EVALUATION OF THE EFFECTS OF BIRTH ORDER AND OTHER INFLUENCING FACTORS ON PRE-WEANING PIGLET MORTALITY UNDER COMMERCIAL CONDITIONS

BY

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ABSTRACT

The objective of this research was to evaluate the effects of birth order on pre-weaning mortality and to identify factors which could influence piglet survival to weaning. A study of 191 litters born over a two-month period was carried out in two commercial facilities; piglets were allotted to one of four treatments (1. first 25% born, 2. second 25% born, 3. third 25% born, 4. last 25% born, respectively) based on their birth order within each litter. The study was carried out as a split-plot design, with the main plot being the sow. All treatments were represented on each sow. Birth measurements, including birth order, birth weight, rectal temperature and body surface temperature at birth and 3 hours post-natal were recorded. The timing and cause of death of piglets dying prior to weaning, as well as piglet weights at processing, weaning, and death were recorded. Piglets born at the first facility were not cross-fostered, whereas piglets at the second location were cross-fostered. Piglets were cross-fostered between litters born on the same day to create litters of similar piglet size. Piglets born stillborn in their birth litter were born later ($P < 0.001$) in the birth order compared to piglets born alive (birth order of 10.7 vs. 7.2 in litter, respectively; SEM 0.31). Piglets born in the final 25% of the birth order were heavier ($P < 0.001$) at birth compared to piglets born earlier in the birth order (1.51 vs. 1.43, 1.44, and 1.43 kg for treatments 4 vs. 1, 2, and 3, respectively; SEM 0.030). Piglets born in the final 25% of the birth order had higher rectal temperatures ($P < 0.001$) at birth compared to piglets born earlier in the birth order (36.83 vs. 36.50, 36.60, and 36.55°C for treatments 4 vs. 1, 2, and 3, respectively; SEM 0.062), however, temperatures taken at 3 hours post-natal were similar ($P = 0.82$) for all treatments. Piglets born in the first 25% of the birth order had the highest levels ($P < 0.001$) of immunoglobulin-G in their blood compared to piglets born later in the birth order (13.87 vs. 13.53, 13.38, 12.65% blood serum for treatments 1 vs. 2, 3, and 4, respectively; SEM 0.340). The main cause of death for piglets dying pre-weaning was crushing by the sow (54.6% of all pre-weaning mortality), and most deaths occurred within the first 3 days of age (44.3% of all pre-weaning mortality). Piglets surviving to weaning had heavier ($P < 0.001$) birth weights (1.43 vs. 1.16 kg; SEM 0.015) and higher rectal temperatures ($P < 0.001$) (36.58 vs. 38.23°C, respectively; SEM 0.062) at birth compared to piglets dying prior to weaning. This study confirms that the major cause of pre-weaning mortality in piglets is crushing by the sow and suggests that piglets dying prior to weaning have decreased birth weights and decreased body temperatures at birth. Piglets born in first 25% of the birth order had the highest levels of immunoglobulin-G, with decreased levels as birth order increased.

Key words: birth order, birth weight, pigs, pre-weaning mortality

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CHAPTER I

LITERATURE REVIEW

Advances are being made continually to increase the number of pigs weaned and marketed across production systems. In the last 20 years, improvements in management practices, as well as in the number of piglets born alive, have resulted in an increase in number of piglets weaned per sow per year (USDA, 1991, 1995, 2000, 2007). Although litter size has increased, the rate of pre-weaning mortality has actually decreased; however, pre-weaning mortality levels still create a major loss for producers, according to the National Animal Health Monitoring System (USDA, 1991, 1995, 2000, 2007). Pre-weaning mortality is a significant production loss, and considerable research has been conducted to try to fully understand the characteristics of piglets, both prepartum and postpartum, to reduce the pre-weaning mortality rate.

Stillborn Occurrence

Stillborn piglets can account for anywhere from 10-15% of total pre-weaning mortality of piglets (Herpin, 2001; Baxter, et al., 2008) to 25% (Cutler et al., 1992). Stillbirth piglets can be divided into two types, depending on the timing of mortality. In type-I stillbirths, death occurred before farrowing (also referred to as prepartum or antepartum), with the cause of mortality usually linked to intrauterine infection. In type-II stillbirths, death occurred during farrowing, or intrapartum, and is generally linked with anoxia or dystocia (Curtis, 1974; Mota-Rojas, 2002).

Leenhouwers et al. (2003) categorized stillborns into four groups, based on timing of mortality. The first category was made of partially decomposed stillborns that show signs of degeneration, with a brown skin color; these piglets probably died more than a week prior to farrowing, and most likely were categorized as a mummified piglet according to producers. The second category included prepartum stillbirths that showed no external signs of decay, but had a reddish-color of internal organs due to hemolysis and autolysis; these piglets most likely died within 3 days prior to farrowing. The third class of stillborns was intrapartum stillbirths that had a normal color of abdominal organs and mucus in their trachea, showing that the piglets most likely died in the process of parturition. The last category of stillborns was postpartum stillbirths that had slightly-aerated lungs, showing the piglets have respired after birth, but have no colostrum in their stomach, and have died shortly after birth (Randall and Penny, 1967; Leenhouwers et al., 2003).

According to Cutler et al. (1992), approximately 70% of piglets that are classified as stillborns are actually born alive. However, the piglets die within minutes of birth and are severely anoxic although the heart probably continued to beat for some time after birth. Intrapartum anoxia, or asphyxia, during farrowing or after birth, as well as umbilical cord damage, were important events that can lead to type-II stillbirths in pigs (Randall et al., 1972b; Mota-Rojas et al., 2002). As fetal anoxia occurs, blood was redistributed in the fetus, causing intestinal peristalsis and even causing the fetus to gasp violently inside the amniotic sac due to oxygen depletion, and this resulted in amniotic fluid and meconium being passed into the lungs (Mota-Rojas et al., 2002). Umbilical cord hemorrhaging has been linked to sows receiving oxytocin during farrowing, and reports suggested oxytocin-induced muscle contractions may increase pressure on the umbilical cord of the fetus, which in turn decreases blood flow and can cause anoxic death (Curtis, 1974).

In a study conducted by Mota-Rojas et al., (2002), evaluating the effect of oxytocin treatment on neonatal survival, researchers found that the highest frequency of intrapartum deaths (75%) in piglets born to sows in the control group was during the last third of the piglets born in a litter. This agrees with reports from previous studies (Randall et al., 1972b). However, with sows receiving oxytocin following the first piglet born, researchers found the highest numbers of intrapartum deaths (81-88%) was observed in the first third of the litter born (Mota-Rojas et al., 2002).

However, the risk of stillborns can also be attributed to other factors, including genetics, the length of the farrowing process, expulsion intervals between piglets, and birth order of piglets. As the duration of parturition increases beyond 4-5 hours, or after 80% of the piglets in the litter have been born, the risk and number of stillborns also increases (Cutler et al., 1992). Randall et al., (1972a, b) found that there was a stillborn rate of 0.4% among piglets born in the first third of the birth order, increasing to 2.2% in the middle third of piglets born, and to 12.5% in the last third of the piglets born. This is in agreement with the statement of Curtis (1974) that over 80% of the total stillbirths occurred in the last third of the birth order of piglets born in a litter.

Many prenatal and postnatal factors have the ability to impact piglet survival. The uterine environment provided by the sow prenatally is crucial to piglet survival, including factors such as blood flow to the uterus, the efficiency of the placenta, ability of nutrients from feed reaching the fetus, and uterine capacity (Baxter et al., 2008). Nutrient supply to the fetus is mediated by the placental blood flow in the uterus (Garnica and Chan, 1996).

Other factors that affect the survivability of a fetus are possibly due to nutrition during gestation. Pettigrew (1981) reported that supplementing the sow’s diets with fat during late gestation increased milk production and the fat concentration of colostrum and milk. This, in turn, had the capability to improve survivability of low birth weight piglets (England, 1986); piglets have limited amounts of body fat at birth and increased colostral fat increased the piglet's energy intake and fat deposition. The amount of fat present in the piglet at birth is primarily structural fat and not available for the piglet to use as energy (Mersemann, 1974; Seerley et al., 1974; Cromwell et al., 1989).

Studies have shown that as litter size increases, the mean piglet birth weight decreases (Johnson et al., 1999; Quiniou et al., 2002). The increase in litter size can be attributed to increased ovulation rates and/or lower embryo and fetal mortality (Foxcroft et al., 2006). These can lead to overcrowding of the uterus and intrauterine growth retardation of the fetuses, causing light fetuses, which may have received fewer nutrients in utero.

There is evidence of variable placental growth along the uterus and associated with that, the position of the fetus within the uterus can also play a major role in fetal growth (Gootwine, 2004). It has been observed that heavier fetuses also have heavier placentas, with piglets that had heavier placental weights also being heavier at birth, and more likely to be born alive and survive until weaning (Baxter et al., 2008). This was possibly due to the increased blood flow to heavier placentas, and, thus, increased nutrient availability to the fetus and also, potentially due to increased gas exchange during fetal development (Schoknecht et al., 1997; Wu et al., 2006).

Factors Associated with Piglet Survivability

Birth Weight. The major determinant factor in a piglet's chances of surviving until weaning is birth weight, which has been shown to have an inverse relationship with pre-weaning mortality. Low birth weight piglets have a lower level of body energy stores, which in turn causes a higher sensitivity to low temperatures, a delayed interval to first suckle causing reduced colostrum intake, and a lower ability to access the better teats on the sow (Le Dividich et al., 1997). Low birth weight piglets have a decreased consumption rate of colostrum and consume less in total due to a delayed time to first suckle, resulting in lower levels of both passive immunity and nutrient intake (Cutler et al., 1992; Quiniou et al., 2002). It has been reported that weight gain during the first 24 h following birth is a good indicator of the amount of colostrum consumed by the piglet (Le Dividich et al., 2005). Le Dividich also reported that heavier birth weight piglets have an advantage at the teat, with colostrum consumption increasing by 26-37 g per 100 g increase in individual piglet body weight (Le Dividich et al., 2005; Devillers et al., 2005). This is an added gain to piglets born heavier at birth, as reported by Wolter et al., (2002), who stated that heavy birth weight piglets were heavier at weaning when compared to light birth weight piglets, and similar results have been reported in other studies (Powell and Aberle, 1980; Milligan et al., 2002; Quiniou et al., 2002).

Litter Size. Lower birth weight piglets have also been widely observed in larger litters (Leenhouwers et al., 1999; Milligan et al., 2002; Quiniou et al., 2002). As litter size increases, the mean piglet birth weight decreases (Johnson et al., 1999; Quiniou et al., 2002). There are reports suggesting a higher variability in body weight within larger litters (Quiniou et al., 2002). Quesnel et al. (2008) reported that litters with fewer piglets (9 piglets) were 0.5 kg/piglet heavier than a litter with more piglets (≥16 piglets). Many producers suggest using the process of cross-fostering to help manage the issues of birth weight variation. The cross-fostering process usually involves moving heavier and lighter piglets between sows that have farrowed at similar times (Leenhouwers et al., 1999). Ideally, cross-fostering of lower birth weight piglets to create litters of similar weights improves weight gains and survival of lower birth weight piglets due to decreased competition, but conflicting results exist as to the actual benefit of cross-fostering.

Knol et al. (2002) suggests an increase of 3% in total piglet survival due to cross-fostering, but Milligan et al. (2001) did not find any effect on cross-fostering on pre-weaning survival.

Birth Order. Many reports suggest that the area of the uterus of the sow in which the piglet develops also has a role in the piglet's survivability. Dziuk and Harmon (1969) found that fetuses in a particular uterine horn were delivered in the order in which they were located within the horn during development. The piglets born later in parturition are located at the anterior end of the uterine horn and must move the furthest during delivery. Those piglets may also have an increased risk of umbilical cord stretching (Curtis, 1974). This agrees with other reports that more stillbirth occurrences were during the last third of the birth order (Randall et al., 1972a; Curtis, 1974). Baxter et al. (2008) reported that birth order was one of the most significant prenatal survival indicators; piglets born later (piglet birth number 12 or later) in the birth order were more likely to be stillborn. In addition, birth order is an indicator of pre-weaning mortality, with the average birth order of piglets dying prior to weaning being at number 10 in the birth order (Baxter et al., 2008).

Sow Parity. Milligan et al. (2002) found that younger parity sows produced fewer piglets per litter than multiple parity sows, but that the percentage of piglets stillborn increased in older parity sows. This may be due to the fact that as sows age, the duration of parturition increases, causing the risk of stillborns to increase, possibly due to asphyxia (Cutler et al., 1992). Older sows also have a greater variation in the number of functional teats, causing a variation in body weight during lactation among piglets due to variation in milk consumption (Cutler et al., 1992).

Body Temperature. One of the major challenges that a piglet faces after birth is to overcome a cold environment and control its own metabolic processes and body temperature.

The piglet is born almost hairless with very little, if any, adipose tissue, making it the most cold-sensitive ungulate (Herpin et al., 1996). Although piglets in a litter should have the same temperature as the sow within the uterus before being born, many reports suggest that there is much variation in body temperatures among piglets following parturition. Baxter et al. (2008) found that the population of piglets dying pre-weaning had much lower rectal temperatures at birth compared to those that survive to weaning, despite being born into the same environment. Piglets with a lower body temperature following parturition may have less ability for thermoregulatory control, possibly resulting in hypothermia. This could result in chilling, which may predispose the piglet to other forms of pre-weaning mortality, such as crushing, starvation, and disease (Curtis, 1974).

Facility and Equipment Design. As piglet crushing continues to remain the most prominent cause of pre-weaning mortality, producers must look at sow behavior and farrowing crate design as a means to reduce mortality. Many interest groups propose moving sows to loose-housing systems for gestation and lactation to improve sow welfare, with the idea that the sow will exhibit more natural behaviors. However, Marchant et al. (2000) found higher rates of piglet mortality for litters born and raised in loose-housing systems compared to crated systems. Increased crushing is seen in more active sows, and mostly occurs when a sow changes position (Svendsen, 1986), which may be more common when a sow has increased room, such as in a loose-housing system. Many reports suggest that sows that spend increased time lying quietly have much lower rates of pre-weaning mortality (Lay et al., 2001). Restricting the movement of the sow in a farrowing crate is an important aspect in decreasing pre-weaning mortality.

Causes of Pre-Weaning Mortality

Many piglets are predisposed to a high-risk of pre-weaning mortality, and must face environmental challenges immediately after birth. The piglet is born with low body energy stores and a lack of serum immunoglobulins; thus, the ability of the piglet to overcome a cold environment and infections is limited (Le Dividich et al., 2005). Many other factors, including genetics, gender, birth weight, birth order, facility design, and sow and piglet behavior play an important role in the ability of a piglet to survive to weaning, as well as further surviving to marketing.

Several published reports, as well as on-farm surveys, have shown that the main cause of mortality pre-weaning is due to piglets being crushed by the sow. Vaillancourt et al. (1990) concluded that the two major causes of pre-weaning mortality between 0 and 3 days of age were low viability and trauma, or crushing. Reports suggest that crushing losses account for between 32% (Holyoake et al., 1995) up to 83% (Koketsu et al., 2006) of the total pre-weaning mortality. Other major causes of mortality include starvation, low viability piglets, and scours (Holyoake et al., 1995; USDA, 1991, 1995, 2001, and 2007).

After being born, the majority of piglets will move directly toward the sow's udder, depending on the viability and strength of the piglet. Piglets have a highly developed sense of smell following birth and are attracted toward the dam's udder, most likely due to the odor of the sow's milk (Rohde Parfet and Gonyou, 1991). Piglets are also attracted to the odor of birth fluids, as well as the vocalizations from the sow (Lay et al., 2001). Since most piglets move directly toward the udder following birth, it suggests that piglets have a drive to be close to the sow's udder, despite a known lack of significant vision at this time (Lay et al., 2001).

The piglet is in a prime area to be crushed due to its attraction to the udder, whether due to the warmth of the area, odor of the sow's milk, or tactile stimuli. Lay et al. (2001) explored the attraction of piglets to the udder by placing a simulated udder in the farrowing crate that had characteristics similar to the sow's and suggested that this approach may be more successful at attracting piglets away from the sow than heat lamps alone.

Crushing can also be attributed to other factors, such as low birth weights, reduced body temperature, poor facilities, and disease, which add complexity to solving the issue of crushing (Lay et al., 2001). Piglet crushing remains the most common cause of piglet mortality for swine producers and the use of a farrowing crate has been shown to decrease piglet mortality significantly (McGlone and Morrow-Tesch, 1990).

The use of gestation and farrowing crates has become a major target of concern for swine well-being. It has been known that sows perform stereotypic behaviors, such as bar biting, and may have an increase in limb abrasions in restricted housing conditions (Deen and Xue, 1999), but sows in less-restrictive environments, such as those in groups, must vie with competition from penmates and increased aggression. It is not clear how the physical environments affect the sow and her litter, in terms of health, behavior, performance (Baxter, 1984). Several researchers have suggested examining production measurements of the sow, such as feed consumption, return to estrus and other important measures as a means to measure her well-being (Curtis and Stricklin, 1991).

Timing of Pre-Weaning Mortality

Various reports have suggested that over half of the pre-weaning deaths occur in the first 3 to 4 days of life and that the majority of these occur in the first 36 hours of life (Quiniou et al., 2002). Others have proposed that the risk of mortality is inversely related to piglet's age (Quiniou et al., 2002; Koketsu et al., 2006). It has been shown that between 24.3% (Quiniou et al., 2002) to 36.3% (Koketsu et al., 2006) of total pre-weaning mortality occurs in the first 24 hours following birth, increasing to 66.3% of total pre-weaning mortality in the first 48 hours following birth, and between 75% (Quiniou et al., 2002) and 86.3% (Koketsu et al., 2006) of total pre-weaning mortality by day seven of life.

Impact of Pre-Weaning Mortality on Production Measurements

The National Health Monitoring System, conducted by the USDA, reported an average of 11.5 piglets born and 10.5 piglets born alive in 2007, an increase from a 2000 report, with 10.9 piglets born and 10.0 piglets born alive (USDA, 2000; USDA, 2007). Vaillancourt et al. (1990) conducted a study examining the accuracy of producer-recorded causes of pre-weaning mortality. The proportions of piglets classified by producers as being low viability (25.8%), deformed (4.2%), and other (9.1%) were similar to those found were necropsied (29.7, 5.5, and 10.7%, respectively). Producers identified trauma as the major cause of death in over half of the cases submitted, but necropsy examination found only one third of these piglets actually died from trauma (Vaillancourt, 1990). Being able to accurately diagnose the cause of pre-weaning mortality is vitally important in the steps to finding solutions to decrease pre-weaning piglet mortality levels.

Colostrum and Immunoglobulin Levels

As the piglet must face extreme challenges following birth, including environmental, physical, and immunological challenges, its risk of exposure to hypothermia, trauma, and starvation are increased due to the piglet being born with low body energy stores and devoid of serum immunoglobulins (Le Dividich et al., 2005). The piglet is lacking in immunoglobulins at birth and must depend on the transfer of nutrients and antibodies from the dam for immune protection. In utero, the fetus receives a continuous supply of glucose, as well as other nutrients, for growth and metabolism (Le Dividich et al., 2005). However, the fetus is unable to receive maternal immunoglobulins due to the epitheliochorial placentation of sows (Holland, 1990). For this reason, the piglet is born without important immunoglobulins which are vital for protection from illness and disease following birth.

The total amount of fat in the newborn piglet is also very low, with many reports suggesting that the piglet is born without brown adipose tissue (Curtis, 1974; Lay et al., 2001). Therefore, the heat-conserving abilities of the piglet are very low, predisposing the piglet to an increased risk of chilling and hypothermia (Curtis, 1974). Colostrum is a rich source of immunoglobulins, with the highest concentration being of IgG. Other immunoglobulins present in colostrum, although in lesser concentrations, are IgA, IgM, and also IgD (Holland, 1990). IgG is absorbed into lymphatic vessels via the jejunum, whereas IgA coats the gut mucosal surface, forming a barrier against enteric diseases (Lay et al., 2001). As the piglet ages, a process known as gut closure occurs in which the absorptive epithelium becomes less permeable, gradually reducing the absorption levels of immunoglobulins and nutrients directly and eventually stopping (Holland, 1990). Many reports suggested that gut closure occurs within 24 to 48 hours following birth (Holland, 1990), with colostrum IgG concentrations also declining rapidly over the first 24 hours (Bland et al., 2003).

Colostrum consumption by the piglet can depend on many factors, including birth weight, litter size, piglet vitality, as well as characteristics of the sow. Conflicting results exist on the effect of birth order on colostrum consumption, with Le Dividich et al. (2005) reporting that the consumption of colostrum by the piglet is independent of birth order as determined by body weight gain in the first 24 h. It is also reported that colostrum consumption is related positively to birth weight and negatively to litter size. Colostrum consumption is highest during the first few hours following birth (Devillers et al., 2005). Bland et al. (2003) and Lay et al. (2002) report lower IgG concentrations in the colostrum consumed by later-born piglets.

Other influences on colostrum consumption include litter size and piglet birth weight. Whereas total colostrum production by the sow is independent of the total number of piglets born, it has been shown that for each additional piglet born in a litter, colostrum available per piglet decreases by 22 to 42 g (Le Dividich et al., 2005; Devillers et al., 2005). Heavier piglets at birth are also more competitive at the udder, and it has been shown that colostrum consumption increased by 26 to 37 g per 100 g increase in body weight (Le Dividich et al., 2005; Devillers et al., 2005).

Effect of Birth Characteristics on Subsequent Productivity

The impact of poor weight gains, usually of lighter birth weight piglets, represent a potential loss to producers, due to requiring extra facility costs, additional feed to reach market weight, and resulting in lower meat production (Deen et al., 1998). As producers move toward increasing litter size to increase number of weaned pigs, it is also important to remember that reports suggest this induces a decrease of mean birth weight among piglets (Quiniou et al., 2002). Milligan et al. (2002) reported litters with high variation in birth weight had increased pre-weaning mortality, which was increased even further if the mean birth weight of the litter was low. This may also be due to an increased level of competition between pigs with high variation of birth weight within litter, due to differing body weights and sizes (Milligan et al., 2001).

Wolter et al., (2002) reported that heavy birth weight piglets were also subsequently heavier at weaning compared to piglets with light birth weights. It has also been reported that lighter pigs at weaning are unable to achieve compensatory growth rates during the grow-finish period compared to piglets with heavier weaning weights and thus take longer to reach market weight (Mahan, 1993; Deen et al., 1998). In a study evaluating differing birth weight categories [light, medium, and heavy (mean birth weight of 0.9, 1.4 and 1.8 kg, respectively)] Rehfeldt and Kuhn (2006) reported that lighter birth weight piglets had the lowest growth rates. These results are similar to other reports, indicating that light birth weight piglets are also lighter at weaning, and continue to be lighter through subsequent production compared to their heavier littermates (Milligan et al., 2002; Wolter et al., 2002; Peterson et al., 2008).

Conclusions

Success of a breed-to-wean unit is measured by the number of piglets weaned per sow per year, and the survival of piglets depends on many factors, such as birth weight, body temperature, birth order, genetics, and milk production by the sow, as well as other important aspects:

- Pre-weaning mortality represents an excessive loss of piglets in production, and continues to remain at high levels across pork production systems, despite advances in production management.

- Stillborn piglets comprise a significant percentage of all piglets dying prior to weaning, and can be attributed to many factors, including genetics, total farrowing length, expulsion intervals between piglets, and birth order of piglets.
- Many factors impact the piglet's chance of surviving until weaning, including birth weight, litter size, birth order, sow parity, body temperature, and facility design, although conflicting reports exist as to the actual impact of the factors on the piglet's survivability.
- Lighter birth weight piglets are predisposed to an increased risk of pre-weaning mortality, as well as piglets born in larger litters, but the effects of birth order and body temperature on the piglet's chance of surviving to weaning is unknown.
- Colostrum intake is critical to a piglet's chance of survival in the first few hours of life, due to the fact that the piglet is born with little body energy stores and without serum immunoglobulins, and must rely on colostrum from the sow. Consumption of colostrum varies between piglets and depends on factors such as birth weight, litter size, vitality of the piglet, as well as milk production by the sow.

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CHAPTER II: EVALUATION OF THE EFFECTS OF BIRTH ORDER AND OTHER POTENTIAL INFLUENCING FACTORS ON PRE-WEANING PIGLET MORTALITY UNDER COMMERCIAL CONDITIONS.

INTRODUCTION

Although advances are made yearly to increase the number of piglets weaned per sow per year, pre-weaning mortality continues to be as a significant production loss to swine industry producers. According to USDA reports, litter size has increased in the past 20 years (USDA, 1991, 1995, 2000, 2007). However, this has come at a cost to the size of piglets born; many reports have found that as litter size increases, piglet's birth weight decreases (Johnson et al., 1999; Quiniou et al., 2002). Birth weight is a primary factor in determining whether a piglet will survive until weaning (Le Dividich et al., 2005).

Many factors influence a piglet's chances of surviving until weaning, including birth weight, litter size, sow parity, colostrum production by the sow, body temperature of the piglet at birth, and birth order. Due to these factors and how they influence the individual piglet, many piglets are pre-disposed to a high risk of pre-weaning mortality at birth. A knowledge of which factors have the greatest impact on the individual piglet can give the producers the capability of identifying those piglets with an increased risk of pre-weaning mortality sooner, allowing remedial action to be taken, thus, reducing pre-weaning mortality in their litters.

The objectives of the research described in this thesis were to evaluate the effects of birth order on pre-weaning mortality and to identify characteristics that could potentially impact piglet survival to weaning.

MATERIALS AND METHODS

The protocol for this research was approved by the University of Illinois Institutional Animal Care and Use Committee prior to the start of the study.

Experimental Procedures

The objective of this study was to evaluate the effects of birth order and other influencing factors on pre-weaning mortality in piglets. This study was conducted between May and June, 2011 as a split-plot design with 4 treatments to collect all birth information on litters from sows under typical commercial conditions. Two locations were used, both being breed-to-wean facilities owned by The Maschhoffs, located in Carlyle, IL, and Louisville, IL. The treatments were: 1) First 25% born within a litter, 2) Second 25% born within litter, 3) Third 25% born within a litter, and 4) Final 25% born within a litter. The main plot was the sow, with all treatments represented on each sow. Sow parity, teat count, and body condition score were recorded prior to farrowing. All piglets born within a litter were recorded, including stillborns and mummified piglets, in the assessment of birth order. Stillborn and mummified piglets were identified according to standard commercial procedures, with a stillborn piglet defined as one that was fully formed that had the periople (the cartilaginous covering on the top of the hooves) still present (Holyoake et al., 1995) and a mummified piglet defined as one that was not fully-developed and at least partially decomposed.

At birth, piglets were given a unique identification (ear tag), and weighed. Piglet birth measurements were collected within ten minutes of birth of piglet. Birth times of all piglets were also recorded. Rectal temperature was recorded using a ReliOn digital thermometer and body temperature was scanned in the axilla area of the piglets using a Love IR100 infrared thermometer at birth and 3 hours post-natal. On all live-born piglets, 1 ml of blood was collected via jugular venipuncture at one-day of age. Blood samples were sent to the U.S. Meat Animal Research Center in Clay Center, NE, to measure immunoglobulin-G levels, as measured in % blood serum (Vallet, personal communication, May 1, 2011). A total of 191 sows were used, with 2,393 total born piglets. 2,286 piglets born-alive, 67 stillborn, and 40 mummified were included in the study.

At the Carlyle, IL, location, sows were not induced with oxytocin and piglets were not cross-fostered and were kept with their natural birth sow until weaning due to disease status of the facility. At the Louisville, IL, location, sows were induced on day 115 of gestation with oxytocin and piglets were cross-fostered onto sows according to specific farm procedures. These procedures were conducted within 6 hours of birth. Piglets were moved across litters born on the same day to create litters of similar size piglets. Piglets were weighed prior to standard commercial processing and prior to weaning, between days 16 and 21 of age. Piglet processing consisted of docking of tails, castration of entire males, and injection of all piglets with 1 ml iron dextran and 0.5 ml of Excede (Pfizer Pharmaceuticals, Madison, New Jersey).

Housing

The studies were carried out in two locations. The first breed-to-wean facility was located in Carlyle, IL, and was mechanically ventilated. A total of 6 rooms were used in the 16 farrowing-room building and 52 individual farrowing crates were located in each room. The second breed-to-wean facility was located in Louisville, IL, and was also mechanically ventilated. There were 15 rooms within the building, of which 5 rooms were used in the study, and 56 individual crates were located in each farrowing room. Each room within the two locations was equipped with propane heaters and air temperature was maintained using thermostatically controlled space heaters and fan ventilation. Temperature in the room was maintained at 22°C during farrowing. A heat lamp was placed in each crate to provide supplementary heat to the piglets during all the entire lactation period.

Morbidity and Mortality

All the piglets that died were recorded, and the reason of death was determined following examination; the weight of the piglet, site, room, crate, date, and sow identification were also recorded. All dead piglets were also subjected to necropsy procedures to validate the cause of mortality. For piglets dying within the first 72 hours following birth, stomach and intestinal contents were also examined and scored based on presence or absence of milk content. Standard necropsy procedures were performed, using the procedures outlined in *A Guide for Swine Necropsy* (2008). The necropsies were carried out once piglets were collected each day. All sows and piglets were checked by the research crew twice a day, with all piglets dying being collected and recorded twice each day.

Statistical Analysis

All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). A descriptive statistical analysis was performed using the PROC MEANS procedure of SAS (SAS Inst. Inc., Cary, NC).

Descriptive statistical analysis was performed using the PROC MEANS and PROC FREQ procedures of SAS (SAS Inst. Inc., Cary, NC). Piglet birth characteristics and growth performance, as well as sow characteristics, were analyzed using the PROC MIXED procedure. Least squares means were compared using the PDIFF option of SAS. Data were analyzed with 4 treatments (birth order classification). The model included the fixed effects of the sow and birth order classification. Individual pig was the experimental unit. Pre-weaning mortality data were analyzed using the PROC MEANS procedures of SAS (SAS Inst. Inc., Cary, NC) and Chi-square rank-based test (Steel and Torrie, 1980) using the PROC RANKS procedure of SAS.

RESULTS AND DISCUSSION

Descriptive statistics including means, standard deviation, and minimum and maximum values for piglet and sow measurements are presented in Table 1. The 191 sows involved in this study produced a total of 2,409 piglets, with an average of 12.5 total born per litter, 12.0 piglets born alive per litter, 0.3 stillborn piglets per litter, and 0.2 mummified piglets per litter. Pre-weaning mortality was 13.0%, and on average, piglets that died weighed 1.24 kg. Piglets alive at time of processing weighed 1.93 kg and were 3.89 days of age on average. Piglets alive at weaning weighed 5.79 kg and were 19.02 days old on average.

Measurements for stillborn piglets are presented in Table 2. 2.9% of all piglets born in the study were born stillborn. On average, piglets born alive weighed 1.40 kg and stillborn piglets weighed 1.27 kg ($P < 0.001$). There was no difference ($P > 0.05$) between piglets born alive or stillborn for the size of the litter in which they were born, although stillborn piglets were numerically from larger litters. Stillborn piglets were born later in the birth order compared to piglets born alive ($P < 0.001$), in agreement with previous reports (Randall et al., 1972b; Curtis, 1974; Baxter et al., 2008).

Least squares means for the effect of sow parity on sow performance measurements are represented in Table 3. There was no difference ($P > 0.05$) in sow performance measurements among the parities represented in the study population. Numerically, the largest number of piglets born alive were with sows in parity 5 (13.15 live-born piglets) and the lowest number of live-born piglets were found in sows with parities 10 – 12. The greatest rate of stillborn piglets was found in parity 10 - 12 sows (0.83 stillborn piglets per litter).

The parity of the sows also impacted immunoglobulin-G levels in piglets, with the highest level of immunoglobulin-G in piglets from mid-parity sows (parities 4, 5, 6, and 7) and the lowest levels of immunoglobulin-G in parity 1 sows and sows with parity higher than 10 ($P < 0.001$), as shown in Table 3.

Causes of Pre-weaning Mortality. The causes of pre-weaning mortality are presented in Table 6. Crushing by the sow was the main cause of pre-weaning mortality and represented 54.6% of total deaths. Other important causes were starved piglets and low viability/runt piglets. The remainder of causes for pre-weaning mortality each accounted for less than 2.0% of the total pre-weaning mortality.

Timing of Pre-weaning Mortality. The timing of mortality (days of age) are presented in Table 6. The highest incidence of pre-weaning mortality occurred in the first few days following birth of the piglet, with 44.3% of total deaths occurring in the first 3 days of age, similar to levels found by Quiniou et al. (2002). Subsequently, there was a steady decrease throughout the first week of life, and for the remainder of the pre-weaning period.

Birth Order Effect on Piglet Measurements

Least squares means for the effect of birth order are presented in Table 7. Piglets born later in the birth order were heavier ($P = 0.001$) on average than piglets born earlier in the birth order (1.51 vs. 1.43, 1.44, and 1.43 kg for treatments 4, 1, 2, and 3, respectively). This weight difference between treatments remained at the time of processing and weaning ($P < 0.001$ and $P = 0.02$, respectively).

Body Temperature. Piglets born later in the birth order had higher ($P < 0.001$) rectal temperatures at birth compared to their littermates born earlier in the birth order [36.83°C (treatment 4) vs. 36.50°C (treatment 1), 36.60°C (treatment 2), and 36.55°C (treatment 3), respectively]. Body surface temperature at birth for piglets born later in the birth order had higher temperatures compared to their littermates ($P < 0.01$). Rectal and body surface temperatures taken at 3 hours post-natal showed no difference in temperature between the four treatments of piglets.

Immunoglobulin Levels. Piglets born in the first 25% of the birth order had the highest levels of immunoglobulin-G with 13.87% blood serum. Piglets in the second 25% born had immunoglobulin-G levels of 13.53% blood serum, and piglets in the third 25% born had immunoglobulin-G levels of 13.38% blood serum. Piglets in the final 25% born had the lowest levels of immunoglobulin-G, with 12.65% blood serum ($P < 0.001$), showing that as birth order increases, the level of immunoglobulin-G decreases, which is similar to results reported by Bland et al. (2003) and Lay et al. (2002).

Pre-weaning Mortality. The effects of birth order treatment on the causes and timing of pre-weaning mortality are presented in Table 9. The highest percentage of pre-weaning mortality occurred in piglets born in the first 25% of the birth order, with similar measurements for piglets born later in the birth order [3.49% of piglets (treatment 1) vs. 2.62% (treatment 2), 2.70% (treatment 3), and 2.57% (treatment 4) of piglets, respectively].

Least squares means for the effect of birth order treatment on measurements of piglets that died prior to weaning are presented in Table 10. There were no differences ($P > 0.05$) found for birth measurements across treatments for piglets dying prior to weaning. Measurements of birth weight, rectal temperature and body surface temperatures, for birth and 3 hours post-natal, were similar ($P > 0.05$) across all treatments. Numerically, piglets in second 25% born were lighter than other piglets at time of mortality (1.13 kg vs. 1.18, 1.25, and 1.43 kg, respectively).

Least squares means for measurements taken on piglets surviving to weaning compared to piglets dying pre-weaning are represented in Table 11. Piglets surviving to weaning had heavier ($P < 0.001$) birth weights compared to piglets dying pre-weaning, with a weight of 1.43 kg compared to 1.16 kg. Piglets surviving to weaning also had increased ($P < 0.001$) birth and 3 hours post-natal temperatures compared to piglets dying prior to weaning, with rectal temperatures of 36.58 and 38.23°C compared to 35.72 and 37.75°C, respectively, in agreement with Baxter et al., 2008. Body surface temperature measurements also showed that piglets surviving to weaning had higher ($P < 0.001$) body surface temperatures at birth and 3 hours post-natal compared to piglets dying, with temperatures of 33.72 and 36.55°C compared to 32.75 and 36.10°C, respectively. Piglets dying pre-weaning also were from larger litters, with an average of 15.29 piglets per litter compared to 13.60 for piglets surviving to weaning ($P < 0.001$).

Piglets dying prior to weaning also showed lower ($P < 0.001$) levels of immunoglobulin-G in their blood (11.58% blood serum) compared to 13.15% blood serum for piglets surviving to weaning (Table 9). This possibly suggests that birth order plays a role in colostrum consumption, in disagreement with reports found by Le Dividich, et al. (2005), who reported colostrum consumption was independent of birth order.

CONCLUSIONS

- Piglets born later in the birth order had increased birth weights, but similar weaning weights compared to their littermates, with similar results for body temperature, as piglets born later in the birth order had increased rectal and body surface temperatures at birth compared to their littermates, but similar temperatures at 3 hours post-natal.
- The main cause of pre-weaning mortality was crushing by the sow, accounting for 54.6% of total pre-weaning deaths. Other important causes of pre-weaning mortality were piglets dying due to starvation.
- Piglets dying prior to weaning had lower birth weights and body temperatures at birth compared to piglets surviving to weaning.
- Piglets born in the first 25% of the birth order had the highest levels of immunoglobulin-G, with piglets born in the final 25% of the birth order having the lowest levels.

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TABLES

Table 1. Descriptive statistics for measured variables.

Item	Number	Mean	Standard deviation	Minimum	Maximum
Piglet Measurements					
Body weight, kg					
Birth	2353	1.39	0.357	0.41	2.70
Process	2065	1.93	0.502	0.54	3.47
Weaning	1957	5.79	1.359	1.69	9.68
Temperature, °C					
Rectal temperature					
Birth	2230	36.48	1.463	31.61	39.83
3 hours post-natal	1876	38.17	0.810	31.61	40.28
Body surface temperature, °C					
Birth	1649	33.60	1.655	24.83	37.67
3 hours post-natal	1189	36.50	1.038	30.50	38.83
Age					
Process	2171	3.89	0.526	3.00	5.00
Weaning	1979	19.02	1.285	16.00	21.00
Sow Measurements					
Total farrowing duration, h	189	3.11	1.489	0.33	8.75
Parity	188	3.96	2.310	1.00	12.00
Number of piglets/litter					
Total born	191	12.5	3.97	3.0	25.0
Born alive	191	11.9	3.76	2.0	20.0
Stillborn[a]	191	0.3	0.65	0.0	3.0
Mummies	191	0.2	0.53	0.0	3.0
Litter size weaned[b]	96	10.4	2.89	2.0	15.0

[a] Piglets born of mature size that were not breathing, according to production protocol measurement.

[b] Smaller reported value due to cross-fostering protocol of one research facility.

Table 2. Least square means comparing piglets born alive and stillborn piglets.

Item	Born Alive	Stillborn[c]	SEM	*P*-value
Number	2293	70	-	-
Piglet traits				
Birth weight	1.40[a]	1.27[b]	0.025	0.01
Farrowing traits				
Litter size	13.7	14.3	0.25	0.23
Birth order	7.2[a]	10.7[b]	0.31	<0.001

[a,b] Means within a row with different superscripts are different ($P < 0.05$).

[c] Piglets born of mature size that were not breathing, according to production protocol measurement.

Table 3. Least square means for the effect of parity on piglet measurements.

	Parity										
Item	1	2	3	4	5	6	7-9	10-12	Unknown	SEM	*P*-value
Number	19	40	36	25	27	17	17	6	3	-	-
Total farrowing duration, h	2.87	2.74	2.83	3.64	3.62	3.04	3.24	3.37	3.08	0.372	0.19
Number of piglets/litter											
Total born	11.95	12.40	12.00	12.64	14.07	13.17	12.47	8.33	14.33	1.049	0.11
Born alive	11.32	11.85	11.61	12.28	13.15	12.67	11.94	7.50	13.67	0.993	0.09
Stillborn[e]	0.21	0.35	0.28	0.20	0.63	0.22	0.41	0.83	.	0.162	0.13
Mummies	0.42	0.20	0.11	0.16	0.30	0.22	0.06	0.00	0.67	0.132	0.28
Litter size weaned[fg]	9.86	10.11	9.71	11.07	11.33	11.86	9.29	-	11.00	0.835	0.44
IgG levels, % blood serum	11.91[d]	12.75[bc]	12.64[c]	13.46[a]	13.92[a]	13.67[a]	13.31[ab]	11.34[d]	12.66[bc]	0.290	<0.001

[a,b,c,d] Means within a row with different superscripts are different ($P < 0.05$).

[e] Piglets born of mature size that were not breathing, according to production protocol measurement.

[f] Smaller reported value due to cross-fostering protocol of one research site.

[g] No data for litter size weaned for parity 10-12 sows due to cross-fostering procedures of location; data was not able to be kept accurately.

Table 4. Least square means for the effect of gestation length and parity on piglet measurements.

	Gestation length, days[c]						Parity					
Item	114	115	116	117	SEM	*P*-value	1-3	4-6	7-9	10-12	SEM	*P*-value
Number												
Piglet measurements												
Body weight, kg												
Birth	1.56	1.49	1.51	1.33	0.065	0.25	1.38	1.48	1.42	1.62	0.095	0.05
Process	2.13	1.97	2.08	1.84	0.115	0.18	1.93	2.05	1.93	2.11	0.115	0.29
Weaning	6.61^{a}	5.87^{b}	6.20^{ab}	5.45^{b}	0.273	0.008	5.91	6.20	5.97	6.05	0.162	0.33
Body temperature												
Rectal temperature, °C												
Birth	36.53	36.36	36.31	35.95	0.290	0.60	36.40	36.42	36.34	35.98	0.292	0.80
3 hours post-natal	37.98	37.93	37.95	37.79	0.177	0.87	37.92	37.81	38.00	37.92	0.184	0.62
Body surface temperature, °C												
Birth	33.56	33.60	32.83	33.82	0.587	0.39	33.68	33.65	33.36	33.12	0.490	0.67
3 hours post-natal	36.13	36.19	35.83	.	0.214	0.24	36.04	36.07	36.32	35.76	0.234	0.46
IgG levels, % blood serum	14.35^{a}	12.75^{b}	13.87^{a}	14.68^{a}	0.713	0.009	13.55	14.62	14.53	12.96	0.710	0.05

[a,b] Means within a row with different superscripts are different ($P < 0.05$).

[c] No data available for body surface temperatures of piglets taken 3 hours post-natal of sows of 117 days gestation length.

Table 5. Least square means for the effects of induction status and farrowing duration on piglet measurements.

	Induction Status				Farrowing Duration, hr					
Item	Induced	Not induced	SEM	*P*-value	>1	1-3	3-5	5-8	SEM	*P*-value
Number										
Piglet measurements										
Body weight, kg										
Birth	1.42	1.44	0.029	0.57	1.66	1.45	1.41	1.38	0.078	0.09
Process	1.94	2.05	0.041	0.07	2.28^{a}	1.99^{b}	1.91^{b}	1.84^{b}	0.112	0.04
Weaning	5.77^{b}	6.16^{a}	0.099	0.007	6.76^{a}	5.94^{b}	5.83^{b}	5.58^{b}	0.266	0.03
Body temperature										
Rectal temperature, °C										
Birth	36.4^{b}	36.87^{a}	0.097	0.001	36.28	36.13	36.35	36.39	0.281	0.57
3 hours post-natal	38.11	38.22	0.055	0.18	37.67	37.97	38.05	37.97	0.175	0.43
Body surface temperature, °C										
Birth	33.70	33.50	0.135	0.30	33.02	33.34	33.63	33.82	0.484	0.36
3 hours post-natal	36.29^{b}	36.80^{a}	0.078	<0.001	36.08	36.00	35.99	36.13	0.208	0.91
IgG levels, % blood serum	12.97	13.26	0.254	0.44	14.41	13.85	13.57	13.82	0.689	0.80

^{a,b} Means within a row with different superscripts are different ($P < 0.05$).

Table 6. Causes and timing of mortality.

Item	Timing of mortality (days of age)										
Causes (number of piglets)	1	2	3	4	5	6	7	8-14[a]	15-21[b]	Unknown[c]	Total
Laid On	22	40	16	12	12	9	6	20	5	1	143
Euthanized	1	7	2	0	3	0	1	4	2	0	20
Starvation	1	2	8	10	5	1	5	21	8	0	61
Runt	0	4	3	1	1	0	0	0	0	0	9
Congenital Defect	0	0	0	1	0	1	0	0	0	0	2
Rupture	1	0	0	0	0	0	1	0	0	0	2
Joint Infections	0	0	0	1	0	0	0	2	1	0	4
Meningitis	0	0	0	0	0	0	0	0	0	0	0
Scours	0	0	0	0	0	0	0	0	0	0	0
Savaged	0	3	0	0	0	0	0	0	0	0	3
Other Diseases	0	3	0	0	0	0	0	2	0	0	5
Other	0	3	0	0	1	1	0	4	1	1	11
Unknown	0	0	0	0	0	0	0	2	0	0	2
Total	25	62	29	25	22	12	13	55	17	2	262
Causes (% of total piglets)											
Laid On	8.4	15.3	6.1	4.6	4.6	3.4	2.3	7.6	1.9	0.4	54.6
Euthanized	0.4	2.7	0.8	0.0	1.1	0.0	0.4	1.5	0.8	0.0	7.6
Starvation	0.4	0.8	3.1	3.8	1.9	0.4	1.9	8.0	3.1	0.0	23.3
Runt	0.0	1.5	1.1	0.4	0.4	0.0	0.0	0.0	0.0	0.0	3.4
Congenital Defect	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.8
Rupture	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.8
Joint Infections	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.8	0.4	0.0	1.5
Meningitis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scours	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Savaged	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Other Diseases	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.9
Other	0.0	1.1	0.0	0.0	0.4	0.4	0.0	1.5	0.4	0.4	4.2
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.8
Total	9.5	23.7	11.1	9.5	8.4	4.6	5.0	21.0	6.5	0.8	100.0

[a] Piglets that died between 8 and 14 days of age.

[b] Piglets that died between 15 and 21 days of age.

[c] Piglets that died and age was unknown.

Table 7. Least square means for the effects of gender and birth order treatment on piglet measurements.

	Gender				Treatment					
Item	Barrow	Gilt	SEM	*P*-value	1	2	3	4	SEM	*P*-value
Number										
Piglet measurements										
Body weight, kg										
Birth	1.47^{a}	1.44^{b}	0.029	0.005	1.43^{b}	1.44^{b}	1.43^{b}	1.51^{a}	0.030	<0.001
Process	2.04^{a}	1.99^{b}	0.043	0.005	1.98^{b}	2.00^{b}	1.99^{b}	2.10^{a}	0.043	<0.001
Weaning	6.10^{a}	5.98^{b}	0.107	0.03	5.94^{b}	6.04^{ab}	6.01^{b}	6.17^{a}	0.113	0.02
Body temperature										
Rectal temperature, °C										
Birth	36.60	36.65	0.122	0.37	36.50^{b}	36.60^{b}	36.55^{b}	36.83^{a}	0.127	<0.001
3 hours post-natal	38.06^{b}	38.14^{a}	0.067	0.02	38.09	38.10	38.13	38.09	0.070	0.82
Body surface temperature, °C										
Birth	33.86	33.81	0.166	0.51	33.72^{b}	33.75^{b}	33.86^{b}	34.01^{a}	0.172	0.008
3 hours post-natal	36.45	36.38	0.105	0.19	36.38	36.39	36.44	36.47	0.111	0.58
IgG levels, % blood serum	13.33	13.39	0.328	0.62	13.87^{a}	13.53^{ab}	13.38^{b}	12.65^{c}	0.340	<0.001

[a,b,c] Means within a row with different superscripts are different ($P < 0.05$).

Table 8. Least square means for the effects of site and litter size on piglet measurements.

	Site				Litter Size							
Item	Facility 1	Facility 2	SEM	*P*-value	1-4	5-10	11-13	14-16	17-19	20	SEM	*P*-value
Number												
Piglet measurements												
Body weight, kg												
Birth	1.45	1.46	0.032	0.89	1.91^{a}	1.62^{b}	1.41^{c}	1.33^{d}	1.29^{d}	1.17^{d}	0.070	<0.001
Process	2.11^{a}	1.92^{b}	0.046	<0.001	2.67^{a}	2.25^{b}	1.96^{c}	1.81^{d}	1.78^{d}	1.63^{d}	0.169	<0.001
Weaning	6.23^{a}	5.85^{b}	0.118	<0.001	8.00^{a}	6.54^{b}	5.89^{c}	5.54^{d}	5.31^{d}	4.95^{d}	0.254	<0.001
Body temperature												
Rectal temperature, °C												
Birth	36.71	36.54	0.134	0.18	37.32	36.75	36.53	36.38	36.42	36.31	0.551	0.18
3 hours post-natal	38.21^{a}	38.00^{b}	0.074	0.01	38.12	38.11	38.13	38.26	38.05	37.95	0.159	0.42
Body surface temperature, °C												
Birth	33.63^{b}	34.04^{a}	0.187	0.03	35.56^{a}	33.75^{b}	33.73^{b}	33.42^{b}	33.43^{b}	33.01^{b}	0.402	0.04
3 hours post-natal	36.53	36.31	0.118	0.06	36.60	36.30	36.45	36.67	36.50	35.98	0.023	0.23
IgG levels, % blood serum	13.88^{a}	12.84^{b}	0.362	0.001	15.06^{a}	13.86^{a}	12.99^{ab}	12.81^{ab}	12.41^{ab}	13.02^{a}	0.775	0.04

^{a,b,c,d} Means within a row with different superscripts are different ($P < 0.05$).

Table 9. Effects of birth order treatment on the incidence, causes, and timing of morbidity and mortality of pigs.

	Treatment			
Item	First 25% born	Second 25% born	Third 25% born	Last 25% born
Total mortality				
Number of pigs	80	60	62	59
Percentage of pigs, %	3.49	2.62	2.70	2.57
Causes of mortality				
Laid On	42	33	38	30
Euthanized	8	2	6	4
Starvation	22	16	11	12
Runt	2	3	1	3
Congenital Defect	0	0	2	0
Rupture	1	1	0	0
Joint Infections	2	0	0	2
Meningitis	0	0	0	0
Scours	0	0	0	0
Savaged	0	0	1	2
Other Diseases	1	2	1	1
Other	2	3	1	4
Unknown	0	0	1	1
Timing of mortality				
Day 1	7	5	9	4
Day 2	17	17	16	12
Day 3	10	6	3	10
Day 4	9	6	5	5
Day 5	7	6	6	3
Day 6	4	3	2	3
Day 7	3	5	4	1
Day 8-14	18	12	12	13
Day 15-21	5	0	5	8

Table 10. Least square means for the effect of birth order treatment on piglet birth measurements of piglets dying prior to weaning.

	Treatment					
Item	First 25% born	Second 25% born	Third 25% born	Last 25% born	SEM	*P*-value
Number	80	60	62	59	-	-
Piglet mortality measurements						
Age	3.42	2.57	3.45	4.49	0.914	0.15
Weight	1.18	1.13	1.25	1.43	0.093	0.12
Piglet traits						
Birth weight	1.25	1.23	1.26	1.33	0.072	0.47
Body temperature, °C						
Rectal Temperature						
Birth	35.67	35.75	35.53	35.97	0.230	0.62
3 hours post-natal	37.66	37.90	37.89	37.57	0.178	0.47
Body surface Temperature, °C						
Birth	33.60	33.54	33.30	33.80	0.457	0.73
3 hours post-natal	36.06	36.20	36.31	35.98	0.287	0.84
IgG levels, % blood serum	12.89	12.12	11.72	9.96	0.813	0.06
Farrowing traits						
Litter size	13.61	13.08	13.17	13.39	0.771	0.83

[a,b] Means within a row with different superscripts are different ($P < 0.05$).

Table 11. Least square means comparing piglets surviving to weaning and piglets dying pre-weaning.

Item	Surviving	Dying[c]	SEM	*P*-value
Number	2021	255	-	-
Piglet traits				
Birth weight	1.43[a]	1.16[b]	0.015	<0.001
Body temperature, °C				
Rectal Temperature				
Birth	36.58[a]	35.72[b]	0.062	<0.001
3 hours post-natal	38.23[a]	37.75[b]	0.036	<0.001
Body surface Temperature, °C				
Birth	33.72[a]	32.75[b]	0.082	<0.001
3 hours post-natal	36.55[a]	36.10[b]	0.064	<0.001
IgG levels, % blood serum	13.15[a]	11.58[b]	0.190	<0.001
Farrowing traits				
Litter size	13.60[a]	15.29[b]	0.153	<0.001
Birth order	7.28	7.22	0.187	0.85

[a,b] Means within a row with different superscripts are different ($P < 0.05$).

[c] Piglets dying prior to weaning that were born alive.