2012/ Accepted 20 April 2012

Abstract

Piglets that are born dead may have died at any time during the farrowing process or before. Causes of stillborn piglets can be divided into infectious and noninfectious. Infectious causes perhaps are overemphasized but are certainly important in epidemic situations. Noninfectious causes of stillborns are most common in endemic situations. Genetic, maternal, piglet and environmental factors can all affect the stillborn rate. The review attempts to describe the causes of stillborn piglets and the ways to mitigate them.
Keywords: Stillbirth; piglets; genetic factors; maternal factors; environmental factors

Definition and Pathophysiology

Stillbirths generally account for 3 to 8% of all pigs born (Zale ski and Hacker, 1993; Borges *et al*., 2005; Cutler *et al*., 2006). Almost 80% of the total preweaning mortality occurs during parturition and within the first three or four days after birth (prenatal mortality) (Sense, 1992). Death of the fetus is followed by mummification or by stillbirth when it occurs after day 109 of gestation. Their skin loses its color, the eyes sink and the placenta becomes darker. As water is removed, the fetus becomes drier and finally becomes dark brown, enveloped in its placenta. The bones of the mummified fetus remain intact and so the crown-rump length of the fetus can be measured to establish the time of gestation at which death occurred (Almond *et al*., 2006). Majority of small mummified fetuses are expelled with the placenta and can easily escape detection unless the placenta is meticulously searched (Van deer Lender and Van Runs, 2003). Fetuses dying relatively late during gestation can still be in the initial stages of mummification and can be identified at birth as non-fresh stillborn piglets. Stillborn piglets result from the expulsion of dead fetus at an age when they could normally survive. Survival before day 109 of gestational age is limited because lung maturation has not been completed by this age. After the piglet is born, it must begin to breath. However, some piglets never take their first breaths and are stillborn (Curtis, 1974). Clinical and postmortem studies of stillborn piglets showed that stillbirths typically are classified into two distinct types based on the time of death (Randall and Penny, 1967; Curtis, 1974; Stretcher *et al*., 1974). Type I stillbirths include piglets that die before parturition (pre-partum or ante-partum) and the cause of fetal death is generally attributed to intrauterine infection. The piglets are externally normal, but have internal decomposition upon delivery. Type II stillbirths, include piglets that die during parturition (intra-partum) and is generally associated with non-infectious etiologies such as intrauterine asphyxia and dystocia. The piglets are generally normal in size and appear fresh at necropsy. On post mortem examination, piglets are often wrapped in the fetal membranes, their umbilical cord is long and wet and in some cases, the umbilical cord appears edematous. They have no lung inflation, but usually some heart function can be seen through pulsation of the umbilical cord (Randall and Penny, 1967; Curtis, 1974; Sense *et al*., 1986). Because not all farrowings are continuously observed under farm conditions, different categories of newborn piglets can be encountered near or behind a farrowing sow: mummified piglets

*Corresponding author: Raja Aijaz Ahmad

E-mail address: rajaaijaz.ahmad@yahoo.com

of different sizes, non- fresh stillborn piglets, fresh stillborn piglets and live born piglets (Van deer Lender and Van Runs, 2003). The latter two groups may include asphyxiated piglets (which either died or survived) and piglets crushed by the sow. In these cases, only a thorough post mortem investigation can elucidate to which category a piglet belongs. Stillborn piglets can be distinguished from piglets that were born alive and died after birth by the lung flotation test. This test requires the lungs should be dissected and placed in the water. If the lungs float, the pig had air trapped in its lungs and was born alive and breathed. If the lungs sink, they contained no air and the animal never breathed (Christianson, 1992). Yet, necropsy of dead piglets is not routinely performed under practical circumstances and a stillborn piglet is generally defined as a piglet found dead behind the sow at the first check up after parturition with no signs of decomposition. Although concerns has been raised regarding the reliability of producer-recorded causes of mortality, with incorrect diagnosis of stillbirths and overestimation of crushing (Vaillancourt *et al*., 1990), results from other studies indicate that general conclusions derived from producer recorded database are valid (Edwards, 2002). In many cases the different mortality groups do not represent separate disease entities but are different clinical manifestations of the same basic condition, namely the extent of asphyxiation during parturition. Fetal hypoxia is most related to piglet survival at farrowing and even temporary hypoxia during birth may cause permanent brain damage and reduce the survival of live born pigs (Sense, 1992; Edwards, 2002). Piglets are particularly susceptible to intra-partum anoxia despite the fact that they are relatively mature at the time of birth (Sense *et al*., 1986). Some studies tried to identify the intra-partum anoxia by measuring the acid-base balance (pH, pod 2 , pock2 , HCO_3), base excess (BE elf) and lactate concentration in the umbilical artery blood at birth (Herpin *et al*., 1996; Van Dijk *et al*., 2006; Olmos-Hernandez *et al*., 2008). The recent study reported that overweight piglets were more prone to intra-partum asphyxia and acid-base imbalance with lower pH (7.03) and PO_2 (18.8 mm/Hg) levels and higher lactate (89.5 mg/dl) levels compared to piglets within normal weight (pH: 7.3; PO_2 : 25.9 and lactate: 40.8). Other studies reported a relation between the rate and severity of meconium staining on the skin, meconium aspiration into the respiratory tract and intra-partum anoxia (Mota-Rojas *et al*., 2006). Hypoxia in uteri has been shown to increase intestinal peristalsis and relaxation of the anal sphincter causing the expulsion of meconium into the amniotic fluid, gasping by fetuses and subsequent inhalation of amniotic fluid contaminated with meconium (Curtis, 1974).

Factors affecting the number of stillborn piglets

Causes of stillborn piglets can be divided into infectious and noninfectious. Infectious causes perhaps are overemphasized but are certainly important in epidemic situations. Some infectious causes of fetal death and stillborn piglets are primarily systemic maternal pathogens, whereas others may attack the fetus and/or placenta. Noninfectious causes of stillborns are most common in endemic situations (Christianson, 1992). Genetic, maternal, piglet and environmental factors can all affect the stillborn rate.

Genetic factors

There is a small but significant genetic influence on stillbirth. The reported heritability is between 0.02 and 0.05 for number of stillborn piglets (Holm *et al*., 2004). Although the between-breed variation in the proportion of stillborn piglets is rather limited, Leenhouwers *et al*. (1999) mentioned that purebred lines have significantly more stillbirths per litter than crossbred lines. Crossbreeding has a favorable effect on neonatal survival and the heterocyst is more marked when the piglets are crossbred than when the dam is crossbred (Blasco *et al*., 1995). Additionally, Canaries *et al*. (2006a) mentioned that piglets born from Meehan sows have a lower risk of stillbirth, probably due to a shorter farrowing duration and birth interval as opposed to European breeds (Van Dijk *et al*., 2005). These observations suggest that both the sow and the piglets have a genetic influence on the occurrence of stillbirth. Leenhouwers *et al*. (2003) reported that the sow had a genetic influence on the probability of mortality during farrowing, whereas the piglets have a genetic influence on the mortality before and immediately after farrowing. Based on our experience, available information on the reproductive performance and stillbirth rate in modern hybrid sows is lacking.

Maternal factors

Body condition

Sows normally gain body weight in pregnancy and lose bodyweight during lactation. Over the first parities, pregnancy gains may be assumed to be both, lean and fat tissue. However, in older sows, pregnancy gains are likely composed of mainly fatty tissues (Whittemore, 2006). Some studies found a positive association between a high body condition score of the sow at farrowing and stillbirth rate (Bilked *et al*., 1992; Le Cozier *et al*., 2002), whereas others found no association (Lucia *et al*., 2002; Borges *et al*., 2005). This disagreement can largely be due to the fact that body condition in those reports was based on a single visual scoring. The value of the visual scoring can vary with type of breed, production stage and parity of the sow and there is only a moderate correlation between body condition scoring and back fat measurements (Ames *et al*., 2004). The results of the latter study showed that sows with lower amounts of back fat (<16 mm) at the end of gestation had a significantly higher amount of stillborn piglets, whereas back fat levels approaching 20 mm at farrowing did not have detrimental effects on the number of stillborn piglets (Ames *et al*., 2004). Olivier *et al*. (2010) reported that sows with a backfat level >17 mm had a significant longer farrowing duration. They hypothesized that fat sows probably have more adipose layers around the birth canal, which reducing the diameter of the birth canal and creating a physical obstacle during the expulsive phase resulting in a delayed farrowing. An explanation for the dissimilarities between these two latter studies could be the different breed of sows used (PIC and Deland Hybrid sows vs. Finnish Yorkshire x Finnish landrace sows in the latter study).

Litter size

A positive association between litter size and stillbirth is well documented (Zale ski and Hacker, 1993; Knoll *et al*., 2002; Lucia *et al*., 2002; Borges et al., 2005; Canaries *et al*., 2006a; Wolf *et al*., 2008). A major reason is that large litters are associated with longer farrowings (Van Runs and Van deer Lender, 2004) and greater risk of hypoxia (Herpin *et al.*, 2001). Additionally, Canaries *et al*. (2006b) mentioned that selection for number of total born piglets results in an increase in farrowing duration, stillborn piglets and in birth assistance, whereas selection for number of piglets born alive accelerates the farrowing process and has a limited impact on farrowing duration and birth assistance. Furthermore, Knoll *et al*. (2002) and Canaries et al. (2006a) also found a greater probability of stillbirth in smaller litters. This increased mortality might result in farrowing problems due to oversized piglets.

Parity

An increasing number of stillborns have been reported with increasing parity (Leenhouwers *et al*., 1999; Le Cozier *et al*., 2002; Canaries *et al*., 2006a). In two Brazilian studies, sows of higher parities (> 3 or >5) had a higher risk of stillbirth than those of mid-parities (2-3 or 2-5) (Lucia *et al*., 2002; Borges *et al*., 2005). The association between higher parities and stillbirth risk could be attributed to a poor uterine muscle tone that could lead to a less efficient labor and prolonged farrowing. Several studies confirmed that high parity had a negative influence on the duration of farrowing (Stanton and Carroll, 1974; Cronin *et al*., 1993; Farmer and Robert, 2002), while others found no significant effect (Filmy and Friend, 1981; Van Dijk *et al*., 2005; Olivier *et al*., 2009). According to Cutler *et al*. (2006), the duration of farrowing can have a greater impact on stillbirths than parity. An exception occurs for first parity sows, which can have a relatively high number of stillborn piglets per litter and this may be caused by a too narrow birth canal (Borges *et al*., 2005; Cutler *et al*., 2006; Canaries *et al*., 2006a).

Gestation length

Several reports found more stillborn piglets with a decreasing gestation length (< 113d) (Leenhouwers *et al*., 1999; Annenberg *et al*., 2001; Sasaki and Cokes, 2007; Richer *et al.*, 2008). The reason for a high stillbirth rate at short gestation length may be linked to the immaturity of the piglets (Zale ski and Hacker, 1993). Van Dijk *et al*. (2005) also found that a decrease in gestation length resulted in a significant increase in farrowing duration.

Farrowing duration

Farrowing duration and stillbirth are directly related (Borges *et al*., 2005; Van Dijk *et al*., 2005; Canaries *et al*., 2006a). Probability of stillbirth clearly increases with duration longer than 3 hours and in piglets born late in the farrowing (Zale ski and Hacker, 1993), due to a greater risk of asphyxia of piglets following detachment of placenta or rupture of umbilical cord (Herpin *et al*., 1996). It remains unclear whether stillbirth is the causative factor or the result of an increased farrowing duration. Besides stillborn piglets, several other factors seem to be associated with a prolonged farrowing duration such as pen design, constipation, body condition of the sow and gestation length (Van Dijk *et al*., 2005; Olivier *et al*., 2010).

Piglet factors

Birth Interval-Birth order

The time interval between the expulsions of two successive piglets is on average 12-18 minutes (Sprecher *et al*., 1974; Alonso-Pillsbury *et al*., 2004). Stillborn piglets are born after a longer birth interval compared to their live born littermates (Zale ski and Hacker, 1993; Van Dijk *et al*., 2005). A longer birth interval and a higher stillbirth rate were also associated with piglets with posterior presentation at birth (Van Dijk *et al*., 2005). Van Runs and Van deer Lender (2004) furthermore have shown that not the birth weight of the piglet but the thickness of the placenta is responsible for increased birth intervals. The piglet has to break its own membranes to be able to start its journey through the uterus towards the birth canal. Apparently, a thicker placenta offers more resistance and thus prolongs the process of birth. It has also been documented that piglets in the middle rank of the litter are born after the shortest birth interval compared to their preceding and following littermates (Van Runs and Van deer Lender, 2004, Van Dijk *et al*., 2005). According to Alonso-Pillsbury *et al*. (2004), birth order and birth interval are key factors leading to porcine stillbirths. Physical pressure exerted by fetal or placental tissues on the umbilical cord reduces blood flow causing death due to hypoxia, or weakness and depression at the time of expulsion (Herpin *et al*., 1996). Delayed births that prevent a piglet from breathing for 2 or 3 minutes are frequently associated with laceration, puncture or compression of the umbilical cord (Alonso-Pillsbury *et al*., 2005). The frequency of umbilical cord rupture increases towards the last third of the litter (Moat-Rojas *et al*., 2006).

Birth Weight

An increase in stillbirth rate with a decrease in average birth weight of the litter is commonly reported in literature (Zale ski and Hacker, 1993; Leenhouwers *et al*., 1999; Le Cozier *et al*., 2002) and this may reflect the quality of uterine support of the litter and may be caused by an overall lower vigor of the litter at the onset of parturition. Additionally, a low individual birth weight (lower than the litter average) was found to increase the probability of stillbirth (Stanton and Carol, 1974; Le Cozier *et al*., 2002; Canaries *et al*., 2006a). Also, it has been suggested that stillborn piglets, which tend to weigh less than live born littermates, have smaller umbilical cords which may be more prone to suffer umbilical rupture (Curtis, 1974). Some studies show a higher stillbirth rate and lower individual birth weight for male piglets than females (Knoll *et al*., 2002; Canaries *et al*, 2006a). Lay *et al.* (2002) hypothesized a greater susceptibility of males to farrowing stress due to a greater cortical. On the other hand, extreme selection for larger birth weight is not necessarily a good solution. Some authors found that selection for higher mean birth weight would decrease postnatal mortality, but simultaneously increase the proportion of stillborn piglets (Knoll *et al*., 2002; Leenhouwers *et al*., 2002; Dagmar *et al*., 2003; Holm *et al*., 2004). Heavy piglets are subjected to greater difficulties in farrowing, and due to their large size relative to the maternal pelvis, birth is blocked resulting in hypoxia and risk of dying. Similarly, Olmos-Hernandez *et al*. (2008) found that higher weighted piglets >1.35 kg) showed acid-base imbalances with lower pH levels, and lactic acidosis compared to piglets within normal weight (1-1.35 kg). Overweight piglets are more prone to suffer from intra-partum asphyxia in comparison to piglets with normal weight ranges. Selection for low within litter birth weight variation appears to be a promising method to improve piglet survival, as a lower stillbirth incidence can be observed for very uniform litters (Zale ski and Hacker, 1993; Leenhouwers *et al*., 1999; Dagmar *et al*., 2003). Finally, a recent study (Baxter *et al*., 2008) found that piglet shape and size (= birth weight/(crown-rump length)^3) and body mass (= birth weight / (crown-rump length)^2)

were better indicators of stillborn piglets than birth weight.

Environmental factors

Partus induction

Partus induction is a tool that has been used for years in the swine industry. The tool allows an increased supervision of farrowing to improve neonatal survival and facilitating cross-fostering. The widely accepted and available method of inducing parturition in sows is by injecting $PGF_2\alpha$ up to 2 days before the herd median farrowing date. Guthrie (1985) reported that when this protocol was used, approximately 50% to 60% of sows farrowed within a day of treatment. In cases of partus induction before day 113 of pregnancy, there was a higher incidence of piglets with congenital myofibrillar hyperplasia, probably because the fetus is still insufficiently matured (Blockier *et al*., 1996). Probability of stillbirth has also been reported to increase with gestation length less than 112 days, when sows are induced to furrow (First *et al*., 1982; Zale ski and Hacker, 1993; Cutler *et al*. 2006). Inducing parturition using $PGF_2\alpha$ in combination with oxytocin resulted in an increased predictability of parturition (Dial *et al*., 1984; Cutler *et al*., 2006). Nevertheless, some caution with oxytocin administration is indicated. Moat-Rojas *et al*. (2002) found that although oxytocin-treated sows had a significant decrease in farrowing time and expulsion intervals, they also had more stillbirths than the controls. In contradiction, other studies found that the application of oxytocin or carbetocin did not cause an increase in stillborn piglets and intrauterine hypoxia (Cesar *et al*., 2004; Where'd *et al*., 2005; Kayaked, 2006; Heller *et al*., 2009). The different results may be attributed to the lower dosage of oxytocin (10-20 IU vs. 20-50 IU) used in the latter studies. Moreover, when the treatment protocol '$PGF_2\alpha$ + oxytocin 24 hours later' was compared with the application of $PGF_2\alpha$ alone, there was no significant difference in farrowing duration (Cesar *et al*., 2004; Where'd *et al*., 2005; Kayaked, 2006). Heller *et al*. (2009) found that the use of carbetocin resulted in a shorter farrowing duration (118-140 min.) than oxytocin (180 min) without a significant increase in stillbirth rate. The likelihood of farrowing during the next day (<26 hours) was also increased when two injections of $PGF_2\alpha$ were administered at a 6 hours interval (split dose) (Kirkwood and Herne, 1998; Straw *et al*., 2008). The split-dose administration had no detrimental effects on the number of stillborn piglets. The route of hormone administration for inducing sows varies from herd to herd. Smith *et al.* (2009) demonstrated that sows induced on day 116 tended to have more stillborn piglets compared to sows induced on day 113 (0.8 vs. 0.56). Also, in herds where farrowing is induced late in gestation (> 50% of the induced litters having a gestation length = 116d), the induced litters had fewer piglets born alive in comparison to sows that furrowed naturally in the group with gestation length = 116d (Ichikawa and Cokes, 2009).

Farrowing supervision and manual birth assistance

There are several studies that clearly indicate the importance of attending farrowings. Holyoake *et al*. (1995) have shown experimentally that intensive supervision reduces the prenatal mortality rate by decreasing the number of stillbirths per litter and deaths due to low viability and trauma. Similarly, White *et al*. (1996) and Le Cozier *et al*. (2002) reported a substantial reduction of stillbirth rate with increasing rate of supervision of farrowings. The association between manual birth assistance and the probability of stillbirth is somewhat expected because assistance is given when farrowing problems occur. In particular, Holm *et al.* (2004) found that prolonged or difficult farrowings are associated with a greater need for birth assistance and more stillborn piglets. Similarly, more vaginal palpations with a higher occurrence of stillbirth was reported by Lucia *et al.* (2002) and Canaries *et al*. (2006a). Additionally, frequent supervision of farrowing also has been associated with a lower risk for postpartum dysgalactia syndrome in sows (Papadopoulos *et al*., 2010). Olivier *et al*. (2008b) used photo sensors for measuring movement to predict the onset of farrowing and thus alert the farmer for supervision The study found that average time spent by the sow standing, was significantly higher in the 24 hours before farrowing than in all the other periods monitored.

Pharmacological interventions during parturition.

Attempts to reduce the stillbirth rate by speeding up the delivery process with uterotropic drugs, such as oxytocin, immediately after the birth of the first piglet increased the stillbirth rate, the number of piglets with ruptured umbilical cord and meconium staining on the skin, and the need for obstetrical intervention, despite a significant reduction of the farrowing duration (Alonso-Pillsbury *et al*., 2004; Moat-Rojas *et al*., 2005, 2006). It was concluded that oxytocin treatment at the onset of parturition (immediately after the birth of the first piglet) increased the myometrial activity and decreased the uterine blood supply that may result in fetal distress. Because damaged umbilical cords are more common in stillbirths than in viable pigs, it has been suggested that oxytocin may adversely increase tensile stress of the umbilical cords and, therefore, the risk of intra-partum mortality in piglets (Moat-Rojas *et al*., 2002; Alonso-Pillsbury *et al*., 2004). A recent study of Moat-Rojas *et al.* (2007) showed that oxytocin administered late in labour gives mild uterotonic effects without substantially decreasing the placenta perfusion and resulting in better fetal outcomes. Yet, causality relationships between probability of stillbirth and farrowing treatment remain unclear.

Nutrition

Generally, restricted feeding levels during gestation are advised because with high planes of nutrition, especially in later parities, more energy is available for fat deposition (Close and Cole, 2000). These high levels of fatness at farrowing lead to a longer duration of farrowing and more stillborn piglets (Bilked and Blockier, 1993). Overfeeding during gestation has also a negative impact on gamogenesis (Farmer and Sorensen, 2001) and on the voluntary feed intake during lactation (Dour mad, 1991; Weldon *et al*., 1994; Revel *et al*., 1998). Very low levels of energy (<15 MJ digestible energy /day) intake during gestation have no effect on litter size and number of stillborn piglets, but piglets will generally be lighter and have a higher death risk during lactation (Plucked *et al*., 1995). Feeding the sow below requirements during gestation seems to cause a decrease in the concentration of growth regulating factors, such as insulin-like growth factors, in both sow and fetuses, which most likely results from an impaired supply of nutrient to the fetuses (Reflect *et al*., 2004). Supplementation of sow diets during gestation with L-carnitine (125 mg/day) increases the body weight of the piglets at birth (Musser *et al*., 1999; Romania *et al*., 2004). L-carnitine treated sows had higher plasma concentrations of insulin-like growth factors at the end of gestation, enhancing the development of the placenta and the condition of the fetuses leading to increased birth weights (Deferens *et al*., 2006). It is recommended to offer sows a daily minimum amount of a diet containing >7-8% crude fiber on the days near parturition (Tabling *et al*., 2003), as parturition causes an increase in the dry matter of the faeces and reduces the defecation frequency leading to constipation. The higher the dry matter content of the faeces during the last 3 days of pregnancy, the longer their farrowing and the higher the rate of stillborn piglets (Bilked and Blockier, 1993; Olivier *et al*., 2009). Large amounts of dry contents in the large intestine and rectum create physical obstacle during birth by pressing on the birth canal. Another hypothesis could be that the discomfort and pain associated with such constipation lead to stress which can disturb the hormonal pattern of parturition (Olivier *et al*., 2009). Also, endotoxins from intestinal Gram-negative bacteria in the chyme are thought to influence peripartal problems in the sows because of their forced release and absorption caused by delayed digesta transport and increased intestinal microbial growth (Martineau *et al*., 1992). Recent studies regarding the supply of a diet rich in fibres (containing 45% sugar beet pulp) during gestation found no relation between the feeding strategy and number of stillborn piglets (Van deer Peet-Schwering *et al*., 2004; Peltoniemi *et al*., 2009). Besides, a gestation diet containing 12.7% crude fiber had no effect on the parturition process (Guillemot *et al.*, 2007). Feeding additional fat (5-10% supplemental fat) to a fibrous diet in late-gestation sows did not increase piglet birth weight, but increased the number of stillborn piglets (Van deer Peet-Schwering *et al*., 2004). Weldon *et al*. (1994) indicated that feeding gestation sows extra energy might cause glucose intolerance. It seems that feeding extra energy from fat in late-gestation sows may induce glucose intolerance, but that feeding sows extra energy from starch (14.6% wheat starch) improve glucose tolerance (Van deer Peet-Schwering *et al*., 2004). Pregnancy is associated with a reduced maternal glucose tolerance in late gestation and the number of stillborn piglets was higher in sows with a decreased glucose tolerance (Schaefer *et al*., 1991). Additionally, the results of a study by Kemp *et al.*

(1996) indicate that sows that are less glucose-tolerant have greater pig mortality during the first 7 days after farrowing.

The dietary supplementation of fish oil in animal diets has the potential to improve reproductive performance of sows (Kim *et al*., 2007). Offering fish oil to sows throughout pregnancy at a level of 1.75% improved piglet survival, probably through supplying omega-3 fatty acids (O3FA) to the piglets in uteri for improved organ development (Rookie *et al*., 2001a). The fatty acid composition of the O3FA source has also been suggested as a factor in piglet birth weight (Mateo *et al*., 2009). Using salmon oil instead of tuna oil in the diets resulted in a higher ratio of n-6 to n-3 acids and eicosapentaenoic acid (EPA) to docosahexaenoic acid (Rooke *et al*., 2001a; Rookie *et al*., 2001b). EPA has an inhibitory effect on the arachidonic acid synthesis (Rookie *et al*., 2001a), which status has been correlated with birth weight in human (Carlson, 1996). Additionally, Papadopoulos *et al*. (2009) reported that dietary supplementation of fish oil from 8 days before farrowing ensures an improved sow's feed intake and piglet growth during the first days postpartum. Higher gestation lysine intake had no effect on the number of piglets born per litter and piglets born alive (Cooper *et al*., 2001; Yang *et al*., 2009), but resulted in greater litter birth (Yang *et al*., 2009). Experimental induced hypocalcaemia during the parturition process leads to a reduction in uterine activity (Ayliff *et al*., 1984). Although there was evidence of a delay in the expulsion of piglets in the hypocalcaemia sows, there was no evidence of an increased number of stillborn piglets. Towards the end of parturition, the maternal calcium absorption increases in response to an increased fetal demand of calcium. Supplementation of dietary calcium during gestation had a positive effect on serum calcium concentration of the sow (Wuryastuti *et al*., 1991).

Insufficient ventilation / Toxic gases

Field-case reports indicate that stillborn piglets can result from high concentration of atmospheric carbon monoxide (> 120 pap) in farrowing houses (Wood, 1979; Dominick and Carson, 1983; Pessac *et al*., 2008). Carbon monoxide acts by competing with oxygen for binding sites on hemoglobin leading to tissue hypoxia (Carson, 2006). Carbon monoxide (CO) poisoning results from malfunctioning of gas-fired heaters and inadequate ventilation in the farrowing unit. A high percentage of sows, which appears clinically normal, deliver whole litters born dead within a few hours of being put in the farrowing unit. Common gross lesions in stillborn piglets were cherry red discoloration of the subcutaneous tissues, muscle and viscera (Dominick and Carson, 1983; Pessac *et al*., 2008).

Stress / Farrowing environment

Breeding sows may encounter different types of stressors: social environment (number of sows housed together in a pen), stocking density (area of floor space per pig), housing environment (crates versus groups housing), feed restriction in pregnant females, extreme ambient temperatures and human-animal interactions (fear of the stockpersons) (Van Borelli *et al*., 2007). Early research of Baxter and Pathetic (1980) proposed the 'restraint-stillbirth' hypothesis; i.e. stress caused by the prevention of normal pre-farrowing behavior in restrictive crates results in endocrine changes that reduces the speed of delivery of piglets and leads to more stillbirths. Lawrence *et al*. (1992) demonstrated that sows, exposed to acute stress by moving them to crates after the birth of the first piglet, experienced a prolonged parturition. Sows exposed to chronic stress by moving them to crates already a few days before parturition, showed only lower values of oxytocin during the last part of farrowing compared to sow in pens, but there was no difference in progress of delivery between the two groups (Lawrence *et al*., 1995). The increase in plasma cortical prior to birth of the first piglet is affected by environment (Lawrence *et al*., 1994; Jarvis *et al*., 1998), but during parturition itself, housing has very little influence on plasma cortical (Jarvis *et al*., 1998, 2001). A recent study by Olivier *et al*. (2008a) found that duration of farrowing and birth interval was significantly longer for sows placed in farrowing crates compared to penned sows enriched with straw. Because the longer farrowing duration in the crated sows was associated with lower oxytocin pulses after each piglet expulsion, a dysfunction of the endocrine regulation of parturition was hypothesized. Sows with long farrowing times had lower basal as well as lower peak levels of oxytocin during farrowing in comparison to sows with short farrowing times (Cistern *et al*., 1993).

Some studies reported that environmental stimuli may also have an effect on farrowing duration and/or stillbirth rate. Providing crated sows with sawdust in small amounts shortened the duration of farrowing, and reduced the incidence of intrapartum stillborn piglets, but only for sows of parities 1 to 3 (Cronin *et al*., 1993). Provision of straw had not only effect on the timing and quantity of nest building, but also decreased the duration of farrowing (Thunberg *et al*., 1999).

Heat stress

Ambient temperature above the evaporative critical temperature (27-30°C) has an influence on the performance of reproductive sows. Ambient temperature around 18-23°C are usually recommended in farrowing houses, since higher temperatures are suggested to reduce the feed intake and milk production of sows (Bunsen *et al*., 1996; Punier *et al*., 1997). Odehnalova *et al*. (2008) reported that the lowest number of stillborn piglets took place in deliveries at optimal farrowing room temperature. Machado-Neto *et al.* (1987) demonstrated that elevated temperature around farrowing exerts stress on the sow, resulting in a higher cortisol concentration in the blood serum and lower immunoglobulin's in colostrums.

Stockmanship

Hems worth *et al*. (1999) examined the potential for the human- animal relationship to affect the performance of sows in the farrowing unit. The results indicate that high levels of fear of humans by sows through stress responses may interfere with parturition and thus adversely affect the stillbirth rate. Several other studies reported that high fear levels by sows during a human approach test was associated with longer farrowing duration and greater birth interval between piglets as well as a decreased survival rate of the piglets (Thunberg *et al*., 2002; Janczak *et al*., 2003; Mossier *et al*., 2009). Behavioral interactions in the farrowing unit which may increase the sow's fear of humans include slapping/hitting the sow to move her into a farrowing crate prior to parturition or to force her to stand (to feed and drink), quick and sudden startling movements by the stockperson working in the unit. Minimal human contact during gestation may result in maintaining or increasing fear levels of humans, particularly if levels are high at mating (Hems worth *et al*., 1999). Additionally, labor savings that have occurred through facility design and automation have generally reduced the human contact with the animals in modern production units. Consequently, opportunities for positive human contact are reduced and many routine husbandry tasks (vaccination, parental treatments, moving animals) undertaken by stock people often contain aversive elements (Hems worth and Cronin, 2006).

Infections

Stillborn piglets can also be caused by infections. Some pathogens (e.g. Rubella sues, Aujeszky's disease, classical swine fever), which can exert an effect on the reproductive tract and cause abortions and/or mummified and stillborn piglets, have become rare in most EU-countries as a result of national control programs. Other pathogens (e.g. porcine parvovirus, porcine reproductive and respiratory syndrome virus and porcine circovirus type 2) are more relevant and will be discussed briefly. Porcine parvovirus and porcine enteroviruses cross the placenta at any stage of pregnancy and spread rather slowly in the uterus. When infection is very early in gestation, litters may be smaller as a result of embryonic death and desorption, but such litters are still likely to contain dead fetuses because of intrauterine spread of the virus with litter mates becoming infected at progressively later times in gestation. There may also be an increased number of stillborn pigs when, as a result of fetal death, farrowing times are delayed or farrowing intervals are prolonged (Mangling *et al*., 2000; Ames *et al*., 2007). Porcine reproductive and respiratory syndrome (PRRS) virus, which crosses the placental barrier preferentially late in pregnancy (>90 days), spreads rather rapidly within the uterus. As results of this, the effects on pregnancy include late-term abortion (107–110 days), premature farrowing (110–113 days) or farrowing at term. The uterine contents consist of stillbirths, autolysis normal sized pigs, weak pigs or live and vital pigs, late return to estrus and repeat breeders (Mengeling *et al*., 2000; Pender *et al*., 2004). Following an initial outbreak, a storm of reproductive failure may occur consisting of premature farrowings, late term abortions, an increase in stillbirths, mummified fetuses and weak neonates. The stillbirth may reach 35-40%. Weakborn piglets die within one week and contribute to high preweaning mortality (Mengeling *et al*., 2000). The transmission of encephalomyocarditis virus is believed to be transplacental, since the virus is regularly isolated in aborted fetuses and stillborn piglets (Ames *et al*., 2007). However, the pathogenesis of reproductive failure following infection by encephalomyocarditis virus is not well understood (Almond *et al*., 2006). There have been several reports of reproductive failure due to porcine circovirus type (PCV2) since the original report of West *et al*. (1999) in Canada (Ladekjaer-Mikkelsen *et al*., 2001; O'Connor *et al*., 2001). Clinical signs include increased abortions, stillbirths, mummies, and preweening mortality. Affected herds are typically gilt startups or new populations. Porcine circovirus 2 (PCV2) has been associated with a variety of disease syndromes in pigs, including postweaning multisystemic wasting syndrome (PMWS) in weaned pigs, respiratory disease, and, most recently, myocarditis in stillborn piglets (West *et al*., 1999).

Leptospirosis in pigs commonly occurs in chronic form and is characterized by abortion and a high incidence of stillbirths. Piglets produced at term may be dead or weak and die soon after birth. Kumagai *et al*. (1988) reported neonatal toxoplasmosis in pigs. Seven piglets were born to one of seven sows on a farm in Japan; four of these piglets were stillborn. Three of the seven piglets had gait abnormalities and died before they were 15 days old. On necropsy, the piglet had evidence of encephalitis, pneumonitis, and lymph node necrosis. The diagnosis was confirmed immunohistochemically, and by finding antibodies to *T. gondii* (Kumagai *et al*., 1988). Similarly, neonatal toxoplasmosis in pigs in Brazil was reported by Giraldi *et al*. (1996). They found T. gondii in tissues of two aborted fetuses, six stillborn, and 10 neonatal piglets; in histological sections of brains from 15 piglets, hearts of 13 piglets, lungs of 12 piglets, livers of 11 piglets, retinas of 10 piglets and spleens of five piglets.

Recently, Kim *et al*. (2009) reported an outbreak of clinical toxoplasmosis in adult sows in a larger herd in Jeju Island, Korea. Affected sows were febrile, anorectic, had neurological signs and few aborted. T. gondii was found histologically in tissues of four adult sows and five aborted littermate piglets.

Conclusion:

Farrowing a large litter without stillborn piglets forms the final and most important step of pregnancy. The identification of specific factors associated with stillborn piglets is a key element to reach this foremost goal. A schematic representation of the possible risk factors is given in Fig. 1. Nevertheless, it has to be clear that many risk factors are not independent but highly interrelated with each other and that a high stillbirth rate must be seen as a multifactorial problem.

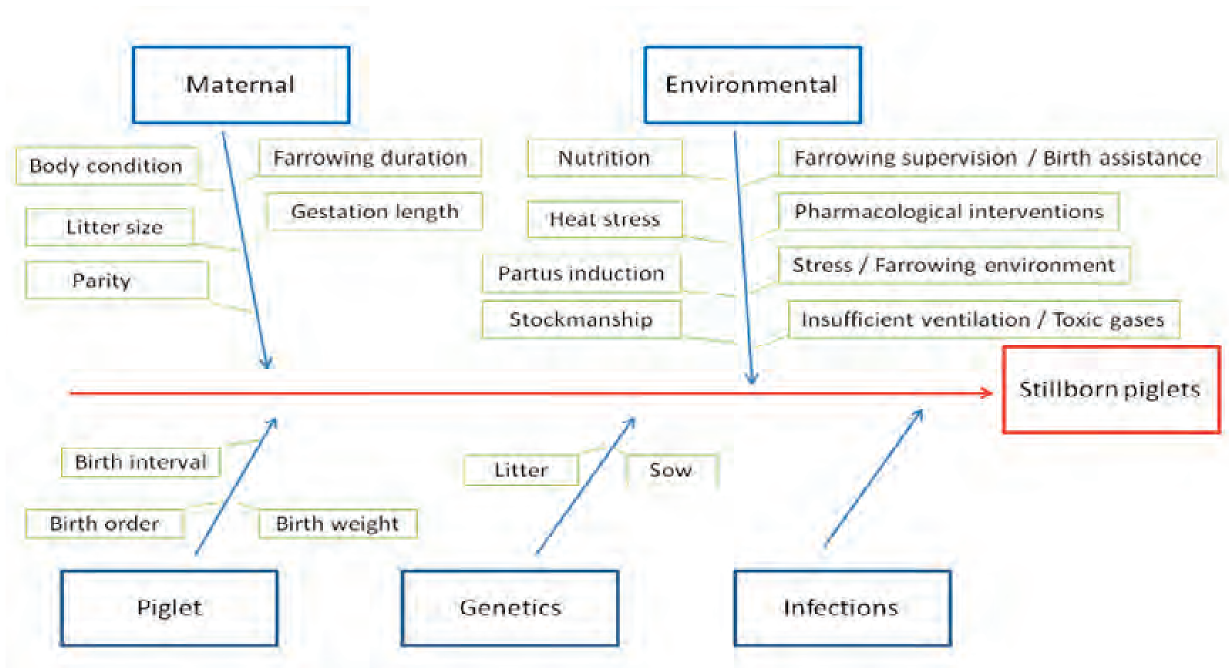

Fig.1. Schematic representation of risk factors associated with stillborn piglets

References:

Almond, G.W., Flowers, W.L., Batista, L., Dallier, S., 2006. Diseases of the reproductive system. In: Straw BE, Zimmerman, J.J., Dallier, S., Taylor, D.J. eds. Diseases of Swine 9th ed. Blackwell Publishing, pp. 113-147.

Alonso-Pillsbury, M., Mota-Rojas, D., Martínez-Burnes, J., Arch, E., López-Mayagoitia, A., Ramírez-Necoechea, R., Olmos, A., Trujillo, M.E., 2004. Use of oxytocine in penned sows and its effect on fetal intra-partum asphyxia. Animal Reproduction Science 84, 157-167.

Alonso-Pillsbury, M., Moat-Rojas, D., Villanueva-Garcia, D., Martínez-Burnes, J., Orozco, H., Ramírez-Necoechea, R., López-Mayagoitia, A., Trujillo, M.E., 2005. Perinatal asphyxia path physiology in pig and human. Animal Reproduction Science 90, 1–30.

Ayliff, T.R., Nooks, D.E., Robalo-Silva, J., 1984. The effect of experimental induced hypocalcaemia on uterine activity in the sow during parturition and post-partum Theriogenology 21(5), 803-822.

Baxter, M.R., Pathetic, J.C., 1980. The effect of restraint on parturition in the sow. Proceedings of the 6th International Pig Veterinary Society, 84.

Bunsen, N.J., Van Borelli, E.H., Ford, S.P., 1996. Effects of space allocation and temperature on periparturient maternal behaviors, steroid concentrations, and piglet growth rates. Journal of Animal Science 74, 2641-2648.

Bilked, G., Blockier, A., 1993. The effects of feeding regimes in last month of gestation on the body condition and reproductive performance of sows of different body condition and parity. Tierärztliche Umschau 48, 629-635.

Bilked, G., 1992. The effect of different zoo technical practice methods on the duration of labor in swine with reference to the body condition of the sow. Tierarztliche Praxzis 20(2), 153-158.

Blasco, A., Bidanel, J.P., Haley, C.S., 1995. Genetics and neonatal survival. In: Varley M.A., ed. The neonatal pig: Development and Survival. Cab International Wallingford, UK, pp. 17-38.

Bolcskei, A., Bilkei, G., Biro, O., Clavadetscher, E., Goos, T., Stelzer, P., Bilkei, H., Wegmuller, S., 1996. The effect of timing of labor induction on the occurrence of congenital myofibrillar hypoplasia – short clinical report. DeutscheTierärztliche Wochenschrift 103(1), 21-22.

Borges, V.F., Bernardi, M.L., Bortolozzo, F.P., Wentz, I., 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine 70, 165–176.

Canario, L., Cantoni, E., Le Bihan, E., Caritez, J.C., Billon, Y., Bidanel, J.P., Foulley J.L., 2006a. Between-breed variability of stillbirth and its relationship with sow and piglet characteristics. Journal of Animal Science 84, 3185–3196.

Canario, L., Roy, N., Gruand, J., Bidanel, J.P., 2006b. Genetic variation of farrowing kinetics traits and their relationships with litter size and perinatal mortality in French Large White sows. Journal of Animal Science 84, 1053-1058.

Carlson S.E., 1996. Arachidonic acid status of human infants: Influence of gestational age at birth and diets with very long chain n-3 and n-6 fatty acids. Journal of Nutrition 126, 1092-1098.

Carson, T.L., 2006. Toxic minerals, chemicals, plants, and gases. In: Straw, B., Zimmerman, J., D'Allaire, S., Taylor, D. eds. Diseases of Swine, 9th edn., Blackwell Publishing, Ames Iowa, USA, pp. 971-984.

Cassar, G., Kirkwood, R.N., Friendship, R., Poljak, Z., 2004. Sow and litter performance following farrowing induction with prostaglandin: Effect of adjunct treatments with dexamethasone or oxytocin. Journal of Swine Health and Production 13, 81-85.

Castrèn, H., Algers, B., de Passille, A.M., Rushen, J., Avnas-Moberg, K., 1993. Preparturient variation in progesterone, prolactin, oxytocin and somastatin in relation to nest building in sows. Applied Animal Behaviour Science 38, 91-102.

Christianson, W.T., 1992. Stillbirths, mummies, abortions, and early embryonic death. Veterinary Clinics of North America: Food Animal Practice 8, 623-639.

Close, W.H., Cole D.J.A., 2000. Introduction to Nutrition in Sows and Boars. Nottingham University Press, United Kingdom, pp. 1-8.

Cooper, D.R., Patience, J.F., Zijlstra, R.T., Rademacher, M., 2001. Effect of energy and lysine intake in sow performance. Journal of Animal Science 79, 2367-2377.

Cronin, G.M., Schirmer, B.N., McCallum, T.H., Smith, J.A., Butler, K.L., 1993. The effects of providing sawdust to pre-parturient sows in farrowing crates on sow behavior, the duration of parturition and the occurrence of intra-partum stillborn piglets. Applied Animal Behaviour Science 36, 301-315.

Curtis, S.E., 1974. Responses of the piglet to perinatal stressors. Journal of Animal Science 38, 1031-1036.

Cutler, R.S., Fahy, V.A., Cronin, G.M., Spicer, E.M., 2006. Preweaning Mortality. In: Straw, B., Zimmerman, J., D'Allaire, S., Taylor, D. eds. Diseases of Swine, 9th edn., Blackwell Publishing, Ames Iowa, USA, pp. 993-1009.

Damgaard, L.H., Rydhmer, L., Løvendahl, P., Grandison, 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, 604-610.

Dial G.D., 1984. Clinical applications of prostaglandins in swine. Journal of the American Veterinary Medical Association 185, 1523-1530.

Doberenz, J., Birkenfeld, C., Kluge, H., Eder, K., 2006. Effects of L-carnitine supplementation in pregnant sows on plasma concentrations of insulin-like growth factors, various hormones and metabolites and chorion characteristics. Journal of Animal Physiology and Animal Nutrition 90, 487-499.

Dominick, M.A., Carson, T.L., 1983. Effects of carbon monoxide exposure on pregnant sows on their fetuses. American Journal of Veterinary Research 44, 35-40.

Edwards, S.A., 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livestock Production Science 78, 3-12.

Fahmy, M.H., Friend, D.W., 1981. Factors influencing, and repeatability of the duration of farrowing in Yorkshire sows. Canadian Journal of Animal Science 61, 17-22.

Farmer, C., Robert, S., 2002. Hormonal, behavioural and performance characteristics of meishan sows during pregnancy and lactation. Canadian Journal of Animal Science 83, 1-12.

Farmer, C., Sorensen, M.T., 2001. Factors affecting mammary development in gilts. Livestock Production Science 70,141-148.

First, N.L., Lohse, J.K., Nara, B.S., 1982. The endocrine control of parturition. In: Cole D.J.A., Foxcroft, G.R., eds. Control of Pig Reproduction. Butterworths, London, England, p. 311-342.

Gheller, N.B., Werlang, R.F., Mores, T.J., Santi, M., Gava, D., Bernardi, M.L., Barcellos, D.E.S.N., Wentz, I., Bortolozzo, F.P. 2009. Prostaglandin associated with oxytocin or cabetocin in induction of thparturition is sows. Proceedings of the VIII International Conference of Pig Reproduction, Alberta, Canada, 253-12.

Giraldi, N., Freire, R.L., Navarro, I.T., Viotti, N.M.A., Bueno, S.G., Vidotto, O., 1996. Estudo da toxoplasmose conge ˆnita natural em granjas de sui ´nos em Londrina, PR. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 48, 83–90.

Guillemot, R., Hamard, A., Quesnel, H., Père, M-C., Etienne, M., Dourmad. J-Y., Meunier-Salaün, M-C., 2007. Dietary fibre for gestation sows: effects on parturition progress, behaviour, litter and sow performance. Animal 1(6), 872-880.

Gunvaldsen, R.E., Waldner, C., Harding, J.C., 2006. Effects of farrowing induction on suckling piglet performance. Journal of Swine Health and Production 15, 84-91.

Hanenberg, E.H.A.T., Knol, E.F., Merks, J.W.M., 2001. Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs. Livestock Production Science 69, 179-186.

Hemsworth, P.H., Coleman, G.J., Barnett, J.L. 1994. Improving the attitude and behavior of stockpersons towards pigs and the consequences on the behavior and reproductive performance of commercial pigs. Applied Animal Behaviour Science 39, 349-362.

Hemsworth, P.H., Cronin, G.M., 2006. Behavioral Problems. In: Straw, B., Zimmerman, J., D'Allaire, S., Taylor, D., eds. Diseases of Swine, 9th edn, Blackwell Publishing, Ames Iowa, USA, pp. 847-859.

Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., 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 Behavioral Science 65, 43-52.

Herpin, P., Hulin, J.C., Le Dividich, J., Fillaut, M., 2001. Effect of oxygen inhalation at birth on the reduction of early postnatal morality in pigs. Journal of Animal Science 79, 5-10.

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

Holm, B., Bakken, M., Vangen, O., Rekeya, R., 2004. Genetic analysis of litter size, parturition length and birth assistance requirements in primiparous sows using a joint linear-threshold animal model. Journal of Animal Science 82, 2528-2533.

Holyoake, P.K., Dial, G.D., Trigg, T., King, V.L., 1995. Reducing pig mortality through supervision during the perinatal period. Journal of Animal Science 73, 3543-3551.

Ichikawa, H., Koketsu, Y., 2009. A comparison between early and late farrowing induction for reproductive performance in commercial swine herds. Allan, D., Leman Swine Conference 36 (abstract).

Janczak, A.M., Pedersen, L.J., Rydhmer, L., Bakken, M., 2003. Relation between early fear- and anxiety-related behaviour and maternal ability in sows. Applied Animal Behaviour Science 82, 121-135.

Jarvis, S., Lawrence, A.B., McLean, K.A., Chirnside, J., Deans, L.A., Calvert, S.K., 1998. The effect of environment on plasma cortisol and beta-endorphin in the parturient pig and the involvement of endogenous opioids. Animal Reproduction Science 52, 139-151.

Jarvis, S., Van der Vegt, B.J., Lawrence, A.B., McLean, K.A., Deans, L.A., Chirnside, J., 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, 203-216.

Kaeoket, K., 2006. The effect of dose and route of administration of R-cloprostenol and the parturitient response of sows. Reproduction of Domestic Animals 41, 472-476.

Kemp, B., Soede, N.M., Vesseur, P.C., Helmond, F.A., Spoorenberg, J.H., Frankena, K., 1996. Glucose tolerance of pregnant sows is related to postnatal pig mortality. Journal of Animal Science 74, 879-885.

Kim, S.W., Mateo, R.D., Yin, Y.L., Wu, G., 2007. Functional amino acids and fatty acids for enhancing production performance of sows and piglets. Asian-Australalasian Journal of Animal Science 20(2), 295-306.

Kim, J.H., Kang, K.I., Kang, W.C., Sohn, H.J., Jean, Y.H., Park, B.K., Kim, Y., Kim, D.Y., 2009. Porcine abortion outbreak associated with Toxoplasma gondii in Jeju Island, Korea. Journal of Veterinary Science 10, 147–151.

Kirkwood, R.N., Aherne, F.X., 1998. Increasing the predictablility of cloprostenol-induced farrowing in sows. Journal of Swine Health and Production 6, 57-59.

Knol, E.F., Leenhouwers, J.I., Van der Lende, T., 2002. Genetic aspects of piglet survival. Livestock Production Science 78, 47-55.

Kumagai, S., Saga, H., Takahashi, Y., Shimura, O., Hatakeyama, N., 1988. Toxoplasmosis of suckling piglets supposed congenital infection. Journal of Japanese Veterinary Medical Association 41, 251–254 (in Japanese).

Ladekjaer-Mikkelsen, A.S., Nielsen, J., Storgaard, T., Botner, A., Allan, G., Mc Neilly, F., 2001. Transplacental infection with PCV2 associated with reproductive failure in gilt. Veterinary Record 148, 759-760.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Gilbert, C.L., Chapman, C., Russell, J.A., 1992. Naloxone prevents interruption of parturition and increases plasma oxytocin following environmental disturbance in parturient sows. Physiology and Behaviour 52, 917-923.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Deans, L., Chirnside, J., Vaughan, A., Gilbert, C.L., Forsling, M.L., Russell, J.A., 1995. The effects of chronic environmental stress on parturition and on oxytocin and vasopressin secretion in the pig. Animal Reproduction Science 38, 251-264.

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

Lay, D.C., Matteri, R.L., Carroll, J.A., Fangman, T.J., Safranski, T.J., 2002. Preweaning survival in swine. Journal of Animal Science 80, E74-E86.

Le Cozler, Y., Guyomarc, H.C., Pichodo, X., Quinio, P., Pellios, H., 2002. Factors associated with stillborn and mummified piglets in high-prolific sows. Animal Research 51, 261-268.

Leenhouwers, J.I., Van der Lende, T., Knol, E.F., 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243-253.

Lucia, T., Corrêa, M.N., Deschamps, J.C., Bianchi, I., Donin, M., Machado, A., Meincke, W., Matheus, J.E.M., 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. Preventive Veterinary Medicine 53, 285-292.

Machado-Neto, R., Graves, C.N., Curtis, S.E., 1987. Immunoglobulins in piglets from sows heat-stressed prepartum. Journal of Animal Science 65, 445-455.

Maes, D., Janssens, G., Delputte, P., Lammertyn, A., de Kruif, A., 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57–67.

Martineau, G.P., Smith, B.B., Doizé, B., 1992. Pathogenesis, prevention and treatment of lactational insufficiency in sows. Veterinary Clinics of North America: Food Animal Practice 8, 661-684.

Mateo, R.D., Caroll, J.A., Hyun, Y., Smith, S., 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, 948-959.

Mengeling, W., Lager, K.M., Vorwald, A.C., 2000. The effect of porcine parvovirus and porcine reproductive and respiratory syndrome virus on porcine reproductive performance. Animal Reproduction Science 60-61, 199-210

Mosnier, A., Dourmad, J-Y., Etienne, M., Le Floc'h, N., Père, M-C., Ramaekers, P., Sève, B., Van Migen, J., Meunier-Salaün, M-C., 2009. Feed intake in the multiparous lactating sow: Its relationship with reactivity during gestation and tryptophan status. Journal of Animal Science 87, 1282-1291.

Mota-Rojas, D., Martínez-Burnes, J., Trujillo-Ortega, M.E., Alonso-Spilsbury, M., Ramírez-Necoechea, R., Lopez, A., 2002. Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortality of piglets. American Journal of Veterinary Research 63, 1571-1574.

Mota-Rojas, D., Villanueva-García, D., Velazquez-Armenta, E., Nava-Ocampo, A., Ramírez-Necoechea, R., Alonso-Spilsbury, M., Trujillo, M.E., 2007. Influence of time at which oxytocin is administered during labor on uterine and perinatal death in pigs. Biological Research 40(1), 55-63.

Mota-Rojas, D., Martínez-Burnes, J., Alonso-Spilsbury, M., Lopez, A., Ramírez-Necoechea, R., Trujillo-Ortega, M.E., Medina-Hernandez, F.J., de la Cruz, N.I., Albores-Torres, V., Loredo-Osti, J., 2006. Meconium staining of the skin and meconium aspiration in porcine intrapartum stillbirths. Livestock Science 102, 155-162.

Mota-Rojas, D., Nava-Ocampo, A., Trujillo, M.E., Velazquez-Armenta, E., Ramírez-Necoechea, R., Martínez-Burnes, J., Alonso-Spilsbury, M., 2005. Dose minimization study of oxytocin in early labor in swine: Uterine activity and fetal outcome. Reproduction Toxicology 20, 255-259.

Musser, R.E., Goddband, R.D., Tokach, M.D., Owen, K.Q., Nelssen, J.L., Blum, S.A., Dritz, S.S., Civis, C.A., 1999. Effects of L-carnitine fed during gestation and lactation on sow and litter performance. Journal of Animal Science 77, 3289-3295.

O'Connor, B., Gauvreau, H., West, K., Bodgan, J., Ayroud, M., Clark, E.G., Konoby, C., Allan, G., Ellis, J.A., 2001. Multiple porcine circovirus 2 associated abortions and reproductive failure in a multisite swine production unit. Canadian Veterinary Journal 42, 551-553.

Odehnalova, S., Vinkler, A., Novak, P., Drabek, J., 2008. The dynamics of changes in selected parameters in relation to different air temperature in the farrowing house for sows. Czech Journal of Animal Science 53, 195-203.

Oliviero, C., Heinonen, M., Valros, A., Hälli, O., Peltoniemi, O., 2008a. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Animal Reproduction Science 105(3-4), 365-377.

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

Oliviero, C., Kokkonen, T., Heinonen, M., Sankari, S., Peltoniemi, O., 2009. Feedings sows with high fibre diet around farrowing and early lactation: Impact on intestinal activity, energy balance related parameters and litter performance. Research in Veterinary Science 86, 314-319.

Oliviero, C., Pastelli, M., Heinonen, M., Heikkonen, J., Valros, A., Ahokas, J., Vainio, O., Peltoniemi, O.A.T., 2008b. Using movement sensors to detect the onset of farrowing. Biosystems Engineering 100, 281-285.

Olmos-Hernández, A., Alononso-Spilsbury, M., Nava-Ocampo, A., Truijllo-Ortega, M.E., Orozco-Gregorio, H., Ramírez-Necoechea, R., Mota-Rojas, D., 2008. Heavier newborn piglets are more prone to intra-partum asphyxia and show longer first udder contact vs. average weight pigs. Proceedings 20th IPVS, Durban South-Africa, OR.07.17 pp. 223.

Papadopoulos, G.A., Vanderhaeghe, C., Janssens, G.P.J., Dewulf, J., Maes, D.G.D., 2010. Risk Factors associated with postpartum dysgalactia syndrome in sows. The Veterinary Journal 184, 167-171.

Pejsak, Z., Zmudzki, J., Wojnicki, P., 2008. Abortion in sows associated with carbon monoxide intoxication. Veterinary Record 162, 417-418.

Peltoniemi, O.A.T., Tast, A., Heinonen, M., Oravainen, J., Munsterhjelm, C., Hälli, O., Oliviero, C., Hälmeenoja, P., Virolainen, J.V., 2009. Fertility of sows fed adlibitum with a high fibre diet during pregnancy. Reproduction in Domestic Animals 45, 1008-1014.

Pensaert, M.B., Sanchez, R.E., Ladekjaer-Mikkelsen, A., Allan, G.M., Nauwynck, H.J., 2004. Viremia and effect of fetal infection with porcine viruses with special reference to porcine circovirus 2 infection. Veterinary Microbiology 98, 175-183.

Pluske, J.R., Williams, I.H., Aherne, F.X., 1995. Nutrition of the neonatal pig. In: Varley, M.A. ed., The neonatal pig: Development and Survival. Cab International Wallingford, UK, pp.187-235.

Prunier, A., Messias de Bragança, M., Le Devidich, J., 1997. Influence of high ambient temperature on performance of reproductive sows. Livestock Production Science 52, 123-133.

Ramanau, A., Kluge, H., Spilke, J., Eder, K., 2004. Supplementation of sows with L-carnitine during pregnancy and lactation improves growth of hte piglets during suckling period through increased milk production. Journal of Nutrition 134, 86-92.

Ravel, A., D'Allaire, S., Bigras-Poulin, M., 1996. Influence of management, housing and personality of the stockperson on preweaning performances on independent and integrated swine farms in Québec. Preventive Veterinary Medicine 29, 37-57.

Rehfeldt, C., Nissen, P.M., Kuhn, G., Vestergaard, M., Ender, K., Oksbjerg, N., 2004. Effects of maternal nutrition and porcine growth hormone (pGH) treatment during gestation on endocrine and metabolic factors in sows, fetuses an pigs, skeletal muscle development, and postnatal growth. Domestic Animal Endocrinology 27, 267-285.

Revell, D.K., Williams, I.H., Mullan, B.P., Ranford, J.L., Smits, R.J., 1998. Body composition at farrowing and nutrition during lactation affect the performance of primiparous sows: I Voluntary feed intake, weight loss and plasma metabolites. Journal of Animal Science 76, 1729-1737.

Rooke, J.A., Sinclair, A.G., Edwards, S.A., Cordoba, R., Pkiyachi, S., Penny, P.C., Penny, P., Finch, A.M., Horgan, G.W., 2001a. The effect of feeding salmon oil to sows throughout pregnancy on pre-weaning mortality of piglets. Animal Science 73, 489-500.

Rooke, J.A., Sinclair, A.G., 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, 21-30.

Rydhmer, L., Lundeheim, N., Canario, L., 2008. Genetic correlations between gestation length, piglet survival and early growth. Livestock Science 115, 287-293.

Sasaki, Y., Koketsu, Y., 2007. Variability and repeatability in gestation length related to litter performance in female pigs on commercial farms. Theriogenology 68, 123-127.

Schaefer, A.L., Tong, A.K.W., Sather, A.P., Beltranena, E., Pharazyn, A., Aherne, F.X., 1991. Preparturient diabetogenesis in primiparous gilts. Canadian Journal of Animal Science 71, 69-77.

Smith, H.M., Williams, A.M., Safranski, T.J., 2009. Effects of day of farrowing induction on the suckling piglets performance. Proceedings of the VIII International Conference of Pig Reproduction, Alberta, Canada, 253-25.

Straw, B., Bates, R., May, G., 2008. Influence of method of administration of prostaglandin on farrowing and relationship between gestation length and piglet performance. Journal of Swine Health Production 16, 138-143.

Svendsen, J., Svendsen. L.S., Bengtsson, A.C., 1986. Reducing perinatal mortality in pigs. In: Leman A. et al. (Eds.) Diseases of swine, Iowa State University Press, pp. 813-825.

Svendsen, J., 1992. Perinatal mortality in pigs. Animal Reproduction Science 28, 59-67.

Tabeling, R., Schwier, S., Kamphues, J., 2003. Effects of different feeding and housing conditions on dry matter content and consistency of faeces in sows. Journal of Animal Physiology and Animal Nutrition 87, 116-121.

Thodberg, K., Jensen, K.H., Herskin, M.S., Jørgensen, E., 1999. Influence of environmental stimuli on nest building and farrowing behavior in domestic sows. Applied Animal Behaviour Science 63, 131-144.

Thodberg, K., Jensen, K.H., Herskin, M.S., 2002. Nest building and farrowing in sows: relation to the reaction pattern during stress, farrowing environment and experience. Applied Animal Behaviour Science 77, 21-42.

Turner, A.I., Hemsworth, P.H., Tilbrook, A.J., 2005. Susceptibility of reproduction in female pigs to impairment by stress or elevation of cortisol. Domestic Animal Endocrinology 29, 398-410.

Vaillancourt, J.P., Stein, T.E., Marsh, W.E., Leman, A.D., Dial, G.D., 1990. Validation of producer-recorded causes of preweaning mortality in swine. Preventive Veterinary Medicine 10, 119-130.

Van der Lende, T., Van Rens, B.T.T.M., 2003. Critical periods for foetal mortality in gilts identified by analyzing the length distribution of mummified fetuses and frequency of non-fresh stillborn piglets. Animal Reproduction Science 75, 141-150.

Van der Peet-Schwering, C.M.C., Kemp, B., Binnendijk, G.P., den Hartog, L.A., Vereijken, P.F.G., Verstegen, W.A., 2004. Effects of additional starch or fat in late gestating high non starch polysaccharide diets on litter performance and glucose tolerance in sows. Journal of Animal Science 82, 2964-2971.

Van Borell, E., Dobson, H., Prunier, A., 2007. Stress, behaviour and reproductive performance in female cattle and pigs. Hormones and Behavior 52, 130-138.

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, 1573-1590.

Van Dijk, A.J., Van der Lende, T., Taverne, M.A.M., 2006. Acid base balance of umbilical artery blood of live born piglets at birth and its relation with factors affecting delivery of individual piglets. Theriogenology 66, 1824-1833.

Van Rens, B.T.T.M, Van der Lende, T., 2004. Parturition in gilts: duration of farrowing, birth intervals and placenta expulsion in relation to maternal piglets and placental traits. Theriogenology 62, 331-352.

Wehrend, A., Stratmann, N., Failing, K., Bostedt, H., 2005. Influence of partus induction on the pH value in the blood of newborn piglets. Journal of Veterinary Medicine A 52, 472-473.

Weldon, W.C., Lewis, A.J., Louis, G.F., Kovar, J.L., Miller, P.S., 1994. Postpartum hypophagia in primiparous sows: II. Effects of feeding level during gestation and exogenous insulin on lactation feed intake, glucose tolerance, and epinephrine-stimulated release of non-esterified fatty acids and glucose. Journal of Animal Science 72, 395-403.

West, K.H., Bystrom, J.M., Wojnarowicz, C., Shantz, N., Jacobson, M., Allan, G.M., Haines, D.M., Clark, E.G., Krakowka, S., McNeilly, F., Konoby, C., Martin, K., Ellis, J.A., 1999. Myocarditis and abortion associated with intrauterine infection of sows with porcine circovirus 2. Journal of Veterinary Diagnostic Investigation 11, 530–532.

White, K.R., Anderson, D.M., Bate, L.A., 1996. Increasing piglet survival through an improved farrowing management protocol. Canadian Journal of Animal Science 76, 491-495.

Whittemore, C.T., 2006: Reproduction. In: Whittemore, C.T., Kyriazakis, I., eds., Whittemore’s Science and Practice of Pig Production, Third Edition. Blackwell Publishing, pp. 379-403.

Wolf, J., Záková, E., Groeneveld, E., 2008. Within litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science 115, 195-205.

Wood, E.N., 1979. Increased incidence of stillbirth in piglets associated with levels of atmospheric carbon monoxide. Veterinary Record 104, 283-284.

Wuryastuti, H., Stowe, D., Miller, E.R., 1991. The influence of gestational dietary calcium on serum 1,25-deihydroxycholecalciferol in sows and their pigs. Journal of Animal Science 69, 734-739.

Yang, Y.X., Heo, S., Jin, Z., Yun, J.H., Choi, J.Y., Yoon, S.Y., Park, M.S., Yang, B.K., Chae, B.J., 2009. Effects of lysine intake during late gestation and lactation on blood metabolites, hormones, milk composition and reproductive performance in primiparous and multiparous sows. Animal Reproduction Science 112, 199-214.