RISK FACTORS FOR SOW MORTALITY IN CANADIAN SWINE HERDS

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Abstract

With increasing sow mortality and involuntary culling rates on commercial farms over the past two decades, more producers, researchers, and experts in swine health are looking into the causes and risks of sow mortality. In addition to increasing agricultural expenses and biosecurity risk for animals already in the herd, sow deaths also indicate compromised animal welfare. Understanding what is causing the high rates of sow mortality and culling in Canadian herds will provide a scientific basis for management recommendations to increase sow longevity, will benefit producers by reducing costs, and will help to support good animal welfare. The overall goal of this project was to identify the risk factors and causes of sow mortality in Canadian sow herds. Specific objectives included reviewing previous literature on sow mortality, examining causal factors related to housing, management, and genetics, and evaluating culling and removal reasons on Canadian commercial swine herds, with the aim to evaluate the risk factors of sow mortality. A simplified sow necropsy procedure was also developed to use on-farm for assessment of major causes of death. Chapter 2 of this study collected information regarding sow culling and mortality in Canadian swineherds from producers through an online survey. One hundred and four producers provided complete responses to 49 questions about sow management, culling and mortality factors. Data were analyzed in SAS 9.4 using Pearson's correlation coefficients (r, PROC CORR) and regression analysis (PROC REG and PROC GLM). The survey results found that in 2019, the average sow replacement per year was 44% (range: 5% to 65%, SD= 9.88%), average sow mortality per year was 5.7% (range: 2% to 20%, SD= 3.9%), and average parity of the herd was 3.5 (range: 1.6 to 9, SD= 1.22). The two most common reasons for sow removal (i.e., sum of culling, euthanasia, and death) were 'old age' (72%) and 'poor reproductive performance' (61%). Average sow mortality (%) per year showed a significant positive correlation with herd size (P= 0.001) and number of barn staff (P <0.001), with the number of barn staff accounting for 17% of the variation in average sow mortality per year (P <0.001). It was found that 65% of the survey participants did not perform necropsies on dead sows. Survey participants from Quebec (QC) and Saskatchewan (SK) were then invited to participate in the next experiment (Chapter 3), which consisted of a farm visit with live sow observations and a necropsy demonstration (in SK). For chapter 3, thirteen farms were visited, with a total of 1,389 live sows observed (8 farms in QC: 945 sows, and five farms in SK: 444 sows). Live sows were evaluated based on animal-based measures (body condition score [BCS], lameness, and injury scores), and each farm's annual sow mortality and parity were also recorded. The study results show that BCS 3 (ideal condition, where ribs, hips, and backbone can be palpated with firm pressure but cannot be observed visually) was the most prevalent in both provinces (47.9% in QC and 61.5% in SK). Of the 1,389 sows observed, 1,205 (88.8%) had no signs of lameness and 1,003 had no signs of injury (72.2%). Data from chapter 3 were analyzed in SAS 9.4 using a weighted Pearson's chi-square statistic to determine relationships among variables. Sows in farrowing had the highest proportion of thin sows (BCS2) (20.9%) while sows in breeding had the highest prevalence of lameness score 1 (13.9%), and sows in stall gestation had the highest incidence of injury score 1 (30.8%) versus other stages. Saskatchewan in comparison to QC had a higher percentage of thin sows (24.8% vs 18.2%) and sows with injury score 1 (40.3% vs 14.7%). Conversely, Quebec had a higher proportion of lameness score 1 than SK (12.8% vs 3.8%), with sows showing signs of locomotor difficulties in at least one leg and reluctance to bear weight on the same leg. Herd size affected average sow mortality and parity. Larger herds (>1,000 sows) had a higher incidence of 'high' sow mortality rates (Avg. mort. >6%) than mid-size herds (40% vs 32.3%; P <0.03). Smaller herds (<500) had a higher proportion of old sows (parity >5) than larger herds (>1,000 sows) (27.6% vs 7% respectively; P <0.001). In addition to the sow observation in SK, a necropsy of four dead sows on different farms was performed to demonstrate the protocol developed for the study. In conclusion, the average mortality rate of the Canadian herds included in the survey was 5.7%, having a moderate average sow mortality rate according to the study. Herds with moderate (avg. mortality >4 – ≤6) and 'high' (avg. mortality >6) average sow mortality were represented by large herds (>1,000) which also showed the highest percentage of young sows (parity 0 – 2), conversely, smaller herds showed acceptable average sow mortality (avg. mortality ≤4) and higher average parity (>5).

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

ABM	animal-based measures
BCS	body condition score
FI	feed intake
LHL	left hind limb
LFL	left fore-limb
LS	least square
NPD	non-productive day
PCB	penetrating captive bolt
PM	*post-mortem*
PSC	Prairie Swine Centre
PWSY	piglets weaned per sow per year
QC	Quebec
RHL	right hind limb
SAS	Statistical Analysis Software
SD	standard deviation
SEM	standard error of the mean
SK	Saskatchewan
TPB	total pigs born per litter

1.0 Chapter 1. Literature Review

1.1. Introduction

Sow mortality has always been a concern in swine herds (Bradley et al., 2018), and the subject is gaining importance because mortality numbers have increased in recent years (Keith, 2000; Ketchem et al., 2020a). The term 'mortality' represents sows found dead or euthanized on-farm (Balogh et al., 2015). Mortality rates in studies conducted in the 1990s ranged between 3 and 9% (Chagnon et al., 1991; Christensen et al., 1995; Abiven et al. 1998) and established a 5% threshold to separate herds with high mortality from those with low mortality (Abiven et al., 1998). However, more than 15 years later, studies are reporting annual mortality rates greater than 5%, such as 13.91% in the U.S. (PigCHAMP, 2020a), 12.7% in Denmark (Knage-Rasmussen et al., 2015), 10.14% in Canada (PigCHAMP, 2020b), and 7.1% in Spain (Iida et al., 2019).

The reasons for this increase in sow mortality are being researched, and there are suggestions that mortality may be linked to multiple factors, including inadequate nutrition, housing, management, genetic, environmental factors, herd size, and susceptibility to pathogens (Rodriguez-Zas et al., 2003; Díaz et al., 2017; Sørensen and Thomsen, 2017; Kikuti et al., 2020a). Overall removal rates in North America herds stand at approximately 50% per year (Mote et al., ,2009; Nikkilä et al., 2013; Ketchem et al., 2020b), and include three types of removals: culling, natural death, or euthanasia (Stalder et al., 2012). Culling involves the shipment of animals to slaughter due to health, performance problems or management decision and accounts for the greatest number of sows removed, with annual culling rates of roughly 40% (Díaz et al., 2015; Ketchem et al., 2020c). However, sow culling numbers can vary between studies. For example, a recent study conducted in Finland (Bergman et al., 2019) reported an annual culling rate of 38%, while a different study in Spain reported a culling rate of 59.7% (Iida et al., 2019). In the same year in North America, the culling rates reported for Canada and U.S. were 38.08% and 45.69%, respectively (PigCHAMP, 2019a, 2019b).

The risk of the breeding female being removed from the herd changes throughout its life (Anil et al., 2008). From an economic standpoint, the longer a sow stays in the herd, the greater the opportunity to increase her lifetime net income (Houška, 2009; Sasaki et al., 2012). It is estimated that sows must remain in the herd for 3 or 4 parities to pay for their development costs (Stalder et al., 2004; Díaz et al., 2015), becoming more productive in later parities. The litter size and piglet weights will increase up to the 4th – 5th parities, and the number of pigs weaned/sow/year (PWSY) increases until the 6th and 7th parities (Kraeling and Webel, 2015), after which productivity declines. However, recent figures indicate that 40 to 50% of sows are removed before their 3rd or 4th parity (Lucia et al., 2000; Rodriguez-Zas et al., 2003; Stalder et al., 2003; Hoge and Bates, 2011). Thus, higher removal rates lead to reduced income from slaughter (Engblom et al., 2008a), increased frequency of adding new gilts (Pluym et al., 2013a), which increases farm expenses and the biosecurity risks to animals already in the herd (Stalder et al., 2004; Anil et al., 2008).

Increasing mortality levels, especially in younger animals, can also indicate compromised animal welfare (Hoge and Bates, 2011; Ala-Kurikka et al., 2019; Bergman et al. 2019). In 1965 the Brambell Commission in the United Kingdom defined what is considered to be the first definition of animal welfare, recommending physical and mental health conditions believed to be necessary to promote good welfare in farm animals (Johnson et al., 2012). In 1986, Broom described the welfare of an individual as “its state as regards its attempts to cope with its environment” (p. 254), with poor longevity resulting from the animal's failure to adapt, therefore, raising welfare concerns. Lameness, for instance, is a problem for sow longevity since it is one of the main reasons for removal, impacting animal health and welfare (Iida et al., 2020). Causing pain and affecting mobility, lameness also harms feed intake (FI) and fertility (Seddon and Brown, 2012; Iida et al., 2020; van Riet et al., 2020), imposing an economic challenge to pig producers (Supakorn et al., 2018).

In the past two decades, there has been an increase in sow mortality and longevity studies (Tarrés et al., 2006; Sørensen and Thomsen, 2017). However, limited research on risk factors for sow mortality has been done in Canadian herds, with the most recent studies published in the 1990s (Chagnon et al., 1991; D’Allaire et al., 1991, 1996). The aim of this review is first to describe the main routes by which a sow exits the herd (culling, euthanasia, and sudden death) and their causes and impact on production. This is followed by a review of the risk factors and causes of sow mortality found in previous studies and a discussion of methods to improve data collection to understand better factors affecting sow longevity. This includes methods for accurately recording sow removals and more frequent use of necropsy procedures for diagnosis so that the risk factors and reasons for increasing sow deaths and removals can be better understood and addressed.

1.2. Sow longevity

Hurnik (1993) introduced the concept of longevity as a positive measure that is inversely related to mortality and considered a reliable measure of animal fitness in a human-controlled environment. The author suggested that if a sow has a long productive life, it indicates that she is well cared for and has adapted to the demands of the production system and that her needs for survival, health and comfort are satisfied (Hurnik, 1993). Thus, longevity has been proposed as an indirect indicator of the quality of life (Hurnik, 1993).

The definition of sow longevity in the scientific literature is not clear; it varies according to the objective of the study (Hoge and Bates, 2011; Díaz et al., 2015; Engblom et al., 2016) and can be affected by different factors such as biology, season, management, housing, and the herdsman's decision whether a sow should be removed or not (Engblom et al., 2008b). For example, Rodriguez-Zas et al. (2003) describe sow longevity as an example of time-to-event measure (survival analysis), considering the number of days that a sow remains in the herd until the event (culling, sudden death, or euthanasia). In contrast, Balogh et al. (2015) define longevity as a time-dependent measure (productive lifetime). An improved productive lifetime will significantly affect swine farm profitability by decreasing replacement costs, making it possible to have more mature sows in the herd, thus increasing herd performance (Balogh et al., 2015).

Replacement costs include initial purchase and breeding costs for gilts, housing and feed costs during quarantine and acclimation (Supakorn et al., 2019a). High removal rates require larger numbers of replacement gilts, resulting in a larger proportion of gilt progeny with inferior performance and survivability, and increased disease risks (Bergman et al., 2018; Supakorn et al., 2019a). In a recent industry article, Ketchem et al. (2020a) showed that the highest sow death loss rates (40-50% of all deaths) in North American herds occur in parities 0 and 1. In addition, the frequency of early removals of breeding females from swine herds has been increasing in recent years (Karriker et al., 2013), indicating that first parity sows have difficulty adapting to the production system (Engblom et al., 2008b), and potentially raising questions about selection of replacement sows and gilt development practices.

1.3. Sow removal

A sow can be removed from the swine herd through culling (voluntary and involuntary), euthanasia or sudden death (Stalder et al., 2012; Sørensen and Thomsen, 2017). Culling involves the shipment of sows unsuitable for further production (Stalder et al., 2012) and accounts for the greatest number of sows removed, with annual culling rates of roughly 40% (Ketchem et al., 2020c). In North America, the culling rates reported for Canada and U.S. were 38.08% and 45.69%, respectively (PigCHAMP, 2019a, 2019b). Natural death refers to sows that are found dead, which were apparently healthy (Stalder et al., 2012), and even though it is a fairly common occurrence in sow herds, it frequently involves disorders that are difficult to diagnose (e.g., heart failure and *Clostridium novyi*) (Friendship and O'Sullivan, 2015; Mas and

Anso, 2021). Euthanasia involves the removal of sows that are severely injured and when treatment is no longer an option, or if the animal's continued existence will only prolong its suffering (AASV and NPB, 2016; AVMA, 2020). However, finding different definitions in studies and farms is common, such as including sows removed by euthanasia in culling removal, making comparisons across farms and studies difficult. Removing a sow typically has multifactorial reasons (Chagnon et al., 1991; Campler et al., 2016), involving different risk factors (Sanz et al. 2002). Understanding how all the factors interact can help identify farm-specific problems that impact removals and death loss.

The two most frequent causes of sow removal are reproductive failure (e.g. failure to conceive and anestrus) and locomotor disorders (e.g. lameness and osteochondrosis) ,(Pluym et al. 2013a; Supakorn et al. 2019a; Kikuti et al., 2020a), with both reasons associated with involuntary culling (Ala-Kurikka et al., 2019). The causes of mortality can be determined through information from the farmer and by necropsy (Lucia et al., 2000; Stalder et al., 2004; Sørensen and Thomsen, 2017). Understanding the causes of mortality will allow the identification of predisposing factors, underlying diseases, and management issues (Stalder et al., 2012; Ala-Kurikka et al., 2019).

1.3.1. Culling

Culling has been described as either voluntary/planned (for economic reasons – linked to low productivity) or involuntary/unplanned (biological or forced reasons) removal of sows from the herd (Linden, 2013a; Iida et al., 2020). Cull sows are either shipped for slaughter or, if the animal is not suitable for transport, euthanized on the farm before shipping (NFACC, 2014). However, interpretation of culling numbers can be tricky and confusing. For example, different studies often considered euthanized and dead sows as culled sows (Sasaki and Koketsu, 2008; Zhao et al., 2015), while in other studies, it is unclear if sows that were euthanized and sows that suddenly died are part of the culling numbers.

Annual sow culling rates on pig farms average 50% worldwide (Zhao et al., 2015), and the herd's productivity is negatively affected by high culling rates (Stalder et al., 2004; Linden, 2013b). In 2019 in North America, the culling rates reported for Canada and U.S. were 38.08% and 45.69%, respectively (PigCHAMP, 2019a, 2019b). Different researchers have reported that poor reproductive performance is the major reason for culling sows in commercial breeding herds (Rodriguez-Zas et al., 2003; Stalder et al., 2004, 2012; Sasaki and Koketsu, 2012). Culling guidelines for high-performing herds suggest culling in parity ≥ 4 for any sows that fail to conceive after the first or second reservice (Sasaki and Koketsu, 2012).

On the other hand, high longevity can also be a problem. Retaining a sow for too long increases the proportion of old sows in the herd, which are more likely to acquire certain diseases and show decreased production over time (de Jong et al., 2014). Research has shown that high removal rates are more common than excessively low rates and that an optimal value of herd replacement by culling is 35–36% (Houška, 2009; Stalder et al., 2012). Therefore, a proper culling policy in sow herds is essential to maintain a consistent parity profile and stable production flow (de Jong et al., 2014). However, inappropriate culling practices can cause economic losses and increase disease risks to animals already in the system (Stalder et al., 2012).

1.3.1.1. Voluntary/planned culling

Voluntary culling is carried out to manage the parity profile of the herd or to remove sows showing an incompetent performance (Linden, 2013a) since sows must remain productive to remain in the herd (Anil et al., 2008; Balogh et al., 2015). Old age, conception problems, small litter sizes, poor progeny (e.g., low birth weight piglets), and lactation problems are common voluntary culling reasons (Lucia et al., 2000; Stalder et al., 2004; Anil et al., 2008; Engblom et al., 2008b; Lisgara et al., 2015). In planned culling, the producer decides the reason for removal and the timing (Stalder et al., 2012) in order to reduce non-productive days and keep the age structure of the herd stable to maintain a constant production of pigs (Iida et al., 2020).

1.3.1.2. Involuntary/unplanned culling

Unplanned culling is different from planned culling, as, in unplanned culling, the producer does not have much control over the causes of removal (Stalder et al., 2012; Iida et al. 2020). There is also an overlap between unplanned culling and euthanasia. For example, lame or injured sows that cannot be humanely transported to slaughter will be euthanized on farm. Involuntary culling occurs especially in the first two parities, which can negatively affect employees' morale and can also indicate reduced sow welfare (Stalder et al., 2012; Linden, 2013a). Unplanned culling is typically related to removing females in early parities (0 to 3) due to problems such as reproductive failure, lameness, genetic, and disease (Engblom et al., 2008; Linden, 2013a; Supakorn et al., 2018). Reproductive disorders such as pregnancy failure, anestrus, failure to cycle, inability to conceive, and diseases affecting the reproductive system are major factors related to involuntary culling as they cause inadequate performance leading to economic losses (Stalder et al., 2004; Tani and Koketsu, 2016). Lameness is another important reason for removal that has been associated with an increase in involuntary culling

(Pluym et al., 2013a). It can indirectly affect reproduction by reducing FI, leading to reproductive disorders; lameness represents a high economic loss (Anil et al., 2008; Stalder et al., 2012).

1.3.2. Euthanasia

Euthanasia is necessary when an animal is suffering, and treatment is no longer an option or if the animal's continued existence will only prolong illness and distress (AASV and NPB, 2016; AVMA, 2020). According to the American Association of Swine Veterinarians and the National Pork Board, "euthanasia is the humane process whereby an animal is rendered insensible, with minimal pain and distress, until death" (AASV and NPB, 2016). In addition, animal handling should minimize distress experienced by the animal prior to loss of consciousness (AVMA, 2020). New guidelines established by the American Veterinarian Medical Association describe a series of requirements with updated methods, techniques, and agents for proper euthanasia (AVMA, 2020). The guidelines recognize that euthanasia involves more than the process itself and recognize the importance of appropriate pre-euthanasia preparations, training, handling of animals, and disposal of the carcass. In addition, evidence such as the loss of rhythmic breathing, absence of jaw tone and palpebral reflex should be used to confirm that the euthanasia technique has been effective, and a secondary method must be identified if the first method is not effective (NFACC, 2014).

The recommended target for mortality (euthanasia and sudden death) ranges from 3 to 5% (Stalder et al., 2012). However, euthanasia can represent a significant proportion of sow removal in practice. A study conducted by Engblom et al. (2007) on sow removal patterns in Swedish commercial herds reported that from the 14,234 sows removed during the study, 10.5% (1,494) of sows were euthanized, which is more than double the recommended target. The reasons for euthanasia can vary due to differences in health, management, nutrition, environment, and culling policies among farms (Supakorn et al., 2019a). Compromised animals that are likely to suffer during transport should be euthanized on-farm (NFACC, 2014); it is also the elected choice for severely injured and non-ambulatory animals in pain or with little possibility of recovery (Stalder et al., 2012; AVMA, 2020).

Sows are often euthanized when the expectation of a successful treatment is very low in a practical amount of time (Supakorn et al., 2019a), with locomotive disorders being the main factor (Sørensen and Thomsen, 2017). For example, in a review study conducted by Supakorn et al. (2019), sows euthanized due to lameness accounted for 30 to 40% of all mortality reasons. Other reasons that can lead the producer to choose euthanasia include minimizing the suffering of the sow and reducing the economic cost of treatment for conditions with a poor prognosis such as uterine, vaginal, and rectal prolapses in breeding sows (Stalder et al., 2012; Supakorn et al. 2019a).

Euthanasia of sows with prolapses has been increasing in the last years (as well as sudden death). For example, a study conducted by Supakorn et al. (2019b) from 2012 to 2017 in a U.S. commercial farm with 11,481 purebred Large White sows found that the incidence of prolapse was associated with mycotoxins, vitamin deficiency, genetics, acute diarrhea, dystocia problems, and farrowing and gestation crate structure. In addition, the higher levels of prolapse, which occurred between 2013 and 2017, negatively impacted sow longevity as these animals were removed from the herd at early parities (0 to 3) (Supakorn et al., 2019b). Another factor contributing to increasing on-farm euthanasia numbers may be the transportation requirements by the Code of Practice for the Care and Handling of Pig (NFACC, 2014). With the fitness for transport of each animal assessed, unfit animals and those that cannot bear weight on all four legs cannot be loaded, and special conditions are applied for compromised animals, such as extra bedding (NFACC, 2014). However, sows removed from the herd by euthanasia are often recorded in the farm records as culled sows. Affecting not only the actual number of females removed by culling but also complicating the study of sow mortality reasons since information regarding the euthanized sows is not provided.

In Canada, there are three accepted methods of euthanasia that can be applied to sows: anesthetic overdose, gunshot and penetrating captive bolt (NFACC, 2014). The selection of the most appropriate method depends upon equipment and facilities, operator skill and experience, the presence of a veterinarian, human safety, and options for disposal of remains (Engblom et al., 2007; NFACC, 2014; AVMA, 2020). However, regardless of the choice of method for euthanasia, the technique should minimize any pain or distress to the animal and should result in rapid loss of consciousness followed by cardiac or respiratory arrest and, finally, loss of brain (AVMA, 2020).

1.3.2.1. Anesthetic overdose

Non-inhaled agents such as barbiturates cause general anesthesia followed by respiratory and cardiac arrest. Anesthetics must be administered by a veterinarian through intravenous injection. However, the disposal of animals euthanized with barbiturates is complicated considering chemical residue risks, and the animal’s remains must be disposed of according to each province’s legislation (AVMA, 2020)

1.3.2.2. Gunshot

When conducted with an appropriate firearm and performed correctly (proper placement and aim), euthanasia by gunshot will cause instant and irreversible brain damage, resulting in immediate loss of consciousness and rapid death (Stalder et al., 2012; AVMA, 2020). There are three head regions where a gunshot can be applied: frontal, temporal and from behind the ear, directed diagonally toward the opposite eye (NFACC, 2014). The person performing this euthanasia technique must be trained in firearm safety (AVMA, 2020). Concrete surfaces in pig barns represent a hazard for gunshot use as the bullet can ricochet and is a risk to the operator, other animals, or bystanders.

1.3.2.3. Penetrating captive bolt (PCB)

Unlike euthanasia by gunshot, the only acceptable location for PCB is the frontal site (NFACC, 2014). It is essential to get the correct positioning (midline of the forehead, one finger-width above eye level) and angle for this method to be successful as swine brains are fairly small and well protected (NFACC, 2014). In addition, the animal must be restrained (AVMA, 2020). When PCB is correctly performed, it causes concussion and destruction of brain tissue, leading the animal to immediate insensibility, and the effectiveness of the technique can be confirmed by the lack of vital signs (Stalder et al., 2012; AVMA, 2020).

Compared to gunshot, PCB is advantageous for being safer and more effective with minimal cost. However, personnel must be trained to ensure a successful euthanasia as there is a variation in bolt length and ammunition requirements for an effective single-step euthanasia for different sizes and maturities of swine (AVMA, 2020). Therefore, a secondary step to ensure death must be applied for pigs weighing ≥120kg (≥265lbs) (e.g., reapply the captive bolt, pithing, bleeding) that is performed after the animal becomes insensible (NFACC, 2014; AVMA, 2020).

1.3.3. Sudden death

Sudden death or natural death occurs when animals die, which were apparently healthy, with nonspecific premonitory clinical signs (Sanz et al., 2007; Stalder et al., 2012). A review article published in 2021 by Mas and Anso (2021) outlines that 61% of the causes of sudden death in sows have a multifactorial aetiology, which makes it more difficult to control or prevent (Mas and Anso, 2021). Multiple pathologies can indicate that the course of illness was prolonged and the decision to terminate the animal (by euthanasia or culling) or medical treatment was deferred, raising concerns about sow welfare (Ala-Kurikka et al., 2019) as it may suggest that clinical signs may have been ignored or misunderstood. The most common causes of natural death are torsion of abdominal organs, gastric ulcers, heart failure, cystitis–pyelonephritis, mycotoxin poisoning, and heat stress (Stalder et al., 2012; Friendship and O'Sullivan, 2015; Sørensen and Thomsen, 2017; Supakorn et al., 2019a). Pigs are particularly susceptible to heat stress, with a low proportionality of heart weight and cardiac output with body weight, they have a high risk of dying due to cardiac failure (Iida and Koketsu 2014; van Essen et al. 2018). Moreover, gilts and young sows during the peripartum period are more sensitive to dying at high temperatures (Iida and Koketsu, 2014),while old sows in the peripartum period are most at risk of dying in the colder months (Stalder et al., 2012; Iida and Koketsu, 2014) due to heart failure, since the peripartum period is already a challenging time for the sows cardiovascular system (Chagnon et al., 1991). Various studies have shown the relationships between seasonality and sow mortality, indicating that high temperatures can decrease sow longevity (Chagnon et al., 1991; Koketsu, 2000; Kikuti et al., 2020b).

A study performed by Iida and Koketsu (2014) in 2010 in Japan evaluated the associations between climatic factors and sow mortality after service during hot and humid or cold seasons. The authors reported that during the hot and humid season (June – September), mated gilts and lower parity sows were more sensitive to high ambient temperature than multiparous (Iida and Koketsu, 2014). From the 93,837 sows entered the study, 8,381 (8.9%) died from 2003 to 2007, with 40.9% of these deaths occurring during the hot and humid season (June – September) and approximately 56% (11.5% pregnant and 44.3% farrowed) occurring in the 4-week peripartum period. Iida and Koketsu (2014) also reported that in sows of parity four or higher, the cold season (December – March) was associated with more deaths, accounting for 30.7%. Thus, controlling the ambient temperature to prevent death caused by heat stress and cold stress is crucial (Friendship and O'Sullivan, 2015).

1.4. Risk factors and causes of sow mortality

Risk factors are elements/conditions that increase the likelihood of an animal developing a disease or health disorder that can result in death; it looks to relationships between mortality levels and specific management factors (Offord and Kraemer, 2000). Causes of mortality are the immediate reasons related to the death of a specific individual and indicate a disease and a management factor that directly affects sows (Erhardt, 1958).

Sow mortality figures typically include both sows euthanized, and sows found dead. Several factors influence mortality levels in the herd, such as health complications, genetics, nutrition, environment, and management policies (Anil et al., 2008; Balogh et al., 2015). Studies assessing risk factors and causes of sow mortality have reported that different pathologies often occur simultaneously in the same herd or animal. However, necropsies that could help to identify specific health events are hardly ever performed on farms unless a study is being conducted on-site or sporadically in the event of complicated cases, resulting in many unknown/unrecognized diagnoses (Küker et al., 2018; Ala-Kurikka et al., 2019).

1.4.1. Risk factors

At herd level sow longevity is affected by environmental factors and herd characteristics, such as living conditions (e.g., herd size and housing system) and management practices (e.g., genetics and nutrition) (Koketsu et al., 2017; Bergman et al., 2018, 2019).

1.4.1.1. Health disorders

Health disorders directly affect sow longevity by reducing the performance of the breeding herd, and often the individual sow's health is neglected in order to maximize the production of the rest of the herd (Friendship and O'Sullivan, 2015). The two body systems most commonly affected by health disorders are the reproductive and locomotor systems (Friendship and O'Sullivan, 2015).

Reproductive disorders. Reproductive disorders are a major factor for sow removals as it is essential for a sow to remain productive to remain in the herd (Anil et al., 2008). A parameter to determine breeding herd reproductive performance and a herd's overall efficiency is PWSY (Lisgara et al., 2015). Therefore, removals due to reproductive disorders that lead to pregnancy failure affect the stability of PWSY in a pig production system, decreasing the overall productivity (Tani and Koketsu, 2016). The most common reproductive disorders are prolapse (uterine, rectal and vaginal), farrowing failure, abortion, anestrus, irregular return to estrus, endometritis, enteropathy, and dystocia, with prolapse responsible for high rates of sow removal (Supakorn et al., 2019b). In addition, reproductive disorders such as prolapse, farrowing failure, and abortion can subsequently reduce the reproductive performance of the sow. Although abortions are uncommon in sows, they can indicate the presence of infectious diseases such as Porcine Reproductive and Respiratory Syndrome virus (PRRSv) and leptospirosis (Friendship and O'Sullivan, 2015).

Gilts and first-parity sows are more likely to be removed for anestrus (Stalder et al., 2012), whereas older sows are more likely to be culled due to the increased number of stillborn piglets over time (Stalder et al., 2012; Supakorn et al., 2019a). Prolapses are the turning inside-out of the rectal lining, vagina, or uterus (National Pork Board, 2019), and rectal prolapse is the most common prolapse seen in swine, occurring after straining to defecate or by physical pressure (Anderson and Jean, 2012; Thomson and Friendship, 2012) such the increase in abdominal pressure (e.g., pregnancy) (Thomson and Friendship, 2012). Vaginal prolapse is uncommon but can occur in the prepartum event, while uterine prolapses are seen in sows during or after parturition (Anderson and Jean, 2012; Stalder et al., 2012). According to Stalder et al. (2012), less than 7% of sows are removed due to uterine prolapse; however, when cases of prolapse of the entire uterus occur, there is a greater threat to life due to extensive bleeding and amputation of the uterus is indicated (Anderson and Jean, 2012) to preserve the sow until her piglets are weaned (Jackson, 2007).

Lameness. Locomotor problems in sows are a significant health and economic concern for producers (Heinonen et al., 2013; Pluym et al., 2013a). Lameness is considered to be the second most frequently reported reason for sow removal in early parities (Supakorn et al., 2018; Iida et al., 2020) and can be caused by several factors, with the most common causes being osteochondrosis, arthritis, hormonal influences, and oxidative stress (imbalance of organic and mineral components) (Bradley et al., 2018).

Different factors can increase the risk of lameness. For instance, Boyle et al. (2014) found that group housing contributes to lameness, and more recently, Supakorn et al. (2018) addressed other key factors affecting the prevalence and severity of lameness. The authors identified housing type, flooring type, toes or dewclaws management, genetic effect for feet and leg conformation, nutrition, especially mineral supplements, and body condition score (BCS) as risk factors for lameness (Supakorn et al., 2018).

In a group-housing study, Pluym et al. (2017) found that lameness can be influenced by the wetness and cleanliness of the lying area. The study included 810 sows, and after 3–5 days of group housing, 32% of the sows were considered 'dirty', with >10% of the body covered with faeces. Sows subjected to more faecal contamination and wet environments are more prone to develop lameness since their feet become soft and floors become slippery resulting in trauma (Carr and Howells, 2013).

In a review article, Heinonen et al. (2013) reported that a high prevalence of lameness is a consistent finding. However, there is always a difference in the percentage of animals affected among studies by variation in the definition of lameness or methods used to assess lameness and variation in the actual levels present. *Post-mortem* examinations can facilitate the identification and establish a clear diagnosis (Heinonen et al., 2013). In live animals, lameness assessment can be performed when sows are moved from one stage to another in the farm (Seddon and Brown, 2012; Pluym et al., 2013a), using a subjective scoring system, such as the Feet First® Swine Locomotion Scoring System by Zinpro (2011) (Minnesota, US), and it should include observation of the animal walking on a solid (unslatted) floor (Heinonen et al., 2013).

Pluym et al. (2013) stated that the prevalence of lameness depends on when in the productive cycle the sow is inspected. For this reason, to effectively prevent lameness, it is important to know at which stage of the reproductive cycle it is predominant. Furthermore, since lameness can indirectly affect sow reproductivity by reducing FI and affecting behavior since it is associated with pain and distress in the animal (Pluym et al., 2013a; Supakorn et al., 2018), lameness can prevent sows from reaching optimal breeding efficiency (Iida et al., 2020).

1.4.1.2. Herd size

Many studies have reported the negative effect that increasing sow herd size has on mortality (Koketsu, 2000; Bergman et al., 2019; Supakorn et al., 2019a). Therefore, in theory, it could be expected that larger farms would be able to hire more specialized employees, ensuring a better quality of sow care (Koketsu, 2000; Koketsu et al., 2017). However, in practice, sow farms typically have high staff turnover, and the increase in mortality may be associated with employees' lack of knowledge and time (Supakorn et al., 2019a). Moreover, the inexperience in identifying when sows are at risk of getting sick (Stalder et al., 2004), lack of treatment options, training, and the limited time to focus on sows showing clinical symptoms is believed to increase mortality rates in large herds (Supakorn et al., 2019a).

Koketsu (2000), in a retrospective analysis estimated the annual sow mortality risk on commercial farms in the U.S. using PigCHAMP data files from producers. The study took place between 1993 to 1997 and included, initially, 825 herds. Of 825 herds, 221 herd were removed due to different reasons such as missing records and annual mortality rates >20% per year. The author reported a direct association between herd size and mortality risks: as herd size increased by 500 females, mortality risk increased by 0.44% (Koketsu, 2000). In addition, the author pointed out that caretakers in larger herds may have less time to observe clinical signs exhibited by the sows when compared to smaller farms due to the intensive management. Even though large farms can hire more skilled workers than small farms, the high number of sows per staff could explain the higher average sow mortality seen in larger herds (Koketsu, 2000).

A recent study conducted in the U.S. by (Ketchem et al., 2020a) at Swine Management Services collected sow removal data between 2006 and 2020 from 493 farms with 916,973 mated females. The study included farms ranging in size from less than 200 to more than 6,000 sows and analyzed the removal rate (death loss and culling) by farm size, considering the removal rate by parity. The researchers found that as farm size increased, the rate of sow removal also increased, especially in parities 0 to 2. For example, farms with less than 800 sows showed up to 50% removal rates. In contrast, farms with 6,000 or more sows showed an average removal rate of 65% (Ketchem et al., 2020b).

Regarding removing younger parity sows, farms with less than 1,600 sows presented removal rates from 14.3% to 19.4%, while farms with 6,000 or more sows presented 30.21% of removal rate for parities 0 to parity 2. The authors concluded that increasing death loss was associated with an increase in herd size, indicating the need to reduce the removal rate, especially in parity 0 to 2 sows on large farms. The authors also emphasized the need for farms to have control of their sow development program, stating that it is an area that needs more study (Ketchem et al., 2020a, 2020b, 2020c).

1.4.1.3. Housing system

According to the Code of Practice for the Care and Handling of Pig (NFACC, 2014), the requirements for housing systems for any pig farm are to provide adequate space, good ventilation, appropriate temperature, comfort and allow the safe, efficient, and humane movement of pigs (NFACC, 2014). This requires regular inspection to reduce risks of injury and includes providing suitable temperatures (thermoneutral zone for gestating sows ranges from 10 to 27oC) (NFACC, 2014). Therefore, most sow herds in Canada are managed intensively in barns with climate controls to maintain temperatures within sows thermoneutral zone.

The type of floor, ventilation, and temperature strongly affect sow's behavior, and welfare assessments are used to determine whether the animal is exhibiting normal behaviors or not (Johnson et al., 2012; Spoolder and Vermeer, 2015). For example, sows lying down in their faeces to cool down under high temperatures (Spoolder and Vermeer, 2015), chronic discomfort caused by bad flooring (e.g., lameness), chronic anxiety or frustration caused by improper housing (e.g., stereotyped behavior - behaviors performed repeatedly without an obvious function) are examples of impaired welfare linked to housing system (Webster, 2001; Johnson et al., 2012).

Several studies have shown that injuries caused by flooring impact the longevity of sows. Gestation housing floors are usually made of solid concrete, slatted concrete, or a combination of the two. The use of slatted concrete is intended to minimize the need for cleaning and maintain sow's hygiene. However, it is a major risk factor for lameness (Boyle et al., 2014; O.A.T. Peltoniemi and Oliviero, 2015) since the roughness and abrasiveness of the concrete contribute to claw and lameness injuries and increase the risk of trauma from falling since the floor is covered with faeces and urine, becoming more slippery (Cameron, 2012; Supakorn et al., 2019a). Adding straw-based bedding reduces the incidence and severity of injuries and scratches, as long as the floor hygiene is maintained, and high stocking density is avoided (Cameron, 2012; Spoolder and Vermeer, 2015). Moreover, the sows will spend less time looking for a resting place since straw bedding provides greater thermal and physical comfort (Spoolder and Vermeer, 2015).

Stall gestation. Individual stalls are small spaces where the animal is confined with only the mobility to lay down and stand (Morgan et al., 2018). According to the Canadian Code of Practice for the Care and Handling Pigs (NFACC, 2014), gestating gilts and sows in stalls should be able to stand at rest without simultaneously touching all sides of the stall; stand without touching the top bar and to lie down without their udders protruding into adjacent stalls (NFACC, 2014).

Sows can show an increased incidence of stereotyped behaviors that indicate stress, such as bar-biting, sham-chewing, belly nosing, tongue rolling, excessive drinking, and increasing posture changes (Welfare Quality, 2009; Johnson et al., 2012; NFACC, 2014; Morgan et al., 2018). For instance, the inability to perform motivational behaviors such as nest building before farrowing can cause stress, triggering the development of these stereotyped behaviors (Johnson et al., 2012). Different physical injuries can also be found in stalls sows, being leg injuries and skin lesions the most common (Morgan et al., 2018).

Group gestation. In group housing systems, the Canadian Code of Practice for Pigs (NFACC, 2014) requirements are "all group housed sows must be able to stand, move about and lie down without interference with each other in a way that compromises welfare, and space must be provided for the separation of dunging from lying and eating areas" (p. 14). Sows will try to keep the lying area in a comfortable place, dry (free from manure and urine), clean, and away from the areas with more movement (drinkers, feeders, and walkways) (Spoolder and Vermeer, 2015). It is recommended by (NFACC, 2014) to increase the space allowance when aggressive encounters and bullying are recurrent.

Since January 2013, group housing systems have been mandatory in the European Union for most part of the pregnancy period of the sow (Morgan et al., 2018; Iida et al., 2020).

Breeding sows in their natural environment will normally form small groups, with roughly performed social encounters to decide their hierarchy to reduce aggression (Webster, 2005). According to Spoolder and Vermeer (2015), large groups of sows, when compared to small groups, are less likely to engage in aggressive interactions and more likely to show avoidance behavior since they will not recognize all the sows.

Stress, injuries, and mortality have been reported in both housing systems (stall and group housing) and while sows in individual gestation stalls are confined in small spaces with decreased freedom of movement, sows in group gestation experience high demands on their locomotion system, with increased chances of having aggressive encounters for competition (food, lying space, and hierarchy) (Anil et al., 2003; Díaz et al., 2015; Morgan et al., 2018). Moreover, different studies have reported that group-housed sows can experience more injuries than stall-housed sows. With violent interactions such as vulva biting, lacerations all over the body, and lameness, the injuries can lead to sudden death, euthanasia, and culling if not treated (Anil et al., 2009; Supakorn et al., 2019a). However, even though gestation stalls help to avoid injuries that may compromise welfare (Anil et al., 2003), the lack of exercise, the fact that sows must lie in their waste which increases the risk of urinary tract infections, and the inability to perform motivating behaviors, such as foraging, negatively impact the welfare and sow longevity (Johnson et al., 2012; Supakorn et al., 2019a). Therefore, it is suggested that the combination of group housing with a short period of stall housing (mixed housing) can help to minimize injuries (NFACC, 2014). According to the Code of Practice: For the Care and Handling of Pigs (NFACC, 2014), gilts must be housed in groups prior breeding and that mated gilts and sows must be housed in group or individual pens. However, individual stalls may be used for a maximum of 28 days after the date of last breeding (additional 7 days are permitted to manage grouping) (NFACC, 2014).

1.4.1.4. Genetics

In the last two decades, pig genetic improvement has focused on production traits and reproduction characteristics (Nikkilä et al., 2013; Bloemhof-Abma and Lewis, 2018). However, the increase in sow mortality can also be associated with changes in genetics (Supakorn et al., 2019a; Ketchem et al., 2020a). The genetic improvements focusing on the increase of piglets born alive and weaned, both per year and throughout their productive life in the recent years have resulted in hyperprolific breeding sows, with females producing average litters of 15 or more piglets born alive (Friendship and O’Sullivan, 2015; Karpiesiuk et al., 2018). However, the increased number of piglets may have reduced their birth weight, along with the risk that when the number of piglets is greater than the number of functional teats, it reduces viability (Edwards and Baxter, 2015; Theil, 2015). In addition, the prevalence of smaller and weaker piglets also brings with it a greater variation in weight within the litter, which are risk factors for piglet mortality resulting in a reduced number of PWSY (Edwards and Baxter, 2015; Kraeling and Webel, 2015).

Traits linked to the quality of legs and feet can also be genetically affected and may be linked to the high frequency of sow culling (Tarrés et al., 2006). The intense genetic selection for faster growth, large muscle mass, and efficient feed conversion has resulted in locomotor disorders by imposing pressure on the animal's joints, with osteochondrosis as one of the main diagnoses (Engblom et al., 2008a; Friendship and O'Sullivan, 2015; Supakorn et al., 2018, 2019a). Osteochondrosis is a hereditary and degenerative disorder resulting from the focal endochondral ossification failure, causing deformation to the articular surface, and leading to abnormal conformation and locomotion traits, consequently causing pain and distress to the animal (Done et al., 2012; Supakorn et al., 2018). The incidence of osteochondrosis is higher in young animals, and the lesions can heal over time, but scar tissue can be seen in older animals (Engblom et al., 2008a; Bradley et al., 2018; Ala-Kurikka et al., 2019). Since locomotor disorders are one of the main reasons for sow removal, improved genetic selection for healthy feet and legs could improve sow retention. However, even though poor leg quality impacts longevity and sow welfare, few studies have reported the effects of genetic selection on the number of sows removed for locomotor disorders (Tarrés et al., 2006; Nikkilä et al., 2013).

The economic importance of specific traits, such as hyperprolific sows, the quality of feet and legs, and their impact on sow removal, can be a significant criterion for genetic selection and improvement of sow longevity (Tarrés et al., 2006; Pluym et al., 2013b). According to Engblom et al. (2016), "sow longevity can be improved by genetic selection; however, it is rarely included in genetic evaluations" (p. 138) and despite the differences among genetic lines, comparison among the lines has been almost impossible as limited research regarding genetic comparisons is available (Serenius et al., 2006).

1.4.1.5. Nutrition

To ensure the welfare of sows, it is imperative to consider the right measures to satisfy their appetite and their nutritional needs, varying according to body condition, weight, and production stage (maintenance, growth, reproduction, or lactation), which requires different feeding strategies (NFACC, 2014; Kraeling and Webel, 2015). Improper nutrition is considered one of the reasons for high levels of culling for reproductive failure in young females (Stalder et al., 2012), and gastric ulcers and torsion of the stomach or intestine are other common problems that are related to sow diet.

Gastric ulcers are responsible for many sudden deaths in sows and can be caused by changes in the diet and feed processing methods (Lauridsen et al., n.d.; Melnichouk, 2002; Trottier et al., 2015). The stomachs of the swine are not entirely covered by protective mucus, in contrast to the glandular surface of the stomach, the squamous epithelium of the pars oesophagea does not contain mucous glands, being susceptible to acid burns when exposed to the acidic contents of the stomach and where gastric ulcers are mostly found (Lauridsen et al., n.d.; Dall, 2016). In addition, different studies have shown that feeding sows with small particles size grains are linked to a higher risk of developing gastric ulcers (Ayles et al., 1996; Liermann et al., 2015; Rojas and Stein, 2017; Cybulski et al., 2021). Fine grinding and pelletizing reduce the viscosity of the chyme and increase its secretion rate in the stomach, increasing the risk of gastric ulcers and mortality rate caused by ulceration (Melnichouk, 2002; Millet et al., 2012). The reduced amount of fibre in the diet is also known to contribute to the appearance of gastric ulcers (Lauridsen et al., n.d.). Therefore, selecting a proper balance of particle size and fibre content for the sow diet will lead to a healthier gut environment (Dall, 2016; Cybulski et al., 2021). However, fibre recommendations have not been clearly outlined for pigs in any phase of production yet (Vista, 2021).

With a reduced appetite and a lean growth rate, replacement gilts from modern line genotypes are more sensitive to nutritional management, with a different diet than the one given to grow-finisher pigs (Whitney and Masker, 2010). Focusing on preparing gilts for a productive life, bone development, and leg and toe health (Whitney and Masker, 2010; Supakorn et al., 2018), a low energy diet will allow them to have a slightly slower growth rate, limiting their mature body size and avoiding feet and leg problems due to excessive body fat gain (Kraeling and Webel, 2015). In modern lean genotypes, it is important to prevent excessive body fat, but a minimum of 0.5 inches (12 mm) backfat at farrowing is adequate to prevent the “thin sow syndrome”, which occurs when nutrition or feed quality is inadequate and does not meet nutritional requirements, especially during lactation (The Pig Site, 2018). Not being able to maintain an adequate BCS due to scarce energy intake, the sow's low body fat levels will be used to maintain her energy supply, followed by muscle protein degradation (The Pig Site, 2018). Consequently, reproductive disorders can happen, such as failure to conceive, and the sow can present a reduced performance (Gadd, 2009), increasing her removal risks.

First parity sows have a disproportionate negative reproductive response to environmental factors (e.g., high ambient temperatures), leading to a reduced appetite, especially during lactation (Kirkwood et al., 2012; Kraeling and Webel, 2015). Since they are still growing, they have additional energy requirements during their first lactation, which can cause a longer wean-to-estrus interval. This problem can be addressed by proper nutrition (Knauer et al., 2012; Kraeling and Webel, 2015) or by skipping the first oestrus after the first litter (skip-a-heat) (Soede and Kemp, 2012). Therefore, nutrition management to improve FI during lactation will prevent the sow from using her body reserves to meet the needs of the piglets, consequently not affecting her future productivity (Stalder et al., 2006) or the chances of being culled due to reproductive inefficiency. Therefore, to reduce sow removal caused by nutrition impairments, monitoring, and managing sow's body reserves is essential to keep their nutritional levels stable throughout all production stages.

The increase of FI of gilts and sows (also known as bump-feeding) during late gestation is common in the swine industry. Applied to provide extra energy and nutrients needed to meet the exponential development of the fetus in late gestation, the practice of bump-feeding also helps to maintain sow's positive energy balance during the end of gestation (Trottier et al., 2015; Gonçalves et al., 2016). In addition, some studies show that bump-feeding better maintained the sow's BCS (Miller et al., 2000; Knauer, 2016). For instance, a study conducted in 104 commercial sow farms in the U.S. by the Iowa Pork Industry Center (Ross, 2019) on the sow removal due to prolapse observed that bump-feeding sows with lower BCS during late gestation reduced the prolapse rates. In addition, the study also reported that water treatment (hydrogen peroxide or chlorine-based treatment) appeared to reduce the annualized total mortality (Ross, 2019).

1.4.1.6. Mycotoxins

Mycotoxins can affect different body organs of the body and cause a variety of clinical signs, compromising sow productivity (Osweiler and Ensley, 2012). Mycotoxins are produced by molds, which invade the feed (carbohydrate source) when combined with sufficient moisture oxygen and given appropriate temperatures (typically 12-25°C) (Osweiler and Ensley, 2012). The risks involved with intoxication by mycotoxin depends on the age, dosage ingested, type of toxin, and animals' health (deficiencies of protein, selenium, and vitamins) (Crenshaw, 2001; Osweiler and Ensley, 2012). Although death is often the outcome of mycotoxin intoxication, low levels can impair animal welfare, performance, and interfere with the absorption of essential vitamins and nutrients (Crenshaw, 2001; Bradley et al., 2018). The most common mycotoxins are aflatoxin, ochratoxin A, deoxynivalenol, ergot, fumonisin, and zearalenone (Osweiler and Ensley, 2012; Maggio de Castro Souto et al., 2017).

Zearalenone is one of the most reported mycotoxins found in the diets and also the main mycotoxin associated with reproductive issues in sows, causing a disturbance in the reproduction cycle such as anestrus and prolonged estrus (Kirkwood et al., 2012; Bradley et al., 2018). Produced by different species of Fusarium, Zearalenone occurs mainly in corn, barley, oats, wheat, sorghum, and rice (Maggio de Castro Souto et al., 2017) and the clinical signs associated with the reproductive system vary according to the dosage and age of the sow exposed (Osweiler and Ensley, 2012). In young sows, the symptoms involved are vulvovaginitis and precocious mammary development, and on mature cycling sows, the mycotoxin can induce anestrus for several months (even after mycotoxin exposure has ceased) (Osweiler and Ensley, 2012; Maggio de Castro Souto et al., 2017). Other clinical signs of zearalenone intoxication are found in female sows, such as retention or absence of milk and rectal prolapse (Maggio de Castro Souto et al., 2017). However, research assessing the impact of ingesting contaminated feed over the lifetime of sows and gilts has on reproductive health and longevity is limited and more studies are needed (Bradley et al., 2018).

1.4.2. Causes of death

The causes of death on the farm can be assessed by information recorded daily by the farmer and through necropsies (which provide a more accurate diagnosis) (Sørensen and Thomsen, 2017). However, according to Sørensen and Thomsen (2017), there is often little agreement between the farmer's assessment and the necropsy report on the actual cause of death of the sow. Causes of death that producers can easily identify are rarely investigated or sent to the laboratory for diagnosis (D'Allaire et al., 1996), resulting in a lack of information about the main causes of death and their causality on Canadian farms. A better understanding of the cause of sow death can be accessed by necropsy procedures, which can assist producers to reduce sow mortality in the herd (Sanz et al., 2002, 2007). The main causes of sudden death in sows reported in previous literature are gastrointestinal problems, heart failure, cystitis-pyelonephritis, prolapses, and events in the peripartum period (e.g., farrowing and weaning) (Anil et al., 2008; Supakorn et al. 2019a).

1.4.2.1. Gastro-intestinal problems

Complications involving the gastrointestinal system often result in death due to sudden blood loss from gastric ulcers or shock associated with torsion of abdominal organs (Friendship and O'Sullivan, 2015). Gastric ulcers are more frequently found in young sows, while torsions are more common in older sows (Stalder et al., 2004; Vearick et al., 2008). The most common ulcers in breeding sows are oesophagal and stomach ulcers, with clinical signs reflecting the degree of blood loss (Thomson and Friendship, 2012; Supakorn et al., 2019a). Animals with slow blood loss due to ulcers will show signs associated with anemia such as paleness, lethargy, weakness, increased respiratory rate, dark faeces, and anorexia. However, pigs with extreme hemorrhages with no symptoms and which are apparently healthy can also be found dead within hours with a pale carcass (Thomson and Friendship, 2012). Torsions are extremely fatal and are commonly associated with rough handling, peripartum period, agitation around the time of feeding, and changes in feeding practices, causing extreme fermentation and gaseous distension (Stalder et al., 2004; Thomson and Friendship, 2012). The stomach becomes distended with gas and fluid, and occasionally the spleen and liver are involved (Friendship and O'Sullivan, 2015; Supakorn et al., 2019a).

1.4.2.2. Heart failure

Heart failure is more problematic in older sows and is usually associated with stressful events (Stalder et al., 2004). It has been described as the main cause of natural death with a difficult diagnosis to confirm, leading to unreported cases or its occurrence being considered irrelevant (Chagnon et al., 1991; Stalder et al., 2012; Friendship and O'Sullivan, 2015; Supakorn et al., 2019a). Pigs, in general, have one of the smallest hearts to bodyweight ratios among domestic animals, making them prone to acute heart failure (Friendship and O'Sullivan, 2015; Supakorn et al., 2019a). Therefore, it has been proposed to base the heart failure diagnosis in breeding herd sows on cutaneous cyanosis, transudate in the pericardial, thoracic, and abdominal cavities, cardiac chamber changes, pulmonary oedema, and passive lung and liver congestions (Supakorn et al., 2019a). Sudden death due to heart problems has also been found to cause frequent deaths in market pigs during transport since heat stress, the primary risk factor for in-transit-loss, can lead to a heart attack (Zurbrigg et al., 2017). The thermal stress increases body heat, causing peripheral vasodilation, which lowers blood pressure and increases cardiac output, leading to increased cutaneous circulation to induce heat loss by radiation and convection. In extreme cases, this response overwhelms compensatory mechanisms and leads to heart failure (D'Allaire et al., 1996).

1.4.2.3. Cystitis-pyelonephritis

Cystitis-pyelonephritis is an inflammatory condition involving the urinary bladder (cystitis) and kidney (pyelonephritis) and can be a direct or an indirect cause of death. The increased incidence of this condition appears to be associated with management changes (Drolet, 2012). It is more frequently found when sows are moved to confinement housing for gestation as their vulvas may then be in direct contact with faeces for an extended period, facilitating contamination (Merlini and Merlini, 2011). The most commonly isolated bacteria from this complex are *Escherichia coli*, *Trueperella pyogenes* (formerly *Arcanobacterium pyogenes*), *Actinobaculum suis*, *Streptococcus spp.*, and *Staphylococcus spp*. (Drolet, 2012; Stalder et al., 2012).

The clinical signs will vary according to the disease's severity and phase. Some animals can be asymptomatic, and others can show subtle clinical signs that may include frequent urination, weight loss, anorexia, hematuria, and pyuria (Drolet, 2012; Supakorn et al., 2019a). In severe acute cases, the animal can be found dead within hours before developing any clinical signs, with renal failure being a possible cause of death (Drolet, 2012; Supakorn et al., 2019a). The risk of developing cystitis-pyelonephritis increases with age (Drolet, 2012; Stalder et al., 2012). As an indirect cause of death, cystitis can predispose the sow to vaginal prolapse (Anderson and Jean, 2012) or other negative consequences of prolonged farrowing time (Sobestiansky et al., 1995).

1.4.2.4. Prolapse

The main factors associated with the incidence of prolapse are nutrition, physiology, hormones, genetics, environment, and other diseases (e.g., diarrhea and dystocia) (Supakorn et al., 2017). A prolapse can occur in the rectum or reproductive tract (vaginal and uterine) (Sørensen and Thomsen, 2017; Supakorn et al., 2019b). Zearalenone often causes rectal prolapses, the primary mycotoxin associated with reproductive disorders (Bradley et al., 2018). Vaginal prolapses can be caused by straining to urinate or defecate or by physical force (Anderson and Jean, 2012; Thomson and Friendship, 2012), and uterine prolapses are typically caused by excessive straining due to dystocia problems, trauma with swelling, and inflammation of the birth canal (Anderson and Jean, 2012). Sows affected with prolapse are often found dead due to hemorrhaging (Sørensen and Thomsen, 2017).

The susceptibility to prolapse varies among sows due to genetic and non-genetic effects, with the chances of prolapse being higher during the farrowing/peripartum period (Anil et al., 2008; Supakorn et al., 2019b). However, the increased sow removal through euthanasia and inaccurate recording keeping of prolapse cases contributes to a lack of genetic parameter estimates for prolapse, limiting knowledge about the proportion of phenotypic variation due to genetics (Supakorn et al., 2019b).

1.4.2.5. Peripartum period

At each stage of production, the risk of sow mortality changes. The peripartum period has the highest mortality risk (Lucia et al., 2000; Anil et al., 2008; Supakorn et al., 2019b), having more deaths per unit of time than any other stage (Anil et al. 2008; Koketsu et al., 2017). During this period, various causes can affect sows, leading to death such as *Clostridium difficile*, *Clostridium novyi*, gastrointestinal torsions, heart failure and uterine prolapse (Anil et al., 2008; Stalder et al., 2012).

In a study on the associations between climatic factors and the occurrence of death in peripartum pigs, Iida and Koketsu (2014) observed an increase in younger sow deaths during months with high temperatures and humidity. In 1999, Deen and Xue, suggested an association between increased mortality in the peripartum period in warmer months and a higher frequency in younger sows. In the study conducted by Iida and Koketsu (2014), from the total of 93,837 sows entered in the study, 8,381 (8.9%) of the sows died, with 40% of deaths occurring during high temperature months and 56% during the peripartum period, supporting the results reported in earlier literature.

1.5. Farm records

When describing sow mortality and risk factors for sow removal, certain limitations must be considered (Kikuti et al., 2020a). Inaccurate record keeping, lack of expertise of the person recording signs of disease, injury and reasons of death, and time to conduct necropsies on farms are a few examples (Knauer et al., 2007; Anil et al., 2008; Stalder et al., 2012; Bradley et al., 2018). In addition to the limited information available on farms about sow mortality (Bradley et al., 2018), the fact that farms do not perform standardized evaluations means that each farm performs a different type of evaluation (e.g., for lameness, for body condition, or even for the need for euthanasia). Furthermore, individuals within a farm may also use different criteria, making it difficult to study the causes of swine mortality. Observational studies using farm data conducted by Lucia et al. (2000) and Anil et al. (2008) recognized that their conclusions were potentially limited since the definition of reasons for removal was not standardized, and clinical diagnosis or necropsy procedures were not done.

Often in farm records, the term 'removal rate' includes all types of removal, not distinguishing which animals were removed by culling, natural death, and euthanasia (Stalder et al., 2012). In addition, the term 'unknown' as a removal reason can be found on countless farms. However, it may have different meanings, for example, when no visible lesions were identified (Sanz et al., 2007), the sum of other removal reasons that are underrepresented (Sasaki and Koketsu, 2010), when no specific reason was found (Zhao et al., 2015), or due to putrefaction (Ala-Kurikka et al., 2019). For example, Lucia et al. (2000) conducted a study between 1986 to 1990 on 28 sow farms in Canada and U.S., analyzing removal reasons and investigating lifetime reproductive performance. From the total of 7,973 sows removed, 13.5% had an 'unknown' or an unrecorded reason for removal, with a further 788 records for culled females classified in the 'miscellaneous category' (Lucia et al., 2000).

Standard protocols for sow observation and evaluation at culling, death or euthanasia, and appropriate staff training are crucial, especially for staff without previous livestock experience (Stalder et al., 2004). Focusing on observations that can be made accurately by caretakers, including the development of standardized recording methods (Ketchem et al., 2020b), can be added to the production software systems. These methods will improve the mortality records and facilitate appropriate treatment decisions for disease or injury and reduce sow mortality on the farm and simplify the study of sow mortality (Ramirez and Karriker, 2012; Boyle et al., 2014). In addition, producers and barn staff often do not value the need of keeping mortality records. Once the animal is dead, it is a loss, which may reflect a lack of knowledge in production and management. Having standardized protocols that include the number of sows removed by euthanasia, death, and culling, and the reasons for removal can illustrate to producers and barn staff that there is a potential for improvement on the farm, which will consequently increase sows productivity.

1.6. Necropsy procedures

Necropsy examinations in sows that are euthanized or found dead are extremely important, not only for confirming a diagnosis (Lucia et al., 2000). Necropsy results also play an important role in investigating disease outbreaks and enable producers to develop prophylactic measures (Küker et al., 2018). In addition, by performing necropsies on numerous sows, common causes of death can be determined (Stalder et al., 2004), providing a more precise diagnosis than only relying on assessments performed by the producer or barn staff (Sørensen and Thomsen, 2017; Ala-Kurikka et al., 2019).

However, necropsy procedures are often ignored in sow mortality studies (D'Allaire et al., 1987; Sasaki and Koketsu, 2008) due to lack of interest or time (Sanz et al., 2002). *Post-mortem* (PM) examinations to monitor the animal health on the farm are rarely done (Sasaki and Koketsu, 2008). Necropsies are more often executed when the sow mortality rate increases unexpectedly with higher levels than in previous years (Abiven et al., 1998; Sanz et al., 2002), in the most complicated cases (Ala-Kurikka et al., 2019), or when conducted for research purposes. In situations where the cause of death is easily identified by the producer (e.g., prolapse), PM is rarely performed, which results in a low representation of these cases when assessing mortality levels (Sanz et al., 2007; Stalder et al., 2012).

Besides the producers' lack of interest in routine PM assessment (Sanz et al., 2002), there is a lack of expertise and time to perform on-farm necropsies, which impacts the information available on the reasons why sows die (Bradley et al., 2018). In addition, when PM examinations are mentioned in the scientific literature, there are insufficient details and no explicit descriptions about the procedures, with different researchers commonly following different protocols (Sanz et al., 2002; Ala-Kurikka et al., 2019).

A study conducted in Brazil by Vearick et al. (2008) found that out of 78 sows necropsied, 24 (30.8%) presented with urinary tract infections. In the same year, a study conducted by Engblom et al. (2008a) in Sweden found that of 96 sows necropsied, 48 (50%) sows presented a disease associated with the locomotor system. In both studies, there is a limited description of the details of the necropsy protocols used. Since PM examinations findings among studies can vary, the necropsy procedures should be reported to understand potential sources of variation better. Even better, using a standardized necropsy protocol would reduce variation among investigators, making it easier to evaluate and compare the collected data (Pretzer et al., 2000). This approach will also improve the diagnosis, creating meaningful data and systematically determining the causes of mortality within a herd and across multiple herds (Pretzer et al., 2000; Stalder et al., 2004).

A suitable necropsy protocol was proposed by Pretzer et al. (2000). It includes the processes of history taking (recording sow information such as parity, clinical history, and stage of autolysis); PM techniques, lesion observation (recording all injuries found on the necropsy form); gross organ evaluation (recording changes in size, shape, color, and texture in the organs); tissue collection and preservation (preserve tissues in 10% buffered formalin for at least four days and examine histologically); backfat measurement (at the tenth rib, 6 cm off the midline); and digital imagery (e.g. digital camera). For the dissection stage, specific steps are followed so that no organ is spoiled, improving the final diagnosis (Pretzer et al., 2000).

Therefore, the overall aim of this thesis is to understand better the risk factors and causes of death in Canadian sow herds. Additional goals include to: 1. review existing literature on risk factors related to sow mortality; 2. examine causal factors related to housing, management, and genetics; 3. evaluate culling and removal reasons on Canadian commercial swine herds; 4. develop a simplified sow necropsy procedure to use on-farm for assessment of major causes of death loss.

1.7. Conclusion

Despite the increase in sow removals and the increasing attention that this subject has had received in recent years, there is still relatively little research on the risk factors and causes of sow death in commercial herds. Moreover, no recent data has been published on the Canadian sow herd. Previous studies have suggested that the increase in sow removal is associated with inadequate nutrition, housing, management, genetic, environmental factors, and susceptibility to pathogens. However, these factors do not act in solitude. The factors appear to be associated with each other at different degrees, affecting the animal-based measures (BCS, lameness, and injury). With reduced BCS, increased lameness and number of injuries, sows become more susceptible to the causes of death. For example, a sow housed in group gestation may be subject to more injuries from aggressive encounters due to competition for food, which can reduce her sow BCS, affecting her reproductive capacity and increasing her risk of being removed from the herd for reproductive inefficiency.

Studying reasons for sow removal in Canada can be difficult since a few studies have been conducted on this topic to date, and most North American studies have looked at U.S. herds. Nevertheless, understanding what is causing high mortality and culling rates in Canadian swine herds will economically benefit producers by reducing sow losses, replacement costs, and biosecurity risks, consequently increasing sow longevity and improving sow welfare. To identify the main risk factors and causes of sow mortality and culling is necessary to access and collect farm records. However, the lack of consistent data in farms and the lack of necropsies performance for monitoring herd health are difficulties encountered when studying sow mortality and culling reasons at herd level and at animal level. Hence, implementing standard protocols for observation and assessment of sows and necropsy can facilitate the study of sow mortality and improve animal welfare.

1.8. Objectives

The overall objective of this thesis is to gain a better understanding of risk factors affecting sow mortality in Canadian swine herds and the primary causes of death by collecting information on sow mortality in Canadian herds through an online survey, observing live sows, and performing necropsies on dead sows. Specifically, the research will: 1. survey Canadian sow farms to examine causal factors for sow mortality related to housing, management, and genetics; 2. compare on-farm measures of sow health with mortality losses and removal reasons; 3. develop a simplified sow necropsy procedure to use on-farm for assessment of major causes of death loss; and 4. develop recommendations for improving removal records.

1.9. Hypotheses

Specific hypotheses have been developed regarding farm factors related to sow mortality and causes of death. Based on existing research, it was hypothesized that two farm factors predictive of sow mortality will be:

- Herd size: Herd size has previously been associated with sow mortality (Sanz et al., 2002; Ketchem et al., 2020c). Although the reasons are not clear, mortality rates increased as herd size increased. One hypothesis for this association is that a lower number of farm staff is available per sow in larger herds, leading to failure to observe problems or lack of time to treat sick or injured animals appropriately.
- Housing system: Group housing systems have been associated with higher mortality levels compared to stall housing, primarily due to aggressive interactions (den Hartog et al., 1993; Supakorn et al. 2019a). This trend may change over time as producers adapt their management to group housing, or as sow genetics are modified to produce sows better adapted to group gestation.

Multiple disorders can affect sows during their lifetime, however, the two most important conditions that can cause a reduced longevity in sows are reproductive and locomotor disorders. Therefore, it was hypothesized that the main causes of sow death on Canadian farms are:

- Reproductive disorders (RD): described by different authors as the most common sow removal reason, usually linked to lower parities (Lucia et al., 2000; Stalder et al., 2012; Ketchem et al., 2020b).
- Locomotor disorders (LD): reported as an important cause of sow removal especially for euthanasia lameness, is an important sow health and welfare issue (Sørensen and Thomsen, 2017; Supakorn et al., 2018).

2.0 Chapter 2. Survey of sow mortality and related risks factors on Canadian commercial swine herds

2.1. Abstract

The objective of this study was to collect information regarding sow mortality in Canadian herds from swine producers through an online survey to identify herd level risk factors and causes of sow mortality. A questionnaire was created to assess sow management practices and factors related to sow culling and mortality in Canadian swine herds. The questionnaire was sent to Canadian pork producers in February 2020 through provincial pork organizations in Alberta, Manitoba, Ontario, Quebec, Saskatchewan, and the Maritime provinces (New Scotia, New Brunswick, and Prince Edward Island). One hundred and fifty-seven producers accessed the survey, but only 104 provided complete responses to the 49 questions. The total number of farms that received the questionnaire was approximately 660. This study considered each farm as one experimental unit. Data were analyzed in SAS 9.4 using Pearson correlation coefficients (r, PROC CORR) to identify collinearity between variables and regression analysis (PROC REG and PROC GLM). If $P < 0.05$, differences were considered significant and if $P < 0.10$, trends were noted. Forty-eight percent of respondents had herds of under 500 sows, 34% had 500 to 2,000 sows, and 18% had over 2,000 sows. The majority of farms used stalls gestation (43%), followed by groups (40%) and mixed housing (combination of groups and stalls: 17% – sows are moved to group housing from breeding stalls after confirmation of pregnancy). The average sow mortality per year was 5.7% (range: 2% to 20%), with the average of sow replacement per year of 44% (range: 5% to 65%). The most common reasons for early sow removal in 2019 were poor reproductive performance (60.6%) and lameness (28% sows). A positive relationship was found between herd size and average sow mortality per year ($r = 0.36$; $P = 0.001$) and negative relationship between herd size and average parity at culling ($r = -0.34$; $P = 0.001$). Larger herds were associated with higher mortality rates and lower average parity at culling. The number of barn staff was positive correlated with average sow mortality per year ($r = 0.41$; $P < 0.001$) and replacement rate ($r = 0.30$; $P = 0.002$), and negative correlated to parity at culling ($r = -0.44$; $P < 0.001$) and parity ($r = -33$; $P < 0.001$). The number of barn staff accounted for 17% of the variation in average sow mortality per year ($P < 0.001$). Farms with group housing in gestation showed a higher average sow mortality per year when compared to farms with stall-housing, while mix-housed sows were intermediate ($P < 0.05$). Although necropsy is an important procedure that can provide valuable information regarding unexpected health events, 65% of respondents never perform a necropsy on dead sows. Moreover, results of this survey indicate that larger herds had a higher average sow mortality per year, higher annual sow replacement, and lower average parity.

Keywords: survey, sow mortality, sow removal, sow management, risk factors.

2.2. Introduction

Sow mortality and culling numbers have been increasing in the last decades, and the reasons why sows are removed vary among herds (Keith, 2000). Studies have suggested that the longevity of the sow is constantly challenged by a variety of factors such as genetic selection, diseases, environment (e.g., thermal stress), nutrition (e.g., mycotoxins), and management (e.g., housing system) (Keith, 2000; Díaz et al., 2017; Sørensen and Thomsen, 2017). An increase in sow death losses can lead to decreased performance and reflects poor sow health (Díaz et al., 2017; Supakorn et al., 2019a), causing economic inefficiency and raising animal welfare concerns (Sanz et al., 2007; Stalder et al., 2012). With an annual removal rate of approximately 50% worldwide, sows are often replaced before their third or fourth parity (Engblom et al., 2007; Hoge and Bates, 2011) through culling, sudden death or euthanasia. A high removal rate of low parity sows results in a lower average herd parity, and consequently, a lower level of production and profitability since sows are able to cover their replacement cost at/or around third parity (Stalder et al., 2004; Engblom et al., 2007; Supakorn et al., 2019a). In addition, animals that are found dead must be considered when computing the numbers of animals removed from the herd, as well as euthanized animals, which when present in large numbers can be a sign of poor animal welfare (Engblom et al., 2007).

Higher removal levels can also be associated with a lack of experience in barn staff and a lower ratio of staff to sows. With increasing herd size, the number of workers per animal is likely to decrease (Supakorn et al., 2019a). Therefore, staff working in larger herds may find themselves in a fast-paced environment, not having enough time (or skills and training) to recognize clinical symptoms and to deliver the right intervention (treatment, cull, or euthanize) (Ala-Kurikka et al., 2019; Supakorn et al., 2019b). In addition, records of health events (e.g., clinical symptoms and treatments provided) are collected in different ways since the ability of staff to interpret the signs of the disease vary, and there is no standard protocol to be followed (Ala-Kurikka et al., 2019).

With sow mortality levels increasing over the past 20 years (Supakorn et al., 2019a; Ketchem et al. 2020a), more studies have begun looking into the causes and risks of mortality. Studies conducted in U.S. and EU show high average annual mortality rates, with 10.7% in the U.S. (Supakorn et al., 2019a), 11.3% in Denmark (Sørensen and Thomsen, 2017), and 16% in Hungary (Balogh et al., 2015). However, there are no recent reports on mortality levels or factors related to sow death in Canadian sow herds. Therefore, the objective of this chapter was to collect information regarding sow mortality in Canadian herds from swine producers through an online survey to determine risk factors for sow mortality. It was hypothesized that mortality rates would be higher in farms with larger herds (>2,000 sows) due to the fewer farm staff available per sow. Also, that mortality rates would be higher in farms with sows housed in group gestation due to higher activity levels and aggressive interactions. It was also hypothesized that farms with large herds (>2,000) would have higher removal rates of young animals (average parity 3 or less) (Ketchem et al., 2020a) which leads to an increase in the frequency of adding new gilts to the herd (Pluym et al., 2013a).

2.3. Materials and Methods

This study was approved by the Research Ethics Board of the University of Saskatchewan (Approval number: BEH-1607).

2.3.1. Data collection

An electronic survey was created using the Zoomerang survey program (SurveyMonkey, Palo Alto, CA) and was sent out through provincial pork organizations in January 2020 via email to Canadian pork producers in Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia, and the Maritime provinces. The questionnaire included 49 questions about sow herd management and factors related to sow culling and mortality, divided into three categories: General management factors (23 questions); Herd performance/Performance report (5 questions); and Sow losses (19 questions). The full list of survey questions is included in Appendix A. Survey participation was voluntary and was available from January 2020 to April 2021. The completion of the survey was encouraged by offering a virtual gift card to participants and approximately 660 farms received the questionnaire. Survey responses were extracted from SurveyMonkey as a Microsoft Excel file. The datasets from the provinces were combined in one and 104 producers were selected for further analysis.

2.3.2. Statistical analysis

Each farm was considered as one experimental unit. Descriptive analyses are given as average and frequency (n) with percentage (%) to present variables associated with sow mortality and longevity. The data analyses were performed using the statistical package SAS 9.4 (SAS Institute, Cary, NC, USA). Pearson correlation coefficients (r, PROC CORR) were calculated between variables to identify collinearity; variables with $r = \geq 0.50$ and $P < 0.05$ were considered highly correlated. A separate regression analyses (PROC REG and PROC GLM) for each variable were performed to determine if there was a linear relationship between farm factors and average mortality (%) per year. The effect of gestation housing system on average mortality per year was analyzed using PROC GLM, with least-square means (LSMEANS) of fixed effects compared using Tukey's adjustment. If $P < 0.05$, differences were considered significant and if $P < 0.10$, trends were noted.

2.4. Results

2.4.1. Survey responses

The survey was accessed by 157 producers; among these, 143 started filling out the questionnaire, of which 104 filled out the key questions for the study (related to sow mortality and longevity). For this reason, 53 responses were excluded, and 104 were considered for analysis. The distribution of survey responses by province is shown in Table 2. 1 The highest number of responses was from the province of Quebec (28 respondents), followed by Saskatchewan (27) and Alberta (25). According to "Statistics Canada" (2021), Ontario has the highest number of swine barns, yet only nine farms in Ontario completed the survey. Thus, Ontario farms are not well represented in the survey results.

2.4.2. Descriptive results

The distribution of herd sizes and gestation housing systems are detailed in Table 2. 2. Almost half (50 farms, 48%) of the farms that participated in the survey were farms with herds of less than 500 animals, followed by 35 farms (34%) with herds between 500 and 2,000 sows, and 19 farms (18%) with herds larger than 2,000 sows. Table 2. 3 shows the disease status of herds in Eastern (Maritimes, Ontario, and Quebec) and Western (Alberta, Manitoba, and Saskatchewan) regions. In Eastern provinces, the main reported disease was Porcine Reproductive and Respiratory Syndrome virus (PRRSv), accounting for 40.5% (17 farms) with positive cases, while in Western provinces, the main reported disease was *Streptococcus suis* (*S. suis*), accounting for 51.6% (32 farms) of the positive cases. Space in the survey was provided to list other diseases than those included in the questionnaire, and the most reported disease was Glässer's disease (10 farms).

Table 2. 4 shows the averages of sow replacement per year, mortality per year, sow parity, and sow parity at culling by herd size and province. The overall average sow replacement rate among provinces per year was 44%, with Manitoba exhibiting the highest average (49.8%). The overall average of sow mortality per year was 5.7%, with farms in Alberta and Saskatchewan exhibiting the highest averages (6.1%) while farms in the Maritimes exhibit the

lowest average of sow mortality per year (4%). The lowest average parity was found in Manitoba (2.8), and the highest average parity was found in Quebec (4.5), while the overall average parity among farms was 3.5. The lowest average parity at culling can be seen in Saskatchewan (4.8) and the highest average parity at culling in Quebec (6.9), while the overall average parity at culling among farms was 5.6. The two most common reasons for sow removals (total of culling, euthanasia, and death) reported in 2019 by province were 'old age' (75 farms, 72%) and poor reproductive performance (63 farms, 60.6%) (Table 2. 5) and the two most common observations on dead sows (Table 2. 6) were poor body condition score (35 farms, 33%) and changes in skin color (30 farms, 29%). Blood in urine, lameness, prolapse (uterine, rectal, and vaginal), and twisted organs (seen at necropsy) were other observations on dead sows reported by producers. Table 2.6 also shows the frequencies with which necropsies are performed in each province, with a total of 35% (37 farms) of farms performing a necropsy, either occasionally or frequently, on dead sows.

Table 2. 7 shows a descriptive analysis for farm and production variables. From the 104 surveyed farms, 20 farms did not report the average NPD (84 farms), 8 farms did not report the average parity at culling (96 farms), and 13 farms did not report the annual mortality (91 farms). The lowest average sow mortality per year reported was 2%, and the lowest average parity was 1.66 (Table 2. 7). These values might represent a new herd, thus low average parity and low annual mortality rate are expected.

2.4.3. Statistical results

Table 2. 8 shows the Pearson correlation coefficients comparing the variables associated with sow mortality. The average mortality per year (%) was positively correlated with herd size (r= 0.34; P= 0.001), number of barn staff (r= 0.41; P <0.001), and NPD (r= 0.35; P= 0.002). Also, number of barn staff showed positive correlations with average replacement rate (r= 0.31; P= 0.002), and NPD (r= 0.27; P= 0.014), and negative correlations with parity at culling (r= -0.44; P <0.001) and parity (r= -0.33; P <0.001).

Number of barn staff, herd size and average NPD showed significant and positive relationships with average mortality per year (Table 2. 9). The total number of barn staff accounted for 17% (P<0.001) of variation in average mortality per year, while herd size accounted for 12% (P= 0.001), and NPD accounted for 12% (P= 0.002) of variation in average mortality per year. There was no relationship between average mortality per year and replacement rate, total piglets born per litter (TPB), average parity, or average parity at culling. However, differences among gestation housing system (stalls, mix of stalls and groups, and groups) in average sow mortality per year (%) was found ($P < 0.05$). Sows in group gestation had a higher average mortality per year (%) than sows in stall gestation, while sows in mixed gestation were intermediate (Figure 2. 1).

Table 2. 1 Distribution of sow management and mortality survey responses by Canadian provinces.

	Complete Answers	Incomplete Answers	TOTAL
Alberta	25 (71.4%)	10 (28.6%)	35 (22.3%)
Manitoba	10 (55.5%)	8 (44.5%)	18 (11.5%)
Maritimes	5 (83.3%)	1 (16.7%)	6 (3.8%)
Ontario	9 (75.0%)	3 (25%)	12 (7.6%)
Quebec	28 (53.8%)	24 (46.2%)	52 (33.1%)
Saskatchewan	27 (79.4%)	7 (20.6%)	34 (21.7%)
TOTAL	**104 (66.3%)**	**53 (33.7%)**	**157 (100%)**

Table 2. 2 Distribution of gestation housing systems and herd sizes in surveyed farms in Eastern[1] and Western[2] Canada.

	Herd size	Stall*	Group**	Mixed***	**TOTAL**
Eastern region					
	<500	7	6	8	21 (50.0%)
	500 – 2,000	5	6	4	15 (35.7%)
	>2,000	-	6	-	6 (14.3%)
TOTAL (%)		12 (28.6%)	18 (42.8%)	12 (28.6%)	42 (100%)
Western region					
	<500	19	8	2	29 (46.7%)
	500 – 2,000	10	7	3	20 (32.3%)
	>2,000	3	9	1	13 (21.0%)
TOTAL (%)		32 (51.6%)	24 (38.7%)	6 (9.7%)	62 (100%)
OVERALL TOTAL (%)		**44 (42.3%)**	**42 (40.4%)**	**18 (17.3%)**	**104 (100%)**

[1] Eastern region: Maritimes, Ontario, and Quebec.
[2] Western region: Alberta, Manitoba, and Saskatchewan.
*Stall: gestating sows housed in individual stalls where the animal is confined with the ability to lay down and stand (Morgan et al., 2018).
**Group: gestating sows in groups (4 to 250 sows per group), with various feeding systems (e.g., electronic feeders, floor feeding, free access stalls etc.) and space allowance. Stalls can be used up to 35 days of gestation and space must be provided for separation of dunging from lying and eating areas (NFACC, 2014; Morgan et al., 2018).
***Mixed: farms with both stall and group housing systems. Sows are typically moved to group housing from breeding stalls after confirmation of pregnancy.

Table 2. 3 Disease status (% of affected sow) in Eastern[1] and Western[2] Canadian herds.

	PRRSv [a]	PCV2 [b]	PEDv [c]	Mycoplasma	*S. suis* [d]	Other [e]
Eastern provinces (n=42)						
Positive	17 (40.5%)	12 (28.6%)	-	14 (33.3%)	12 (28.6%)	5 (11.9%)
Negative	22 (52.4%)	18 (42.8%)	37 (88.1%)	24 (57.2%)	19 (45.2%)	11 (26.2%)
Unknown	3 (7.1%)	12 (28.6%)	5 (11.9%)	4 (9.5%)	11 (26.2%)	26 (61.9%)
Western provinces (n=62)						
Positive	7 (11.3%)	27 (43.6%)	4 (6.5%)	6 (9.7%)	32 (51.6%)	19 (30.6%)
Negative	49 (79.0%)	16 (25.8%)	50 (80.6%)	53 (85.5%)	16 (25.8%)	16 (25.8%)
Unknown	6 (9.7%)	19 (30.6%)	8 (12.9%)	3 (4.8%)	14 (22.6%)	27 (43.6%)
TOTAL POSITIVE	24 (23%)	39 (37.5%)	4 (7.7%)	20 (19.2%)	44 (42.3%)	24 (23.0%)

[1] Maritimes, Ontario, and Quebec; 2 Alberta, Manitoba, and Saskatchewan.
[a] PRRSv: Porcine Reproductive and Respiratory Syndrome virus.
[b] PCV2: Porcine Circovirus type 2.
[c] PEDv: Porcine Epidemic Diarrhea virus.
[d] *S. suis*: *Streptococcus suis*.
[e] Other: Actinobacillosis, Bordetellosis, Exudative epidermitis, Glasser's disease, Ileitis, Porcine parvovirus, Rotavirus, *Staphylococcus aureus*.

Table 2. 4 Frequencies and averages of sow replacement per year, average mortality per year, and sow parity at culling by herd size and province.

Province Herd size	n	%	Avg. replacement rate per year (%)	Avg. mortality per year (%)	Avg. parity	Avg. parity at culling
Alberta	**25**	**24.0%**	**43.96**	**6.15**	**3.32**	**5.19**
<500	15	60.0%	41.14	4.44	3.57	5.62
500 – 2,000	6	24.0%	45.50	4.16	2.74	5.50
>2,000	4	16.0%	52.25	13.75	2.87	3.50
Manitoba	**10**	**9.6%**	**49.80**	**5.18**	**2.76**	**5.40**
<500	2	20.0%	37.50	4.00	3.15	7.50
500 – 2,000	6	60.0%	55.00	4.63	2.55	5.06
>2,000	2	20.0%	46.50	8.00	3.00	4.30
Maritimes	**5**	**4.8%**	**40.60**	**4.00**	**3.00**	**5.78**
<500	1	20.0%	30.00	-	3.00	7.00
500 – 2,000	4	80.0%	43.25	4.00	3.00	5.37
>2,000	-	-	-	-		-
Ontario	**9**	**8.7%**	**44.13**	**5.16**	**3.33**	**5.09**
<500	4	44.4%	38.33	3.68	4.00	5.50
500 – 2,000	1	11.1%	30.00	5.70	4.20	6.00
>2,000	4	44.4%	52.00	6.50	2.45	4.45
Quebec	**28**	**26.9%**	**39.11**	**5.35**	**4.45**	**6.93**
<500	16	57.1%	41.25	5.32	4.30	7.17
500 – 2,000	10	35.7%	35.10	5.49	5.02	7.04
>2,000	2	7.1%	42.00	5.00	2.73	4.71
Saskatchewan	**27**	**26.0%**	**47.85**	**6.14**	**2.96**	**4.76**
<500	12	44.4%	47.58	6.37	3.08	5.31
500 – 2,000	8	29.6%	48.00	4.68	2.70	3.75
>2,000	7	25.9%	48.17	7.21	3.07	4.96
OVERALL TOTAL/Avg.	**104**	**100%**	**44.04**	**5.68**	**3.46**	**5.56**
<500	50	48.0%	42.21	5.15	3.68	6.11
500 – 2,000	35	33.7%	43.91	4.74	3.46	5.41
>2,000	19	18.3%	49.01	8.29	2.85	4.45

Table 2. 5 Common sow removal reasons (C, U and D)[1] reported on 104 Canadian farms surveyed in 2020, by province.

Province	n	Poor reproductive performance	Lameness	Injured/downer	Old age	Prolapse[2]	Other[3]
Alberta	25	11 (44.0%)	6 (24.0%)	1 (4.0%)	21 (84.0%)	3 (12.0%)	3 (12.0%)
Manitoba	10	8 (80.0%)	3 (30.0%)	3 (30.0%)	6 (60.0%)	1 (10.0%)	-
Maritimes	5	4 (80.0%)	-	1 (20%)	5 (100%)	-	-
Ontario	9	5 (55.6%)	2 (22.2%)	-	6 (66.6%)	-	1 (11.1%)
Quebec	28	20 (71.4%)	12 (42.8%)	1 (3.6%)	17 (60.7%)	8 (28.6%)	3 (10.7%)
Saskatchewan	27	15 (55.6%)	6 (22.0%)	3 (11.0%)	20 (74.0%)	1 (3.7%)	4 (14.8%)
TOTAL	**104**	**63 (60.6%)**	**29 (28.0%)**	**9 (8.7%)**	**75 (72.0%)**	**13 (12.5%)**	**11 (10.6%)**

[1] C: Culling; E: Euthanasia; D: Death.
[2] Prolapse: vaginal, uterine, and/or rectal.
[3] Other: Difficulty farrowing/retained piglets, intestinal complications, and disease.

Table 2. 6 Common observations on dead sows and frequency of necropsy performance reported on 104 Canadian farms surveyed in 2020, by province.

Province	n	Necropsy[1]	Injury	Poor BCS[a]	Shoulder sore	Skin colour	Other[2]
Alberta	25	9 (36.0%)	6 (24.0%)	6 (24.0%)	1 (4.0%)	7 (28.0%)	8 (32.0%)
Manitoba	10	3 (30.0%)	3 (30.0%)	2 (20.0%)	1 (1.0%)	2 (20.0%)	3 (30.0%)
Maritimes	5	1 (20.0%)	2 (40.0%)	3 (60.0%)	-	2 (40.0%)	2 (40.0%)
Ontario	9	6 (66.6%)	-	1 (11.1%)	1 (11.1%)	2 (22.2%)	3 (33.3%)
Quebec	28	6 (21.4%)	2 (7.1%)	12 (42.8%)	1 (3.6%)	6 (21.4%)	7 (25.0%)
Saskatchewan	27	12 (44.4%)	17 (63.0%)	11 (40.7%)	3 (11.1%)	11 (40.7%)	10 (3.07%)
TOTAL	**104**	**37 (35.6%)**	**25 (24.0%)**	**35 (33.7%)**	**7 (6.7%)**	**30 (28.8%)**	**33 (31.7%)**

[a] BCS: Body condition score.
[1] Necropsy: necropsies performed occasionally or frequently.
[2] Other: Blood in urine, lameness, prolapse (uterine, rectal, and vaginal), and twisted organs.

Table 2. 7 Descriptive statistics for farm and production variables from 104 Canadian sow farms surveyed in 2020.

Variable	n	Mean	Minimum	Maximum	Std Dev	Std Error
Herd size (sows)	104	1,101	500	3,000	852.98	83.64
Barn staff (number)	104	6.22	1	27	5.32	0.52
Avg. replacement per year (%)	102	44	5	65	9.88	0.98
Avg. TPB [1]	103	15	12	18	1.05	0.10
Avg. NPD [2]	84	36	0	88	18.18	1.98
Avg. parity	100	3.5	1.66	9	1.22	0.13
Avg. parity at culling	96	5.6	1	11	1.75	0.18
Avg. sow mortality per year (%)	91	5.7	2	20	3.9	0.41

[1] Avg. TPB: Average total piglets born per litter.
[2] Avg. NPD: Average non-productive days.

Table 2. 8 Pearson correlation coefficients (r) and P-values between farm, production, and mortality variables for 104 Canadian sow herds. Significant correlations ($P < 0.05$) in BOLD.

Variable	Barn staff	Avg. replacement	Avg. TPB[1]	Avg. NPD[2]	Avg. parity at culling	Avg. parity	Avg. sow mortality per year
Herd size	**0.78**	**0.22**	-1.02	**0.37**	**-0.34**	**-0.23**	**0.34**
	<0.001	**0.027**	0.215	**0.001**	**0.001**	**0.020**	**0.001**
Barn staff		**0.31**	-0.03	**0.27**	**-0.44**	**-0.33**	**0.41**
		0.002	0.762	0.014	**<0.001**	**<0.001**	**<0.001**
Avg. replacement			0.03	**0.25**	**-0.31**	**-0.42**	-0.04
			0.741	**0.020**	**0.002**	**<0.001**	0.7
Avg. TPB [1]				0.094	-0.16	**-0.17**	0.11
				0.395	0.120	**0.009**	0.278
Avg. NPD [2]					**-0.24**	**-0.29**	**0.35**
					0.033	**0.007**	**0.002**
Avg. parity at culling						**0.64**	-0.06
						<0.001	0.615
Avg. parity							0.059
							0.57

[1] Avg. TPB: Average total piglets born per litter.
[2] Avg. NPD: Average non-productive days.

Table 2. 9 Linear regression results for the relationships between farm factors and average sow mortality (%) per year. Significant variables (P < 0.05) in BOLD.

Variable	Estimate	n	SE	R sq	T value	P > |t|
Herd size	0.0014	91	0.0004	0.1158	3.41	**0.001**
Barn staff (number)	0.29	91	0.07	0.1692	4.26	**<0.001**
Avg. replacement	-0.017	89	0.0452	0.0017	-0.38	0.704
Avg. TPB[1]	0.435	90	0.399	0.0013	1.09	0.278
Avg. NPD[2]	0.069	75	0.022	0.1207	3.17	**0.002**
Avg. parity	0.231	88	0.416	0.0036	0.56	0.579
Avg. parity at culling	-0.121	85	0.239	0.0030	-0.50	0.615

[1] Avg. TPB: Average total piglets born per litter.
[2] Avg. NPD: Average non-productive days.

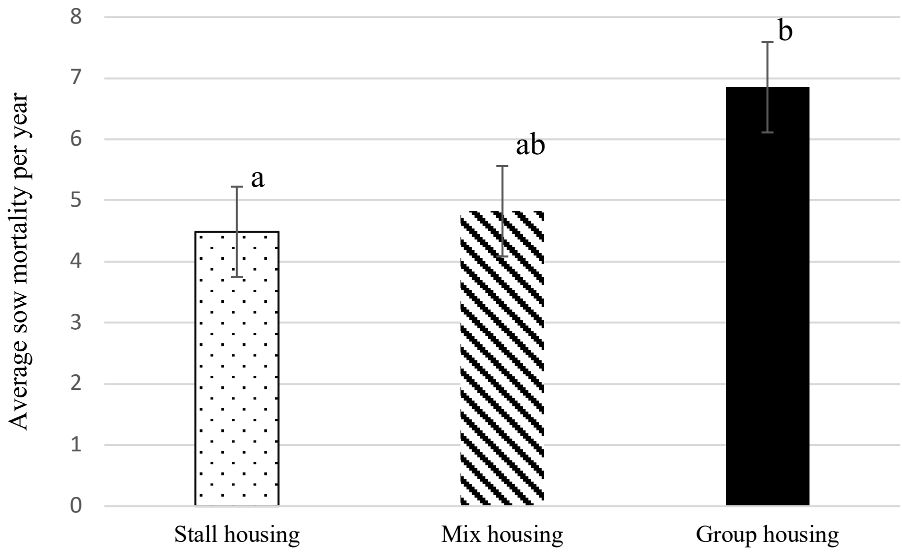

Figure 2. 1 Average sow mortality per year (%, LS means ± SEM) for gestating sows housed in stalls, mixed housing (farms with both stall and group gestation), and group housing. Items with different superscripts differ (P <0.05), post hoc Tukey's test.

2.5. Discussion and conclusion

High mortality and culling rates in sows have become a major focus of study for many researchers. Studies show that sow removal rates vary among herds, and multiple risk factors challenge sow longevity. The size of the herd and housing system are examples of challenging factors, which interact with the number of barn staff per sow and average herd parity, influencing sow health, economic performance, and animal welfare. However, the majority of modern studies in sow mortality and culling rates have looked at U.S. sow herds (Mote et al., 2009; Nikkilä et al., 2013; Chipman et al., 2018), with the most recent study in Canada performed more than three decades ago (Chagnon et al., 1991). Therefore, the results of this study can shed light on understanding what is causing high mortality and removal rates in Canadian sow herds.

Many studies worldwide are trying to unravel what is causing the increase in sow removals since it represents an economic loss for producers and an animal welfare problem. Recent studies in Spain and the U.S. found high annual average sow mortality rates such as 7.1% and 9.1%, respectively (Iida et al., 2019; Kikuti et al., 2020a) while this present study found a moderate average sow mortality of 5.7% per year. Potential causes of this variation in annual sow mortality rates among researches from different countries can be related to genetics, environment, management, housing system, health status, and removal policy. Moreover, the increase in removal rates is likely to be more attributed to management decisions than to welfare issues. Furthermore, it is important to note that some difficulties are faced when conducting a survey, such as not reaching the desired number of respondents and missing answers. For example, out of 104 participating farms, 13 farms did not report average sow mortality per year.

Multiple previous studies (Christensen et al., 1995; Ketchem et al., 2020b; Koketsu, 2000; Stalder et al., 2008) have found that sow mortality rates increase with increasing herd size. The results of this study agree with these findings. The average sow mortality per year reported for large herds (>2,000 sows) was 8.3% and for small herds (<500 sows) was 5.2%. Researchers (Koketsu, 2000; Supakorn et al., 2019a) have suggested that caretaker experience and the number of sows per staff may explain the association between increased sow mortality rates and large herds. Working in a fast-paced environment like large operations, barn staff may not have time to focus on clinical symptoms that sows exhibit or attend to their health status in general (e.g., water and feed intake). In addition, there is often a high employee turnover rate on large farms, which can make it challenging to train staff on new protocols and processes (The Pig Site, 2020; Thompson, 2020). Moreover, it can be stressful for the animals since they must adjust to different employees more frequently. Consequently, treatments or management decisions are not executed in time, and the sow is eventually culled, euthanized, or found dead. However, little literature was found that considered the effect of the number of barn staff available per group of sows (Jensen et al., 2012). The present study found that the number of barn staff showed a stronger correlation and accounted for the highest variation in average sow mortality per year than did farm size.

In recent industry articles, Ketchem et al. (2020a, 2020b, 2020c) point out that in addition to having higher mortality rates, larger herds also had higher removal rates for young sows. This study found a negative correlation between herd size and average parity, which agrees with Ketchem et al. (2020a, 2020b, 2020c) findings, indicating that smaller herds tended to keep sows for a longer time than larger herds (average parity 3.7 vs 2.9 respectively). Similarly, in the descriptive analysis of this study, the average parity at culling decreased as herd size increased (4.5 for large herds and 6.1 for small herds); consequently, larger herds tend to be composed of higher proportions of young sows and gilts.

Another factor linked to the increase in average sow mortality is the housing system in gestation, where sows are kept either individually (in stalls) or in groups. Sows housed in stall gestation are confined in small spaces, having only the mobility to lay down and stand. Living with physical and social restrictions, sows housed in stall gestation have their welfare compromised, tending to exhibit more abnormal behaviors such as bar biting and sham chewing (Johnson et al., 2012; NFACC, 2014; Morgan et al., 2018). For this reason, different countries in the EU, Australia, New Zealand, and several states in the U.S. banned stall gestation or implemented compulsory group housing for some stages (CEC, 2008; Primary Industries Standing Committee, 2008; NAWAC, 2010; National Hog Farmer, 2022). Group gestation provides greater freedom of movement to the sow, allowing the females to express their innate behaviors. However, sows housed in groups are at a higher risk of having aggressive interactions than stall-housed animals. Several recent studies have reported a higher incidence of injuries and mortality in group housing systems (Anil et al., 2009; Jensen et al., 2012; Spoolder and Vermeer, 2015; Supakorn et al., 2019a). In accordance with these studies, this survey found that farms that housed gestating sows in group systems had higher average mortality per year ($P= 0.033$) than sows housed in stalls Figure 2. 1. However, the transition to group gestation is an ongoing process so potentially, as producers learn more about managing group systems, mortality levels will drop off. In addition, the increase in culling numbers of sows with poor leg health may also influence the overall quality of the sows in group gestation. Hence, researchers along with producers are investigating the mortality risks that this type of housing system brings, thus adapting the facilities and the genetics of the animals to achieve a system that operates better, is more profitable, and offers better animal welfare than stall gestation.

Previous studies have also found that season influences sow longevity, indicating that thermal stress can increase mortality rates (Chagnon et al., 1991; Koketsu, 2000; Kikuti et al., 2020b). For instance, in a study conducted in Canada, Chagnon et al. (1991) found higher mortality during the summer months. However, survey respondents in the current study reported no association between seasonality and sow mortality or sow removal rates. This finding might be because, for example, farmers were not aware of the possible effects of the seasonal changes on their animals, or because the surveyed farms follow the guidelines proposed by the Canadian Code of Practice for the Care and Handling of Pigs guidelines (NFACC, 2014) including adequate ventilation, or simply because other dominant factors were contributing to the sow mortality such as pathogens.

Increasing sow mortality can also be linked to various diseases caused by different pathogens. The most frequent diseases reported in the Canadian herds surveyed in this research were *S. suis* (42.3%) and PCV2 (37.5%). *Streptococcus suis* (*S. suis*) is an opportunistic swine pathogen, causing different diseases such as meningitis, arthritis, and endocarditis, and emerging zoonotic diseases among humans (Gottschalk, 2012; Hoa et al., 2013). In addition, *S. suis* can increase the severity of other diseases by acting as a secondary pathogen, such as in combination with PRRSv (Obradovic et al., 2021). Porcine Respiratory and Reproductive Syndrome virus (PRRSv) is a major global disease affecting the swine industry, causing reproductive failure in pregnant sows (Obradovic et al., 2021). In this study, PRRSv was considered the third most common disease in herds (23%) along with ‘other diseases’ (23%). In sows, PCV2 is also associated with reproductive failure causing late-term abortions and stillbirths (Segalés et al., 2012).

Poor reproductive performance was the second most common cause for sow removal in this study (60.6% of respondents), only behind old age (72% of respondents), with lameness being the third most common cause of removal (28% of respondents). Older sows are known to be culled even when they are still prolific, to maintain a desired parity distribution in the herd. This is unwarranted in terms of animal welfare since it involves the removal of otherwise healthy and productive animals. In addition, if more of these older elite females were retained in the herd, producers could voluntarily cull low-performing sows, decreasing the numbers of replacement gilts entering the breeding herd and consequently reducing economic costs and biosecurity risks (Mote et al., 2009). Regarding reproduction performance, reproductive disorders such as prolapse, farrowing failure and abortion can subsequently reduce the reproductive performance of the sow. In this study, only 12.5% of the survey respondents reported prolapse as a cause for sow removal. Furthermore, lameness is not only a condition affecting the locomotor limbs; it can also induce the development of other conditions due to reduced feed intake and changes in postural behavior, such as poor reproductive performance (Iida et al. 2020). However, few studies to date have investigated the relationship between lameness and poor reproductive performance (Iida et al. 2020).

Even though the questionnaire was sent to approximately 660 producers, only 157 (23.8%) producers accessed this survey and 104 (15.7%) producers filled out the key questions (e.g., average sow mortality and average parity of the herd) for the study, which were near the end of the questionnaire. The Amazon gift certificate was an easy compensation to offer and encourage producers to participate in the research, however, there was a lack of control over the distribution of the survey resulting, for example, in low participation rates overall from Ontario producers. In addition to the difficulties involved with the sample of farms participating in the survey and missing responses, other challenges occurred during this study. The Canadian pork industry entered an unprecedented crisis due to the pandemic in 2020. With countless employees across the country testing positive for Covid-19, the pandemic led to temporary closures of packing plants due to different reasons such as the shortage of employees. The closure of packing plants led to overpopulated farms, so animals had to be culled and euthanized, resulting in biosecurity and pollution risks posed by mass carcass disposal, and in an impact on the pig economy (Hein, 2020; Marchant-Forde and Boyle, 2020).

In conclusion, the low number of respondents in this survey makes it difficult to reach clear conclusions. For this reason, it is recommended that future farm surveys be shorter and that key questions are asked at the beginning of the survey, thus avoiding respondent fatigue, and resulting in a larger data sample. Nevertheless, even with such limitations, the present study provides valuable information about sow mortality in Canadian sow herds. It was possible to conclude from the results of this survey that the size of the herd and housing system plays an important role in sow mortality. It was hypothesized that larger herds would have higher average sow mortality, due to the lower number of farm staff available per sow, and a higher removal rate of young animals. The results of this survey suggests that with the increase in herd size, there is an increase in average sow mortality and a decrease in parity of the herd and parity at culling. However, the results are only suggestive and more research on the topic is needed to clearly understand the problem on larger farms. It was also hypothesized that farms with sows housed in group gestation would have higher average sow mortality compared to stall gestation, which was confirmed by the findings in the study. However, since well-trained workers with fundamental skills to detect health problems are essential to maintain a healthy and productive herd, researchers have suggested that the quality of barn staff and management have a greater impact on the longevity and mortality of sows than the housing system itself. Thus, once the risk factors linked to the group gestation are better understood, they can be controlled, and the system can provide better housing conditions for the animals.

3.0 Chapter 3. On-farm evaluation on factors related to sow welfare and mortality

3.1. Abstract

The objective of this study was to visit Canadian commercial sow herds to collect live sow observations and management information on-site in order to explore connections with data obtained in the survey on herd and farm management. Survey participants (Chapter 2) were contacted, and thirteen farms consented to an on-farm visit arranged between November 2020 and June 2021. One team in Quebec (QC) visited 8 farms, and another team in Saskatchewan (SK) visited five farms. The total number of sows observed was 1,389, with 945 in QC and 444 in SK. The females were evaluated based on the animal-based measures used in the Canadian Pork Excellence PigCARE Program, which included body condition (BCS: score 1 to 5), lameness (score 0 to 2), and injury scores (score 0 to 3). Only healthy sows from all production stages (breeding, gestation, and farrowing) were included in the sample. On each farm visited, the researchers observed roughly 2/3 of sows in breeding and gestation and 1/3 in farrowing. This study considered each sow as an experimental unit. Data were analyzed in SAS 9.4 using a weighted Pearson's chi-square to determine relationships among variables. Stall gestation and group gestation were considered as separate categories in the analysis. Forty-six percent of respondents (6 farms) had herds under 500 sows, 22.3% had herds between 500 and 1,000 sows (three farms), and 31.7% had herds over 1,000 sows (four farms). The predominant herd size visited in QC was small herds (<500 sows) (58.1%), and more sows were observed in group gestation (34.8%, 329 sows) compared to other housing systems; in SK, the predominant herd size was mid-size herds (500 – 1,000 sows) (43.4%), and the highest number of sows observed were in stall gestation (30.6%, 136 sows) compared to other housing systems. Body condition score 3 (BCS 3) was the most commonly observed BCS in both provinces (47.9% in QC and 61.5% in SK). Of the 1,389 sows observed, 1,205 (88.8%) sows had no signs of lameness, and 1,003 showed no signs of injury (72.2%). Differences in parity and average mortality were compared among different herd size. Smaller herds had a higher proportion of old sows (parity >5) than large herds (>1,000 sows) (27.6% vs 7.0%, respectively; $P < 0.001$) and large herds had a higher proportion of 'high' mortality levels than mid-size herds (40% vs 32.3%, respectively; $P \leq 0.03$). Overall, Quebec had a higher number of small herds and group gestation units than SK. Smaller herds showed a higher number of old sows, and the highest parity sow (15) was observed on a small farm in Quebec. Group gestation was associated with more lameness than stall gestation, however, sows in breeding had the highest incidence of mild lameness (score 1). Saskatchewan had a higher number of large farms and more stall gestation than QC. Larger farms were associated with higher average sow mortality, and sows in stall gestation showed the highest incidence of mild injury (score 1). Thus, in each type of farm

different welfare problems were observed, and it is evident that larger farms are challenged by higher levels of injury and mortality, while farms with group gestation had higher lameness than stall gestation.

Keywords: on-farm observation, animal-based measures, sow mortality, herd size.

3.2. Introduction

Observation of animals is an important procedure to evaluate their welfare and reduce mortality. With regular observation, barn staff become more aware of sow health conditions and can provide timely treatment (Stalder et al., 2004). The reproductive performance of the farm can be affected by the lack of skills and poor attitudes in staff, with sows having a poor conception rate and litter size (Kraeling and Webel, 2015; Tokareva, 2021). Nearly 30 years ago, den Hartog et al. (1993) mentioned that decreased production levels could be caused by higher levels of aggressive behavior in sow herds and that the "methods of handling and relocating the animals influence their reactions toward humans and toward each other". Supakorn et al. (2019a), in a review study, pointed out three essential skills that a stockperson must have: "good observation skills to identify sows problems, farm management knowledge and skills to solve significant problems, and an active attitude to promptly fix the given problem" (p. 10). In addition, culling and mortality rates are influenced by common management practices delivered by inexperienced labor force (Stalder et al., 2006).

Inaccurate record keeping, lack of data records, lack of expertise and time to conduct necropsies on farms makes it difficult to study risk factors for sow mortality and reasons to retain, cull or euthanize a sow (Knauer et al., 2007; Anil et al., 2008; Stalder et al., 2012; Bradley et al., 2018; Ala-Kurikka et al., 2019). It is estimated that 39% of sow deaths on-farm are of unknown aetiology. Since necropsies are rarely performed on dead sows, many diagnostic conclusions remain undetermined (Mas and Anso, 2021). There are necropsies that are performed on site by the veterinarian in charge of the farm, and there are also those performed when the animal is sent to a pathology laboratory. The latter having a more in-depth look at the animal, providing a more detailed PM examination (Küker et al., 2018). According to Ala-Kurikka et al. (2019), when necropsies are performed, they are usually done following various protocols, which are often not described in sufficient detail. Furthermore, documentation of the circumstances surrounding mortality cases is rarely collected in a standardized way, and the ability of staff to interpret the signs of the disease varies even within the same farm (Ala-Kurikka et al., 2019).

In an observational study, Pluym et al. (2017) discussed the existence of advantages and disadvantages in observational studies. The author described as an advantage the fact that observing animals in their natural location will result in high external validity; however, the disadvantage is that different factors can vary between sows and between herds. Therefore, those studies may have limited power to detect significant differences (Pluym et al., 2017). These limitations can help explain the different results found in different observational studies, especially considering that most researchers do not use standard protocols for observing and evaluating sows and a standardized necropsy procedure (Pretzer et al., 2000; Stalder et al., 2004). On-farm evaluation is necessary as studies on causes of sow mortality are scarce, and their records are often combined, or there is missing information. Moreover, necropsy procedures can potentially identify unexpected health events in a population, allowing early detection of new diseases or even endemic diseases (Küker et al., 2018).

The objectives of this chapter are to observe live sows and perform necropsies on dead sows to better understand the risk factors affecting sow mortality and the primary causes of death in Canadian swine herds. In addition, explore connections between the data found in the live sow observations and the information collected in Chapter 2 on herd and farm management, such as mortality rate, average parity, and herd size. The study also developed and demonstrated a simplified sow necropsy procedure that staff can use on-farm to assess major causes of sow death loss. It was hypothesized that sows housed in group gestation would show a lower BCS and more frequency of lameness and injuries due to the higher number of aggressive encounters caused by competition for food, lying down space, and hierarchy (Morgan et al., 2018). It was also hypothesized that larger herds would show a lower average parity since as the herd size increase, the mortality rate among low-parity sows also increases (Ketchem et al., 2020a).

3.3. Materials and methods

This study was approved by the Research Ethics Board of the University of Saskatchewan (Approval number: 20200017).

3.3.1. Data collection

The on-farm study was conducted in 13 commercial sow barns in Canada (farms selected from the Survey (Chapter 2)) from November 2020 to June 2021. Two researchers visited SK farms and one researcher visited QC farms on different days, following biosecurity protocols outlined by the Canadian Pork Excellence PigSAFE program (Canadian Pork Council, 2018a). A down time of 48-72h between barn visits and specific biosecurity protocols in effect in each farm visited were followed. One team in SK visited five farms, and another team in QC visited 8 farms. The total visit for each farm took approximately 6 hours and included a study overview, a short survey, sow observations in breeding, gestation and farrowing, and necropsy demonstration (when possible).

3.3.1.1. Sow observation

Live sows were evaluated based on the animal-based measures (ABM) used in the Canadian Pork Excellence PigCARE Program (Canadian Pork Council, 2018b), including body condition, lameness, and injury scores. At each farm, approximately 100 sows were observed with roughly 2/3 in breeding and gestation and 1/3 in farrowing (for example: Observe 100 sows, with 67 in breeding/gestation and 33 in farrowing).

In breeding, stall gestation and farrowing, the selection of sows was performed by first identifying the number of sows to be observed in each production stage, then divided by the number of rooms to calculate N (number of sows observed in each room), then sows in every Nth stall were observed. In group pens, a similar method was used to identify pens, and a sample of sows within selected pens was chosen randomly for observation. Only healthy sows were included in the sample (sows undergoing treatment or in hospital stalls/pens were not observed/excluded). The sow's identification number was recorded (using data form: Appendix E) along with parity, production stage (breeding, gestation, or farrowing), and the ABM described below.

The scoring systems used for ABM were modified from those described in the CPE PigCARE program. Body condition scores were adapted from those published by Stalder et al. (2012) and Canadian Pork Council (2018c), using a five-point scoring system (Table 3. 1), ranging from BCS 1 (excessively thin, emaciated) to 5 (excessively fat, obese), and with BCS 3 being the ideal score. For lameness, the scoring systems of Feet First (Zinpro, 2011) and Fogsgaard et al. (2018) were adapted (Table 3. 2). Lameness was scored using a three-point numerical scale (0 for normal, 1 for moderately lame, and 2 for severely lame). For sows housed in stalls, lameness was evaluated based on the standing posture of the sow, in terms of her ability to bear weight evenly on all four legs. The ability to stand up or not was evaluated. In addition, the quality of the hooves and legs (e.g., cracks in the hooves, flat feet, overgrown hooves, and bad leg conformation) were observed, any problems were noted but not scored. For sows in group gestation, lameness was evaluated based on the ability to stand, walk, frequent weight changes, and showing compensatory behaviors such as dipping the head or arching the back. For injury score (Table 3. 3), a three-point scoring system based on severity of the injury was adapted from Canadian Pork Council (2018b) and Fogsgaard et al. (2018). Up to three injuries were recorded per sow based on the type of lesion and severity. Healed injuries (with no redness or signs of infection around the scab) were excluded.

3.3.1.2. Necropsy procedures

The necropsies were executed at the end of the farm visit and within 24 hours of sow death. If no dead sow was present at the time of the visit, cull sows in poor health and not suitable for transport were identified, and euthanasia of up to one animal was requested when possible. Necropsy procedures were performed on 8 animals (four in each province and one animal per farm). The PM procedure performed on sows in SK took approximately two hours per animal and it was performed on-farm, while in QC the sows were sent to an outside laboratory for necropsy.

A decision tree (Appendix F) (adapted from Karriker and Waddell, 2007) was developed to assist producers in sow necropsy procedures in making accurate decisions during necropsies and present a standard method of necropsy. Barn staff member(s) were trained when requested. Necropsy procedures followed a necropsy protocol specific to each situation – euthanasia or sudden death.

For each sow necropsied, the following sow characteristics were recorded: parity, production stage, body condition score, gross external and internal findings, and suspected cause of death (Appendix G) (Pretzer et al., 2000). In addition, obvious external lesions or abscesses, skin lesions, and teeth/dentition signs of wear or infection were recorded. Observations were documented using written records and photographs.

3.3.2. Statistical analysis

For sow observations, each animal was considered as an experimental unit. Descriptive analyses are given as average frequency (n) and percentage (%) to report average parity, BCS, lameness, and injuries overall, by province and according to each production stage. The data analyses were performed using the statistical package SAS 9.4 (SAS Institute, Cary, NC, USA). A Pearson's chi-square (PROC FREQ) test was used to determine if there was a relationship between production stage, province, and herd size with the ABM. If $P < 0.05$, the relationship was considered significant. The chi-square was weighted based on the number of sows per production stage, province, or herd size for each variable (BCS, lameness score, injury score, parity, and average mortality). For frequencies (sow count) less than ‘5’, the Chi squared analysis was not done since it might not be accurate. For sow necropsy data (eight sows originating from eight farms), no analysis was done however, descriptive results are presented.

Table 3. 1 Body Condition Score (BCS)*.

Score	Condition	Description
BCS 1	Excessively thin/Emaciated	Ribs, hips, and backbones are prominent
BCS 2	Moderately thin	Ribs, hips, and backbone can be palpated with slight pressure
BCS 3	Ideal condition	Ribs, hips, and backbone can be palpated with firm pressure but cannot be observed visually
BCS 4	Moderately fat	Ribs, hips, and backbone cannot be palpated
BCS 5	Excessively fat/obese	Ribs, hips, and backbone cannot be palpated

*Adapted from Stalder et al. (2012) and Canadian Pork Council (2018c).

Table 3. 2 Lameness Score*.

Score	Condition	Description
0	Normal	Normal ability to stand and move; symmetrical limb movements using all 4 limbs and feet
1	Moderately lame	The sow shows compromised movement and reluctance to bear weight on affected leg
2	Severely lame	Sow is reluctant to stand and/or walk; movement diminished or difficult; unwillingness to bear weight on affected leg(s); frequent weight shifting, showing compensatory behaviors such as head dipping, or arching the back.

*Adapted from Feet First (Zinpro 2011) and Fogsgaard et al. (2018).

Table 3. 3 Injury Types and Scores. Observers recorded up to two injury types per sow, and the severity of each injury[*].

Injury	Score 1	Score 2
Abscesses or swollen ears	One abscess <2.5cm in diameter, crinkled ear	Multiple abscesses or one abscess >2.5cm in diameter, ear swollen or inflamed
Prolapse	Not applicable	Any vaginal, rectal, or uterine prolapse
Hernia	Hernia skin remains intact, it does not interfere with movement	Impedes sows movement, touches the ground when animal is standing or is an open skin wound with ulceration or evident infection
Shoulder sore	Open wounds or ulcerations on the upper shoulder: superficial and <2cm in diameter	Shoulder wound penetrates skin and/or >2cm in diameter
Laceration	Five or fewer fresh marks, red but do not penetrate the skin	Wounds or injuries in any part of the body that have completely penetrated through the skin and are not healed
Udder lesion	Mild inflammation, asymmetrical udder or swollen mammary glands	Acute inflammation, asymmetrical udder, or severely swollen mammary glands
Vulva lesion	Vulva laceration <1cm long, involving superficial skin layers	Vulva laceration > 1cm long, penetrates skin and is not fully scabbed

[*]Adapted from (Canadian Pork Council 2018b; Fogsgaard et al. 2018).
Score 0: no injuries
Score 3: multiple injuries

3.4. Results

The farm visits occurred between November 2020 and June 2021, with eight farms visited in Quebec (QC) and five farms in Saskatchewan (SK). The total number of animals included in the study was 1,389 (945 sows in QC and 444 sows in SK). The goal was to evaluate 33% in farrowing and 67% in breeding and gestation. Overall, 26% of the observed sows were in farrowing, 46% in gestation and 28% in breeding. Table 3. *4* shows the distribution of sows by herd size and production stage in QC and SK. Small herds (<500 sows) were the predominant herd size in QC (58.1% of farms visited), and mid-size herds (500 – 1,000 sows) were the predominant herd size in SK (43.4% of farms visited). In gestation housing, the system with the highest number of sows observed in QC was group gestation (81.1%, 329 sows), while in SK it was stall gestation (59.6%, 136 sows).

The frequencies and averages of parity, body condition score (BCS), and lameness by herd size and housing system are shown in Table 3. *5*. The overall average parity was 3.3, the overall BCS was 3 (scale from 1 to 5), and the overall average lameness score was 0.16 (scale from 0 to 2) among all farms. The highest average lameness score was observed in group gestation (0.20), followed by breeding (0.19). Comparing different herd sizes, small herds had the highest average lameness score (0.19) while mid-size and large herds were similar (0.14) (Table 3. *5*). Descriptive data for herd size, parity, and BCS from the 1,389 sows observed is presented in Table 3. *6*. The lowest overall average BCS was observed in farrowing, and mid-size herds (500 – 1000) had slightly lower average BCS (2.8) than small or large herds (3.1).

From the 1,389 sows observed, the parity of 18 sows was not recorded (n=1,371). The minimum parity observed was 0 and maximum parity was 15, with the highest observed parity pertaining to a small herd (<500 sows) in QC.

Table 3. 4 Distribution of sows by herd size and production stage in 13 visited farms in Quebec and Saskatchewan.

Province	**Production stage**				TOTAL
Herd size	Breeding	Gestation stall	Gestation group	Farrowing	
Quebec					
<500	205 (65.3%)	72 (100%)	144 (43.8%)	128 (55.7%)	549 (58.1%)
500 – 1,000	42 (13.4%)	-	52 (15.8%)	23 (10.0%)	117 (12.4%)
>1,000	67 (21.3%)	-	133 (40.4%)	79 (34.3%)	279 (29.5%)
TOTAL	314 (33.2%)	72 (7.6%)	329 (34.8%)	230 (24.4%)	945 (100%)
Saskatchewan					
<500	15 (18.3%)	45 (33.0%)	-	30 (22.4%)	90 (20.3%)
500 – 1,000	39 (47.6%)	-	92 (100%)	62 (46.3%)	193 (43.4%)
>1,000	28 (34.2%)	91 (67.0%)	-	42 (31.3%)	161 (36.3%)
TOTAL	82 (18.5%)	136 (30.6%)	92 (20.7%)	134 (30.2%)	444 (100%)
OVERALL TOTAL	**396 (28.0%)**	**208 (15.0%)**	**421 (31.0%)**	**364 (26.0%)**	**1389 (100%)**
<500	220 (55.6%)	117 (56.3%)	144 (34.2%)	158 (43.4%)	639 (46.0%)
500 – 1,000	81 (20.4%)	-	144 (32.2%)	85 (23.4%)	310 (22.3%)
>1,000	95 (24.0%)	91 (46.7%)	133 (31.6%)	121 (33.2%)	440 (31.7%)

Table 3. 5 Frequencies (sow count and % by herd size and production stage) and averages of parity, body condition score (BCS), and lameness score by herd size and production stage in 1,389 observed sows.

Herd size Production stage	n	%	Avg. Parity	Avg. BCS [a]	Avg. Lameness score
<500	**639**	**46.0**	**3.9**	**3.1**	**0.19**
Breeding	220	34.5	4.2	3.1	0.22
Gestation stall	117	18.3	4.0	3.1	0.24
Gestation group	144	22.5	3.0	3.2	0.19
Farrowing	158	24.7	4.1	3.0	0.12
500 – 1,000	**310**	**22.3**	**2.7**	**2.8**	**0.14**
Breeding	81	26.1	2.2	2.8	0.16
Gestation group	144	46.5	2.7	2.8	0.15
Farrowing	85	27.4	3.3	2.7	0.08
>1,000	**440**	**31.7**	**2.7**	**3.1**	**0.14**
Breeding	95	21.6	2.7	3.1	0.16
Gestation stall	91	20.7	2.4	3.1	0.01
Gestation group	133	30.2	2.6	3.3	0.26
Farrowing	121	27.5	3.2	2.9	0.09
OVERALL TOTAL/Avg.	**1,389**	**100**	**3.3**	**3.0**	**0.16**
Breeding	396	28.0	3.5	3.0	0.19
Gestation stall	208	15.0	3.3	3.1	0.14
Gestation group	421	31.0	2.8	3.1	0.20
Farrowing	364	26.0	3.6	2.9	0.10

Table 3. 6 Descriptive statistics for herd size, parity, and body condition score[1] (BCS) from 1,389 observed sows.

Variable	n	Mean	Minimum	Maximum	Std Dev
Herd size (sows)	13	1028	500	2,000	669
Parity	1,371	3.3	0	15	2.34
BCS	1,387	3.0	1	5	0.77

[1]Body condition scores: Scale consists of scores from 1 (emaciated) to 5 (obese) (Canadian Pork Council, 2018c).

3.4.1. Body Condition Score (BCS)

The protocol for evaluating body condition score (BCS) is described in Table 3. 1. Table 3. 7 shows the distribution of sows according to their BCS by province and production stage. A BCS of 3 (ribs, hips, and backbone can be palpated with firm pressure but cannot be observed visually) was the most prevalent BCS in both provinces, accounting for 47.9% (452) of all sows observed in Quebec (QC) and 61.5% (273) of all sows observed in Saskatchewan (SK). A BCS 2 was observed in a higher percentage in SK (24.8%) than QC (18.2%), while sows with BCS 4 were observed in a higher percentage in QC (28.4%) than in SK (12.6%). Two sows in breeding did not have their BCS assessed.

Table 3. 8 shows the Chi square results for differences in BCS, showing significant differences in the prevalence of BCS 2, 3 and 4 across production stages. Farrowing had the highest proportion of thin sows (BCS 2), while stall gestation had the lowest proportion (24.7% vs 9.6% respectively; P <0.001). Body condition score 3 (optimum BCS) was the most prevalent in all production stages, with 47.5 to 69.7% of sows having BCS 3. Fat sows (BCS 4) were more prevalent in group gestation than in other production stages (27.3%; P= 0.027).

Table 3. 9 shows that BCS differed between QC and SK, with significant differences in the proportion of BCS 2, 3 and 4 sows. Saskatchewan had a higher proportion of thin sows (BCS 2) sows than QC (24.8% vs 18.2%, respectively; P <0.01), and also a higher proportion of sows with optimum BCS (score 3) sows than QC (61.5% vs 47.9%, respectively; P <0.001).

Table 3. 10 shows that BCS differed according to herd size, with significant differences in the proportion of sows with BCS 2 and 4. Mid-size herds (500 – 1,000 sows) had the highest proportion of thin sows (BCS 2), while small herds (<500 sows) had the lowest proportion (36.8% vs 15.5%, respectively; P <0.001). Larger herds (>1,000 sows) had the highest proportion of moderately fat sows (BCS 4), while mid-size herds had the lowest proportion (27% vs 13.6%, respectively; P <0.001).

Table 3. 7 Distribution of sows by body condition scores[1] sorted by province and production stage from 1,387 sows observed on 13 Canadian farms (8 farms in Quebec and 5 farms in SK).

Province		**Body condition score**				
Production stage	n	1	2	3	4	5
QC						
Breeding*	313	10 (3.2%)	63 (20.2%)	137 (43.9%)	88 (28.2%)	14 (4.5%)
Gestation stall	72	1 (1.4%)	9 (12.5%)	41 (56.9)	18 (25%)	3 (4.2%)
Gestation group	329	5 (1.5%)	43 (13.1%)	160 48.6%)	109 (33.1%)	12 3.6%)
Farrowing	230	6 (2.6%)	57 (24.8%)	114 (49.6%)	53 (23%)	-
TOTAL	943	22 (2.3%)	172 (18.2%)	452 (47.9%)	268 (28.4%)	29 (3.1%)
SK						
Breeding	82	2 (2.4%)	21 (25.6%)	50 (61%)	9 (11.0%)	-
Gestation stall	136	1 (0.7%)	11 (8.1%)	104 (76.5)	19 (14.0%)	1 (0.7%)
Gestation group	92	1 (1.1%)	45 (48.9%)	40 (43.5%)	6 (6.5%)	-
Farrowing	134	-	33 (24.6%)	79 (59%)	22 (16.4%)	-
TOTAL	444	4 (0.9%)	110 (24.8%)	273 (61.5%)	56 (12.6)	1 (0.2%)

[a] Body condition score: Scale consists of scores from 1 (emaciated) to 5 (obese) (Canadian Pork Council 2018c).
* Two sows from Breeding (QC) did not have their BC evaluated.

Table 3. 8 Frequency (sow count) and percent of body condition scores[1] by production stage analyzed using Pearson's Chi square from 13 Canadian farms.

Body Condition Score	**Production stage**				**df**	**Chi-square**	**P-value**
	Breeding[*] (n= 396)	Gestation (stall) (n= 208)	Gestation (group) (n= 421)	Farrowing (n= 364)			
BCS 1	12 (3.1%)	2 (1.0%)	6 (1.4%)	6 (1.7%)	-	-	-
BCS 2	84 (21.3%)	20 (9.6%)	88 (20.9%)	90 (24.7%)	3	19.406	**<0.001**
BCS 3	187 (47.5%)	145 (69.7%)	200 (47.5%)	193 (53.0%)	3	32.926	**<0.001**
BCS 4	97 (24.6%)	37 (17.8%)	115 (27.3)	75 (20.6%)	3	9.179	**0.027**
BCS 5	14 (3.6%)	4 (1.9%)	12 (2.9%)	-	-	-	-

[a] Body condition score: Scale consists of scores from 1 (emaciated) to 5 (obese) (Canadian Pork Council 2018c).
[*] Two sows from Breeding (QC) did not have their BC evaluated.

Table 3. 9 Frequency (sow count) and percent of body condition scores[1] by province analyzed using Pearson's Chi square from 13 Canadian farms.

Body Condition Score	Province		df	Chi-square	P-value
	Quebec[*] (n= 945)	Saskatchewan (n= 444)			
BCS 1	22 (2.33%)	4 (0.9%)	-	-	-
BCS 2	172 (18.2%)	110 (24.8%)	1	7.959	**<0.01**
BCS 3	452 (47.9%)	273 (61.5%)	1	22.229	**<0.001**
BCS 4	268 (28.4%)	56 (12.6%)	1	42.132	**<0.001**
BCS 5	29 (3.1%)	1 (0.2%)	-	-	-

[a] Body condition score: Scale consists of scores from 1 (emaciated) to 5 (obese) (Canadian Pork Council, 2018c).
[*] Two sows from Breeding (QC) did not have their BC evaluated.

Table 3. 10 Frequency (sow count) and percent of body condition scores[1] by herd size analyzed using Pearson's Chi square from 13 Canadian farms.

Body Condition Score [a]	Herd size[*]			df	Chi-square	P-value
	<500 (n= 638)	500 – 1,000 (n= 310)	>1,0000 (n= 439)			
BCS 1	18 (2.8%)	1 (0.3%)	7 (1.6%)	-	-	-
BCS 2	99 (15.5%)	114 (36.8%)	69 (15.7%)	2	66.641	**<0.001**
BCS 3	340 (53.3%)	152 (49.0%)	233 (53.0%)	2	1.683	0.431
BCS 4	163 (25.6%)	42 (13.6%)	119 (27.0%)	2	21.819	**<0.001**
BCS 5	18 (2.8)	1 (0.3%)	11 (2.5%)	-	-	-

[a] Body condition score: Scale consists of scores from 1 (emaciated) to 5 (obese) (Canadian Pork Council, 2018c).
[*] One sow from small herds (<500 sows) and one sow from large herds (>1,000 sows) did not have their BCS evaluated.

3.4.2. Lameness Score

The frequency and percentage of lameness by province and production stage is shown in Table 3. 11. From the 1,389 sows observed, 1,205 sows were classified with a lameness score of 0, with 781 (82.8%) in Quebec and 424 (95.5%) in Saskatchewan. One-hundred and thirty-eight (10.0%) sows presented lameness score 1, showing signs of locomotor difficulties in at least one leg and reluctance to bear weight on the same leg. Out of these 138 sows, 121 sows were from QC where 49 sows were housed in breeding, 42 sows in gestation group, 19 sows in farrowing, and 11 sows in gestation stall. Seventeen sows with lameness score 1 were from SK, where 7 sows were housed in gestation group, 6 sows in breeding, 2 sows in gestation stall, and 2 sows in farrowing Moreover, forty-five (3.2%) sows were evaluated with lameness score 2. Out of these 45 sows, 42 were from QC and 3 from SK.

Table 3. 12 shows differences in lameness score among production stages, with significant differences in lameness scores 0 and 1. Breeding had the lowest proportion of lameness score 0 (normal gait) and farrowing the highest proportion (83.3% vs 92.0% respectively; P <0.001). Consequently, lameness score 1 was most prevalent in breeding (13.9%), with farrowing having the lowest prevalence at 5.8% (P <0.001). Table 3. 13 shows differences in lameness scores 0 and 1 between QC and SK. Quebec had the highest proportion of lameness score 1 (12.8%; P <0.001) while SK had highest incidence of lameness score 0 (95.5%; P <0.001). There was no difference in lameness score among herd size (P >0.05).

Table 3. 11 Distribution of sows by lameness score[1] by province and production stage from 13 Canadian farms.

Province			**Lameness score**		
	Production stage	n	0	1	2
QC					
	Breeding*	313	254 (81.2%)	49 (15.7%)	10 (3.2%)
	Gestation stall	72	53 (73.6%)	11 (15.4%)	8 (11.0%)
	Gestation group	329	269 (81.8%)	42 (12.8%)	18 (5.5%)
	Farrowing	230	205 (90.0%)	19 (8.2%)	6 (2.6%)
TOTAL		943	781 (82.8%)	121 (12.8%)	42 (4.5%)
SK					
	Breeding	82	75 (91.5%)	6 (7.3%)	1 (1.2%)
	Gestation stall	136	134 (85.5%)	2 (1.5%)	-
	Gestation group	92	85 (92.4%)	7 (7.6%)	-
	Farrowing	134	130 (97.0%)	2 (1.5%)	2 (1.5%)
TOTAL		444	424 (95.5%)	17 (3.8%)	3 (0.7%)

[1] Lameness score: Scale consists of score from 0 (normal) to 2 (severely lame) (Zinpro, 2011).
*One sow in breeding did not have her lameness score evaluated.

Table 3. 12 Frequency (sow count) and percent of lameness scores[1] by production stage for analyzed using Pearson's Chi square from 13 Canadian farms.

Lameness score	**Production stage**				**df**	**Chi-square**	**p-value**
	Breeding* (n= 395)	Gestation (stall) (n= 208)	Gestation (group) (n= 421)	Farrowing (n= 364)			
Lameness score 0	329 (83.3%)	187 (89.9%)	354 (84.1%)	335 (92.0%)	3	17.418	**<0.001**
Lameness score 1	55 (13.9%)	13 (6.2%)	49 (11.6%)	21 (5.8%)	3	18.594	**<0.001**
Lameness score 2	11 (2.8%)	8 (3.8%)	18 (4.3%)	8 (2.2%)	-	-	-

[1] Lameness score: Scale consists of score from 0 (normal) to 2 (severely lame) (Zinpro, 2011).
*One sow in breeding did not have her lameness score evaluated.

Table 3. 13 Frequency (sow count) and percent of lameness scores[1] by province for analyzed using Pearson's Chi square from 13 Canadian farms.

Lameness Score	**Province**		**df**	**Chi-square**	**P-value**
	Quebec (n= 945)	Saskatchewan (n= 444)			
Lameness score 0	781 (82.7%)	424 (95.5%)	1	42.971	**<0.001**
Lameness score 1	121 (12.8%)	17 (3.8%)	1	27.250	**<0.001**
Lameness score 2	42 (4.5%)	3 (0.7%)	-	-	-

[1] Lameness score: Scale consists of score from 0 (normal) to 2 (severely lame) (Zinpro, 2011).

3.4.3. Injury score

A description of the data collected, and the frequency of injuries is presented in Table 3. 14. A total of 385 sows reported at least one injury, with 67.0% (258 sows) of the sows presenting laceration, 9.3% (36 sows) presenting shoulder sore, and 9.0% (35 sows) presenting an abscess. Shoulder sore appeared in greater numbers in farrowing (13 sows) and gestation stalls (9 sows). Group gestation was the housing system with the highest number of injuries in Quebec, accounting for 50.3% (92 sows), and gestation stall was the housing system with the highest number of injuries in Saskatchewan, accounting for 28.7% (58 sows). Seventy-seven sows also presented a second injury, and the most common injury found was laceration (45 sows), occurring mostly in breeding (13 sows) and farrowing (13 sows). Healed injuries (with no redness or signs of infection around the scab) were excluded from the observed injuries.

Table 3. 15 show that injury score differs among production stages, with significant differences in injury score 0 and 1. Stall gestation had the lowest incidence of injury score 0 (no injury) and breeding the highest (65.9% vs 79.0% respectively; $P < 0.001$). Consequently, injury score 1 was most prevalent in stall gestation (30.8%), with breeding having the lowest incidence at 16.8% ($P < 0.001$).

Table 3. 16 show that injury score differs between QC and SK, with significant differences in injury scores 0 and 1 based on the province ($P < 0.001$). Quebec had the lowest incidence of injury score 1 and SK the highest (14.7% vs 40.3% respectively; $P < 0.001$). Conversely, QC had the highest incidence of injury score 0 (no injury) (80.7%; $P < 0.001$). Table 3. 17 shows that injury scores differ according to herd size, with significant differences in injury scores 0 and 1. Small size herds (<500 sows) had the highest incidence of injury score 0 (78.2%; $P < 0.001$). Mid-size herds (500 – 1,000 sows) had the highest incidence of injury scores 1 (29.7%; $P < 0.001$).

Table 3. 14 Distribution of injury by province and production stage.

Province	Injury[1]					TOTAL
Production stage	Abscess	Laceration	Shoulder sore	Udder lesion	Vulva lesion	
QC						
Breeding	8 (20.0%)	22 (55.0%)	-	7 (17.5%)	3 (7.5%)	40 (21.8%)
Gestation stall	2 (14.3%)	11 (78.6%)	-	1 (7.1%)	-	14 (7.6%)
Gestation group	7 (7.6%)	73 (79.3%)	2 (2.2%)	5 (5.4%)	4 (4.3%)	92 (50.3%)
Farrowing	7 (18.9%)	15 (40.5%)	5 (13.5%)	7 (18.9%)	3 (8.1%)	37 (2.3%)
TOTAL	24 (13.1%)	121 (66.1%)	7 (3.8%)	20 (10.9%)	10 (5.5%)	183 (100%)
SK						
Breeding	3 (7.0%)	30 (69.8%)	6 (14.0%)	2 (4.7%)	2 (4.7%)	43 (21.3%)
Gestation stall	4 (7.0%)	43 (74.0%)	9 (15.5%)	1 (1.7%)	1 (1.7%)	58 (28.7%)
Gestation group	1 (2.2%)	34 (75.6%)	6 (13.3%)	2 (4.4%)	3 (6.7%)	45 (22.2%)
Farrowing	3 (5.4%)	30 (53.6%)	8 (14.3%)	4 (7.1%)	11 (19.6%)	56 (27.8%)
TOTAL	11 (5.4%)	137 (67.7%)	29 (14.2%)	9 (4.3%)	17 (8.4%)	202 (100%)
OVERALL TOTAL	**35 (9.0%)**	**258 (67.0%)**	**36 (9.3%)**	**29 (7.5%)**	**27 (7.0%)**	**385**

[1] One sow in gestation group in QC presented prolapse.
[a] 2nd injury: sows presenting a secondary injury.

Table 3. 15 Frequency (sow count) and percent of injury scores[1] by production stage for analyzed using Pearson's Chi square from 13 Canadian farms.

Injury score	Production stage				df	Chi-square	P-value
	Breeding (n= 396)	Gestation (stall) (n= 208)	Gestation (group) (n= 421)	Farrowing (n= 364)			
Injury score 0	313 (79.0%)	137 (65.9%)	279 (66.3%)	268 (73.6%)	3	20.817	**<0.001**
Injury score 1	64 (16.4%)	64 (30.8%)	116 (27.5%)	73 (20.0%)	3	23.566	**<0.001**
Injury score 2	18 (4.5%)	7 (3.4%)	25 (5.9%)	20 (5.5%)	-	-	-
Injury score 3	-	-	1 (0.2%)	3 (0.8%)	-	-	-

[1] Injury score: Scale consists of score from 0 (no injury) to 3 (multiple injuries) (Canadian Pork Council, 2018b; Fogsgaard et al., 2018).

Table 3. 16 Frequency (sow count) and percent of injury scores[1] by province for analyzed using Pearson's Chi square from 13 Canadian farms.

Injury Score	Province		df	Chi-square	P-value
	Quebec (n= 945)	Saskatchewan (n= 444)			
Injury score 0	763 (80.7%)	234 (52.7%)	1	117.228	**<0.001**
Injury score 1	139 (14.7%)	179 (40.3%)	1	112.2	**<0.001**
Injury score 2	43 (4.5%)	27 (6.1%)	1	1.479	0.224
Injury score 3	-	4 (0.9%)	-	-	-

[1] Injury score: Scale consists of score from 0 (no injury) to 3 (multiple injuries) (Canadian Pork Council, 2018b; Fogsgaard et al., 2018).

Table 3. 17 Frequency (sow count) and percent of injury scores[1] by herd size for analyzed using Pearson's Chi square from 13 Canadian farms.

Injury score [1]	Herd size			df	Chi-square	P-value
	< 500 (n= 639)	500 – 1,000 (n= 310)	> 1,000 (n= 440)			
Injury score 0	500 (78.2%)	193 (62.3%)	304 (69.0%)	2	28.639	**<0.001**
Injury score 1	114 (17.8%)	92 (29.7%)	112 (25.4%)	2	18.959	**<0.001**
Injury score 2	25 (3.9%)	21 (6.8%)	24 (5.4%)	2	3.804	0.149
Injury score 3	-	4 (1.3%)	-	-	-	-

[1] Injury score: Scale consists of score from 0 (no injury) to 3 (multiple injuries) (Canadian Pork Council, 2018b; Fogsgaard et al., 2018).

3.4.4. Parity distribution and average mortality by herd size

Parity distribution was affected by herd size, which can be seen in Table 3. 18, with significant differences in all groups of parities (young, mid-age and old sows) based on herd size (P <0.05). Smaller herds (<500 sows) had the highest proportion of old sows (27.6%; P <0.001), larger herds (>1,000 sows) had the highest proportion of mid-age sows (46.7%; P= 0.004), and mid-size herds (500 – 1,000) had the highest proportion of young sows in the herd (53.2%; P <0.001). In addition, herd size affected average mortality (Table 3. 19). Average mortality was categorized into three groups that were derived from different mortalities rates found in other studies (Chagnon et al., 1991; Koketsu 2000; Bergman et al., 2019; Supakorn et al., 2019b). The three established groups were acceptable (average mortality < 4), moderate (average mortality > 4 – < 6), and high (average mortality > 6). Larger herds had the highest incidence of 'moderate' and 'high' mortality (with no large herds in the acceptable category). Small herds had the highest proportion of acceptable mortality (small herds: 61.5% compared to mid-size herds: 37.7%; P <0.001), and no small herds were in the high mortality category.

Table 3. 18 Frequency (sow count) and percent of parity groups [1] by herd size for analyzed using Pearson's Chi square from 13 Canadian farms.

Parity category	**Herd size**			**df**	**Chi-square**	**P-value**
	<500	500 – 1,000	>1,000			
Young	223 (35.3%)	165 (53.2)	199 (46.3%)	2	30.228	**<0.001**
Mid age	234 (37.1%)	118 (38.1%)	201 (46.7%)	2	10.775	**0.004**
Old	174 (27.6%)	27 (8.7%)	30 (7.0%)	2	96.4	**<0.001**

[1] Parity groups: young (parity 0 – 2), mid age (parity 3 – 5), and old (parity > 5).

Table 3. 19 Frequency (sow count) and percent of average mortality[1] by herd size for analyzed using Pearson's Chi square from 13 Canadian farms.

Average mortality	**Herd size***			**df**	**Chi-square**	**P-value**
	<500	500 – 1,000	>1,000			
Acceptable	339 (61.5%)	117 (37.7%)	-	1	45.042	**<0.001**
Moderate	212 (38.5%)	93 (30.0%)	264 (60.0%)	2	77.263	**<0.001**
High	-	100 (32.3%)	176 (40.0%)	1	4.686	**0.030**

[1] Average mortality: acceptable (avg. mort. ≤4), moderate (avg. mort. >4 – ≤6), and high (avg. mort. >6) (Chagnon et al., 1991; Koketsu, 2000; Bergman et al., 2019; Supakorn et al., 2019b).

* Herd size: no herds greater than 1,000 sows with acceptable mortality and no herds with <500 sows with high mortality.

3.4.5. Necropsies

A description of the 8 sows necropsied is presented in Table 3. 20. Of all sows necropsied, three sows were found dead, and five were euthanized. Sows from Quebec farms were sent to an outside laboratory for post-mortem (PM) assessment, while for sows in Saskatchewan, the PM was performed on-site by researchers. Of all animals, one sow was in farrowing stage, and seven sows were in the gestation stage. Four sows presented external and internal gross findings related to the locomotor system (sow 2, 3, 4, and 6), and were removed from the herd by euthanasia (captive bolt). The pathogen *Trueperella pyogenes* was isolated from sows 2, 3 and 4. Sow 1, 5, and 8 died from acute or sudden death.

The cause of death of sow 1 was uterine prolapse, and the necropsy findings indicated that there was no other abnormality happening with the sow that could have led her to death. The reason for euthanasia of sows 2, 3, 4, and 6 was locomotor disorder. Sow 2 presented arthritis with an abscess in the femorotibial joint of the left hind limb (LHL); sow 3 presented a large abscess (15cm) in the dorsal aspect of the carpus of the left front limb (LFL). The sow 4 presented severe arthritis in the LFL, with multiple abscesses in the body (left and right shoulder joints; carpus and digit areas of LFL; and lumbar spine). Sow 6 was gestating and showing clinical symptoms of lameness, an euthanasia was performed followed by a C-section. At the necropsy, an abscess was found in the right hind limb (RHL) and areas of inflammation in LHL and left thigh of the sow 6.

Sow 5 was described as doing well all day, with no clinical symptoms and dying from acute death. At necropsy, a perforation was found on the intestine with a large accumulation of fluid in the abdominal cavity, but no reason for the perforation was found. Sow 7 was off feed for two days, and at necropsy, redness was observed in the non-glandular stomach (pars oesophagea), suggesting a gastro-intestinal disorder. Sow 8 had a BCS 4 and died during farrowing. Since no other abnormality was found at necropsy besides redness in the bladder, it can be suggested that the sow had complications during farrowing possibly relating to her BCS. Producers did not provide sow characteristics and pre-mortem circumstances for all sows, and BCS was not collected in QC. Tissue or other material samples were not collected from the sows necropsied in SK. Pictures of the necropsy procedure for sows necropsied in SK were taken using a digital camera for further assessment (Stylus TG-860, Olympus Imaging America Inc., Center Valley, PA, USA).

Table 3. 20 Characteristics and post-mortem findings of eight sows from four Quebec (QC) and Saskatchewan (SK) farms.

		Parity	Stage [a]	BCS [b]	Type [c]	External gross findings	Internal gross findings
QC	Sow 1	5	G	-	D	Prolapse	Uterine prolapse
	Sow 2	1	G	-	U	Not able to stand	Arthritis and endometritis; abscess in LHL [d]
	Sow 3	1	G	-	U	15 cm abscess on LFL [e]	Large subcutaneous abscess on LFL
	Sow 4	-	F	-	U	Not able to stand	Severe arthritis in LFL, endocarditis, pleurisy
SK	Sow 5	5	G	3	D	Acute death	Puncture in intestinal wall, content found in abdominal cavity
	Sow 6	0	G	3	U	Swollen RHL [f]	Abscess in RHL; LHL and hip area inflamed
	Sow 7	5	G	1	U	Off feed for two days	Slight redness found in stomach
	Sow 8	1	G	4	D	Blood in urine	Redness in bladder

[a] Stage: stage of production (B: breeding, G: gestation, F: farrowing).
[b] BCS: body condition score.
[c] Type: type of removal (D: sudden death, U: euthanasia).
[d] LHL: left hind lim.
[e] LFL: left fore-limb.
[f] RHL: right hind limb.

3.5. Discussion and conclusion

Sow observation is an important procedure for evaluating sow welfare and reducing sow mortality and culling rates. Well-trained barn staff with good animal observation skills, and good animal-human relationships, are crucial characteristics when assessing animal welfare (Winkel et al., 2020; Tokareva, 2021). Furthermore, once employees become aware of the animal health conditions, they can provide timely treatment (Stalder et al., 2008). However, as discussed in Chapter 2, employees with little time and/or limited training is associated with higher sow mortality and culling rates. Moreover, necropsy in sows that have been euthanized or found dead is an important and fundamental practice for reducing mortality and culling. By identifying causes of death, detecting new diseases to the herd, common biological factors or endemic disease, necropsy examinations provide additional information about the health of the animals at herd level and at individual level (Stalder et al., 2004; Sørensen and Thomsen, 2017; Ala-Kurikka et al., 2019). To the explore relationships between farm factors, animal-based welfare measures and mortality levels, the present study collected information from live sows observed on-farm and necropsy observations on sows euthanized or found dead.

One hypothesis in this study was that sows in group gestation would have lower BCS, and higher incidence of lameness and injury due to the hierarchy developed in this system. With dominant sows tending to consume more feed than subordinate sows, it becomes difficult to uniformly control the BCS and weight gain of the herd (Kraeling and Webel, 2015). Moreover, aggressive interactions in the gestation group can potentially increase the risk of injury and lameness, leading to a lower feed intake (FI). Thus, with the reduction of FI, a lower BCS is expected in those sows. According to Jensen et al. (2012), solid floors found in group housing, vulva biting, and lower BCS in the lactation unit were associated with increased sow mortality. Solid floors are more likely to be more slippery than other types of floors (e.g., slatted floors) since they are easily covered with faeces and urine, leading to a higher risk of trauma due to falling and infection (e.g., *Mycoplasma hyosynoviae* and *Trueperella pyogenes*) (Done et al., 2012; Jensen et al., 2012). In this study, differences in BCS were found across different production stages; sows in farrowing had the highest proportion of BCS 2 (thin sows) while sows in group gestation had the highest proportion of BCS 4 (fat sows). In addition, the highest incidence of lameness score 1 was found in breeding and the highest incidence of injury score 1 was found in stall gestation. Thus, the hypothesis that group gestation would present lower BCS, higher incidence of lameness and injury scores than other stages is not supported.

Even though BCS 3 (optimum BCS – ribs, hips, and backbone can be palpated with firm pressure, but cannot be observed visually) was the main score in both provinces, differences in

BCS were found between Quebec (QC) and Saskatchewan (SK). Saskatchewan had a higher proportion of thin sows while QC had a higher proportion of fat sows. It is important to note that the main housing system in QC was group gestation and in SK stall gestation. Thus, considering the findings in QC and SK related to BCS, the hypothesis that group gestation would result in a lower BCS was not met.

Different authors have suggested that as herd size increases, mortality rates increase (Sanz et al., 2002; Sasaki and Koketsu, 2008; Stalder et al., 2008; Díaz et al., 2015). In Chapter 3 of this study, larger herds (>1,000 sows) had a higher prevalence of 'high' mortality levels (annual mortality >6%) compared to mid-size herds (500 – 1,000 sows) and small herds (>500 sows) which sowed a greater prevalence of 'moderate' mortality (annual mortality ≤4%). These findings are in agreement with previous results reported by Ketchem et al. (2020a, 2020b), where the author observed that larger farms (5,000 to 5,990 sows) had a higher death loss (12.4%). With larger herds, management challenges are expected such as high staff turnover, greater number of sows per barn staff, and employee's lack of training/knowledge, which can result in unskilled workers, making it difficult to identify clinical symptoms in sick sows, resulting in higher mortality rates (Díaz et al., 2015; Supakorn et al., 2019a). In addition to the increase in mortality rates, different authors have suggested that as herd size increases, average parity decreases (Christensen et al., 1995; Koketsu, 2000; Stalder et al., 2008; Supakorn et al., 2019a; Ketchem et al., 2020b). In this study, mid-size herds had the highest prevalence of young sows (mid-size herds: 35.3% vs small herds: 53.2%, large herds: 46.3%; P <0.001).

Thus, considering that employees may lack time, training, and knowledge in large herds, it was hypothesized that larger herds would present a higher incidence of 'high' (>6%) average sow mortality rate and a higher prevalence of young sows (parity 0 – 2). The hypothesis was partially supported since an increase in average sow mortality was noted in large herds however, the highest prevalence of young sows was observed in mid-size herds. Additionally, it was also hypothesized that a lower BCS, higher prevalence of lameness and injuries would be found in larger herds. Mid-size herds (500 – 1,000 sows) had the highest proportion of thin sows and the highest proportion of injury score 1. In contrast, large herds (>1,000 sows) had the highest proportion of fat sows. Thus, the prevalence of fat sows in larger herds and the highest incidence of injury score 1 in mid-size herds does not support the hypothesis; moreover, lameness score had no difference among herd size. Thus, large herds presented an increase in average sow mortality but did not show an increase in injury and lameness, and a decrease in average parity and BCS.

The differences found between SK and QC may also be the result from interobserver variation in the interpretation of the scoring systems. With Covid-19 restrictions, it was not possible to conduct any training between the two teams with live observations. Instead, we relied on clear definitions and digital images of example scores and sow appearance.

In addition to the importance of performing live sow observations to reduce sow culling and mortality (Stalder et al., 2008), necropsy performance of sows found dead or euthanized is a valuable tool. Necropsies not only can confirm a diagnosis (Lucia et al., 2000) but also are important in investigating disease outbreaks (Küker et al., 2018) and identifying causes of death (Stalder et al., 2004). Moreover, PM procedures are of utmost importance in herds with a high mortality rate (Ala-Kurikka et al., 2019). However, PM procedures are often ignored due to the employer's lack of interest or time (Sanz et al., 2002). Therefore, the purpose of performing PM in dead sows was to demonstrate how to use the necropsy tree to employees in a way that can be implemented in the herd routine. With the impossibility to visit farms in other provinces and the occurrence of outbreaks or biosecurity concerns due to Covid-19, we were unable to travel to other provinces, and necropsies of dead sows were performed only in the provinces where teams participating in the research were located (Quebec and Saskatchewan). Eight sows were necropsies. Four sows in SK were necropsied on-farm with the purpose of performing a necropsy to demonstrate how to use the necropsy tree to barn staff. The four sows necropsied in QC were sent to an outside laboratory for PM assessment. Three sows were found dead, and five were euthanized of all sows necropsied. One was in farrowing, and 7 sows were in gestation.

Four sows presented external and internal gross findings related to the locomotor system, and they were removed from the herd by euthanasia. Locomotor disorder is a very common reason for euthanasia (Jensen et al., 2012; Sørensen and Thomsen, 2017; Supakorn et al., 2019a), with different studies referring to locomotion disorders as the main reason for removal (Pluym et al., 2013a; Ala-Kurikka et al., 2019). In this study, sow 2 was affected with arthritis in the femorotibial joint of the left hind limb (LHL); sow 3 had numerous cracks in her footpads of all four limbs; sow 4 presented severe arthritis in the LFL. In addition, sow 2, 3, and 4 presented abscesses in their affected limbs and the pathogen *Trueperella pyogenes* was isolated. *Trueperella pyogenes* is an opportunistic pathogen associated with disorders of the musculoskeletal system, including inflammatory polyarthritis and fractures and degenerative joint disease by causing purulent infections (Jarosz et al., 2014). Sow 6 was gestating and had clinical symptoms of lameness. Thus, a C-section was performed, followed by euthanasia. At the necropsy, an abscess was found in the right hind limb (RHL) and areas of inflammation in LHL and left thigh of the sow 6, but no samples were collected from the sow.

Four of the eight sows necropsied died from acute or sudden death. Sows that die without assistance often die due to reproductive circumstances and gastrointestinal problems (e.g., torsion and ulcers) (Sørensen and Thomsen, 2017; Ala-Kurikka et al., 2019). Frequently animals that are found dead are apparently healthy, with nonspecific premonitory clinical signs (Sanz et al., 2007; Stalder et al., 2012), or medical treatment was deferred (Ala-Kurikka et al., 2019), which suggests that clinical signs may have been ignored or misunderstood. Sow 1 presented a prolapse. At the necropsy, no other findings were observed. Sow 5 was described as doing well all day. At necropsy, a perforation was found on the intestine with liquid on the abdomen cavity. Sow 7 was off feed for two days, at necropsy, a redness area was found in the non-glandular stomach (pars oesophagea). Sow 8 was scored with a body condition 4 and died during farrowing. At necropsy, a redness was found in the bladder.

In conclusion, when comparing sows housed in gestation systems, sows housed in group had a higher incidence of lameness than sows housed in stall gestation, and sows in stall gestation had a higher incidence of injuries. Although a higher incidence of lameness was observed in group gestation, it is essential to consider that sows confined in stalls not only have a physical limitation but also a social limitation. Furthermore, it should be considered that it is easier to assess lameness in sows housed in groups since it is possible to observe them in movement. Saskatchewan had a higher number of large farms and more stall gestation than QC. Moreover, larger farms were associated with higher average sow mortality. Although only 8 necropsies were performed on this phase of the research due to the impact of the Covid-19 pandemic, necropsies are critical to help understand mortality in the herd by confirming diagnoses, investigating disease outbreaks, and developing prophylactic measures. When combined with live sow observations, facilitates the control of mortality rates and herd health status.

4.0 Chapter 4. Overall discussion

4.1. Discussion

With the significant increase in mortality and culling rates over the last two decades, more research is being conducted to understand what is affecting sow longevity (Supakorn et al., 2019a; Ketchem et al., 2020a). Whilst there is research in this area, it is a complex and multifactorial challenge. With various risk factors associated with the increase in sow removal, it is important to investigate their interaction and how they affect the productivity at herd and individual levels. However, no recent data has been published on sow removal in Canadian herds, with most North American studies looking at U.S. herds. Therefore, this study investigated risk factors for sow mortality in Canadian swine herds using an online survey sent to pork producers across Canada (Chapter 2) and in an observational study of 13 farms in Saskatchewan and Quebec (Chapter 3), which included necropsy procedures.

The survey questionnaire was sent by email to farms via provincial pork organizations across Canada. The total number of farms that received the questionnaire was approximately 660. The survey was accessed by 157 producers (26%); however, only 104 (17.3%) filled out the key questions for the study (related to sow mortality and longevity). Quebec had the highest number of responses (28 respondents). On the other hand, in Ontario, although the province has the highest number of pig barns in Canada (2,550 farms – July 1st, 2020) (Statistics Canada, 2021), only 9 farms completed the survey. In addition to the low participation rate, some participants did not answer all the key questions in the questionnaire. For example, twenty farms did not answer the question on average the number of non-productive days, thirteen did not report the average sow mortality, and eight farms did not report the average parity at culling. Moreover, some producers reported that they do not record specific issues, such as disease status on the farm or the level of mycotoxins.

The low number of respondents and the missing answers in the survey makes it difficult to reach clear conclusions. It is reported in the literature that inaccurate record keeping on the reasons why sows are dying is a limiting factor in understanding the problems associated with sow death (Bradley et al., 2018; Kikuti et al., 2020a) and can lead to the wrong diagnosis and inappropriate recommendations (Ramirez and Karriker, 2012). Thus, it is important to educate producers about good record keeping. Keeping proper records makes it possible to identify trends/problems in the herd and help identify solutions to the health status, consequently leading to reductions in sow mortality (Supakorn et al., 2019a). In addition to educating producers on the importance of accurate record keeping, barn staff should also receive appropriate training, as workers with little or no previous experience in animal husbandry can contribute to high removal rates (Stalder et al., 2008).

Additionally, large herd size has been shown to be a challenging factor associated with higher mortality that is likely related to barn staff. Besides the lack of training and husbandry skills, the high number of sows per barn staff also explains the association between increased average sow mortality and larger herds (Koketsu, 2000; Supakorn et al., 2019a). With reduced overall time that a staff member can devote to each animal, they may not have enough time to observe sows showing clinical symptoms (Supakorn et al., 2019a). Furthermore, the swine industry is known to have high staff turnover, which contributes to the lack of training (Ramirez and Karriker, 2012; Carroll, 2017; The Pig Site, 2020). In our study, four (3.8%) producers classified their employees as having poor/inadequate experience identifying and treating sow illness, and 36 (34.6%) classified their employees as having moderate experience. Moreover, the number of barn staff accounted for the highest variation in average sow mortality per year, accounting for 17% of the variation ($P < 0.001$). To the best of our knowledge, no previous study has explored the number of barn staff as a risk factor at herd level. The only study is that of Jensen et al. (2012), who considered the number of barn staff as a herd variable, with two categories (less than 200 sows per worker, more than 200 sows per worker); however, the study does not discuss the impact of the number of barn staff on average sow mortality. Therefore, the results of this study highlight the importance of adequate numbers of employees with training in husbandry skills. With proper training, workers can improve their observation skills to recognize sows at risk quickly and either start treatment before the problem becomes life-threatening (Stalder et al., 2012) or remove the animal before its welfare is further compromised. Thus, even in fast-paced large operations, barn personnel given adequate support and education can implement effective treatments or adopt management decisions in time, and high rates of sow removal can be avoided.

When studying sow removal reasons, it is possible to observe that most farms do not use standardized evaluations, each performing their own type of health and management assessment. For example, different farms may have their own method of evaluating sows for lameness, body condition and injury, with different classifications for clinical signs and association with treatment or removal, and when to keep or euthanize a sick sow (e.g., when in gestation or lactation). Different individuals within a farm may also record events differently or not at all, increasing variability. In addition, by not following a standard evaluation, farm records can contain errors and can also be based on a symptom of a different reason for culling or mortality (Stalder et al., 2008). In a recent report, Ketchem et al. (2020b) emphasized the need to use standardized removal reasons, suggesting six categories: disease/health, performance, locomotion, reproduction, intestinal, and other. Moreover, standardized recording categories should be added to the production software systems. Adopting this approach would facilitate management decisions and the study of sow removal, and potentially reduce sow mortality on farms (Ramirez and Karriker, 2012; Boyle et al., 2014).

The increase in sow mortality can also be linked to changes in gestation housing systems. With increased pressure from consumers, animal welfare regulations and policies in recent years, the Canadian pig industry has been transitioning from individual stalls to group housing. With these changes being made in different countries (e.g., Australia, EU, New Zealand, and different states in the U.S.), researchers are examining the possible effects of grouping sows during gestation on their welfare and production (Harris et al., 2006; Morgan et al., 2018; Min et al., 2020). While group gestation provides greater freedom of movement, the sows are at a higher risk of having aggressive interactions than stall-housed animals and higher average sow mortality levels have been found (Jensen et al., 2012; Supakorn et al., 2019a; Kikuti et al., 2020a). Similarly, our survey results found that sows in group gestation had higher annual average mortality than sows housed in stalls. However, the transition to group gestation is still a subject of research. Although mortalities and injuries can occur in group gestation, these problems are arguably minimal compared to the harm suffered in stall gestation. For example, Morgan et al. (2018) found in their study a significant improvement in the physical condition (injuries and lameness) of the sows when they were moved to the group gestation. Additionally, with various studies investigating the mortality risks and challenges associated with group housing, it is expected that over time, as producers and sows learn to manage and adapt to the system, greater productivity can be achieved, and better animal welfare can be provided.

When looking at average sow mortality and herd parity, it is well documented that over 40% of young sows are removed or die before their third litter (Lucia et al., 2000; Rodriguez-Zas et al., 2003; Stalder et al., 2003; Hoge and Bates, 2011; Ketchem et al., 2020a). Moreover, different studies have reported that as herd size increases, average parity decreases and removal rates increase (Christensen et al., 1995; Koketsu, 2000; Stalder et al., 2008; Supakorn et al., 2019a; Ketchem et al., 2020b). In this present study, herd size was linked to differences in average sow parity and annual average sow mortality. Results from the survey (Chapter 2) found a negative correlation between herd size and average parity, showing that smaller herds (<500 sows) had an average parity of 3.7, while larger herds (>1,000 sows) had an average parity of 2.9. Additionally, results from the on-farm observations (Chapter 3) indicates that large herds presented an increase in average sow mortality. With larger herds showing a higher prevalence of 'high' annual mortality compared to mid-size herds (large herds: 60% vs mid-size herds: 40%; P: 0.03) and a higher prevalence of 'moderate' annual mortality compared to mid-size and small herds (large herds: 40% vs mid-size herds: 30%, small herds: 38.5%; P <0.001).

The removal of young sows is a topic of great interest since the females start to pay for their development costs by their 3rd or 4th parity (Stalder et al., 2004; Díaz et al., 2015). Removing young sows causes an increase in the cost of replacement sows, a reduction in productivity, and an increase in biosecurity risks (Stalder et al., 2008; Supakorn et al., 2019b; Ketchem et al., 2020b). Similarly, the results of this research found that a higher removal rate of young sows was associated with larger herds (Chapters 2 and 3). In addition, larger herds had the highest mortality level (Chapter 3). Regarding the housing system, females housed in group gestation had higher average mortality (Chapter 2) and a higher incidence of lameness (Chapter 3).

Looking at mortality levels, the average annual sow mortality reported in the on-farm observation study (Chapter 3) for large herds was 8.3%, while in small herds was 5.2%. The average sow mortality found in the analysis of 104 herds in Chapter 2 was 5.7%, which is considered 'moderate' (>4 – <6%) when compared to other studies worldwide (7.1% in Spain, 9% in the U.S, and 12.4% in Denmark) (Ketchem et al., 2019; Iida et al., 2020; Kongsted et al., 2021). The mortality levels in our study are lower than the levels reported in U.S. and Spain, and that could be due to higher temperatures in those countries and the effect of heat stress.

It was expected that the two main conditions affecting the sow's health, and ultimately resulting in their removal from the herd, would be reproductive disorders and locomotor disorders. However, the main reason for sow removal was 'old age' (72%). Poor reproductive performance (60.6%) and lameness (28%) were the following most frequent causes of removals. Díaz et al. (2015) indicate that although the term 'old age' varies among farms, it is often used for sows older than five or six years of age. However, the average parity of the herd in this study was 3.5 (Chapter 2). The average parity at culling reported in our study was 5.6 (Chapter 2), and according to Stalder et al. (2012), some producers cull sows as soon as they reach 5th or 6th parity. Conversely, Stalder et al. (2012) mention that the economic losses associated with replacement gilts make it more profitable to cull sows after parity eight. Therefore, 'old age' is the desired type of removal (voluntary culling) (Ala-Kurikka et al., 2019), with the sow leaving the herd when her production rate is no longer economically valuable (Anil et al., 2008). Additionally, production criteria, such as farrowing rate and litter size, must be considered when evaluating the efficiency of the sow to avoid economic losses (Anil et al., 2008; Mote et al., 2009).

Regarding productivity, different reasons can be associated with poor reproductive performance, such as small litter size and low piglet birth weight (Stalder et al., 2012). It is one of the main reasons for voluntary culling and impacts directly sow longevity (Anil et al., 2008). However, Stalder et al. (2012) indicate that sows presenting poor reproductive performance should not be culled before weaning the third parity. Furthermore, poor reproductive performance can be associated with lameness by reducing feed intake and mobility and causing changes in postural behavior (Iida et al., 2020). Additionally, lameness might indicate inappropriate housing conditions (Heinonen et al., 2013). In our on-farm observation study (Chapter 3), lameness score 1 was most prevalent in the breeding stage (13.9% lame sows). Controversially, other studies found that lameness was more prevalent in farrowing (Heinonen et al., 2013; Iida et al., 2020). Nevertheless, to reach a more precise diagnosis of causes of death, necropsy procedures are a valuable tool, providing more accurate information and more details than only evaluations performed without the assistance of post-mortem or sample collections.

Necropsy procedures are often ignored due to the employer's lack of interest, time, or the unavailability of someone skilled to perform the necropsy (D'Allaire et al., 1987; Sanz et al., 2002; Sasaki and Koketsu, 2008). Of 104 farms participating in our survey (Chapter 2), 65% responded that they never perform necropsies on euthanized or dead sows. However, the necropsy performance of sows found dead or euthanized can provide additional information about the health status of the animal and herd (Küker et al., 2018). Furthermore, it can confirm diagnostics (Lucia et al., 2000; Stalder et al., 2004) and help investigate disease outbreaks (Küker et al., 2018). Different measuring indicators of pig health and welfare have been suggested in a study by van Staaveren et al. (2017), using tail and skin lesions at meat inspection, thus, reducing the need for on-farm welfare assessments. In addition, the authors suggest that it is necessary to perform a longitudinal study to know if changes are occurring in the welfare status of animals on the farm during production. However, considering that typically females are sent to an assembly yard and then transported to specialized slaughter facilities, collecting data for health and welfare assessment of sows at slaughter is not practical. For this reason, performing on-farm necropsies is more feasible. With that in mind, one of the objectives of this study was to develop a simplified sow necropsy procedure (necropsy decision tree) to use on-farm to assess major causes of death loss. At each necropsy performed during the farm visits, the goal was to demonstrate to barn staff the straightforwardness of the technique using the necropsy tree (Appendix F). We performed necropsies on four sows in Saskatchewan; however, due to Covid-19 restrictions, dead sows in QC were sent to an outside laboratory.

One of the main limitations of the research lies in the Covid-19 pandemic. Interfering with plans to visit farms nationwide, the research had to be adapted and only farms in SK and QC were visited. Consequently, different teams visited farms in each province; thus, the result may have suffered from bias between observers in scoring body condition, lameness, and injury. The lameness rates in SK were smaller than the rates in QC; however, this may be associated with the production stage and the difficulty of assessing lameness. It is more difficult to assess lameness in stall gestation than in group gestation. Even though sows are more likely to lie down due to severe lameness, they may also refuse to stand up for other reasons unrelated to the locomotor system (Jensen et al., 2012). Therefore, the SK researchers had difficulties assessing lameness in the visited farms since the main production stage was stall gestation.

Another limiting factor in the study was the low response to the survey, with responses from only 15.7% (104 farms) of 660 farms that received the survey questionnaire. Considering the lack of participation in the survey, it may be more pertinent that future farm surveys should be shorter and that key questions are asked at the beginning of the survey. Thus, avoiding respondent fatigue, resulting in a larger data sample. In addition, actual herd numbers should have been requested instead of categories as this would have given more accurate information for analysis. However, despite the small data sample, our study has shown that different welfare issues occur in each farm model, indicating that larger farms are challenged by higher levels of injury and mortality, while group gestation farms had greater lameness than stall gestation farms.

Furthermore, it is important to reiterate how necessary it is to educate producers and barn staff on good record keeping and proper training. With adequate training in animal husbandry, workers can contribute to maintaining proper records, facilitating the identification of problems in the herd, and reducing mortality rates. The low average parity found in this research (3.5 parity) indicates that a higher proportion of young sows were removed from the herd. Consequently, a higher number of replacement gilts need to be added to the herd, increasing economic expenses. Therefore, the development of replacement gilts deserves more attention, focusing on genetics and selecting more robust females, especially as farms are converting from gestation stalls to gestation groups. Moreover, it was common to feed replacement gilts with a grow-finisher pig diet in the past; however, studies have demonstrated that diets need to focus on preparing the gilts for productivity, bone development, and joint and foot health (Whitney and Masker, 2010; Supakorn et al., 2018).

It is important that systems should adopt consistent categories for recording sow removals so that the causes of female death, culling and euthanasia of sows are standardized. This way facilitates the study of sow mortality and culling and the animal welfare assessment. With consistent data collection across different production software, using standardized categories, it will be possible to maintain more accurate benchmarking, improving the assessment of sow health and mortality records. In addition to the six categories suggested by Ketchem et al., (2020b) for removal reasons (e.g., disease/health, performance, locomotion, reproduction, intestinal, and other), we suggest that the category of 'injury' could be added to this list since other injuries not associated with locomotion can lead to sow removal (e.g., udder injury, severe lesions). This new category will refer to injuries caused by the environment, other animals, humans, and trauma in general. Moreover, to facilitate the study of sow mortality, necropsy examinations of dead sows can simplify the control of mortality rates and herd health status. A standardized necropsy protocol reduces the variation among studies, making it easier to compare the data collected and confirm the diagnosis (Pretzer et al., 2000). Therefore, this study developed a necropsy protocol (Appendix F) to be adopted in the farms for the herd health surveillance.

The present study found a mortality rate in Canadian herds of 5.7% (Chapter 2), with larger herds showing higher mortality rates, lower average parity, and lower average parity at culling than mid-size and smaller farms, indicating a significant impact of herd size on average sow mortality. Farms with group gestation had higher mortality levels and a higher incidence of lameness. However, it is imperative that improvements are made in group gestations since this system provides greater freedom of movement for the sows and a better welfare. In addition, improvement in gilt selection and management must be a focus in the swine industry to reduce sow replacement rates and economic losses. The main reasons for removing sows from the herd found on Canadian farms were 'old age' and 'poor reproductive performance'. The reproductive performance of the herd can be affected by poor husbandry skills of barn staff. Therefore, proper training is essential to improve sow longevity. Moreover, the education on the importance of good record keeping and making recording more consistent for barn workers and producers are also essential to reduce sow mortality. This study provides valuable information about sow mortality in commercial Canadian sow herds with a straightforward necropsy protocol. Further investigations, including a larger sample of Canadian farms would be valuable to better understand the risk factors for sow mortality.

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Appendices

Appendix A – Sow Survey: Complete Version

1. What province are you located in?
2. How many sows in the herd?
3.
    a. What is the breed (line) of sows in your herd?
    b. What is the breed (genetics) of sows in your herd?
4. What is the disease status of the herd? (please indicate positive, negative, or unknown for each of the following)
    a. PRRSv
    b. Circovirus (PCV2)
    c. PEDv
    d. Mycoplasma
    e. *Streptococcus suis*
    f. Other (specify)
5. How many barn staff are employed (including part time staff)?
6. Staff are mostly?
7. In your opinion, how experienced/capable is staff at identifying and treating sow illness?
8. What type of housing is used in gestation?
9. What year was group housing implemented?
10. If sows are housed in stalls throughout gestation, when are they moved from breeding stalls into gestation stalls?
11. If sows are group-housed during gestation:
    a. When are sows mixed into groups?
    b. What is the group size?
    c. What is the composition of pen groups?
    d. What is the space allowance provided to sows in groups?
    e. What feeding system is used?
12. What flooring type is used?
13. How many sows per drinker (if group gestation is used)?
14. If slatted flooring is used - what is the gap width?
15. Are there larger gestation stalls available to accommodate larger sows?
16. What is typical length and width of gestation stalls

17. What type of drinker is used?

18. Water quality in the sow barn is?

19. If water quality is poor or very poor, what is the main concern/problem?

20. What is the source of feed for your operation?

21. Do you measure mycotoxin levels in your feed?

22. Which mycotoxin(s) are measured?

23. How have mycotoxins levels changed in the past three years?

24. Do you practice bump feeding of sows before farrowing?

25. Are any sows induced at farrowing?

26. How are surplus piglets fed?

27. At what age are piglets weaned? (average weaning age)

28. What is the average annual replacement rate for sows (percentage)?

29. Average litter performance for the past 4 months:

    a. What is the average number of total born per litter?

    b. What is the average number of total born alive per litter

    c. What is the average number of total stillborn piglets per litter?

    d. What is the average number of total mummies per litter?

    e. What is the average pigs weaned per mated sow per year?

30. What is the average number of non-productive days (NPD) per sow per year? [NPD/Sow/Year]

31. What program do you use to record production data?

32. In the past year: What is the most common reason for sow removals (including culling, euthanasia, and deaths) on your farm?

33. When lameness is a cause of sow removal, what factors are responsible? (check all that apply)

    a. Housing system

    b. Flooring

    c. Genetic

    d. Nutrition

    e. Disease

    f. Fighting

    g. Other (please specify)

34. What percent of sows die annually on-farm (not culled or euthanized)?

35. Which phase of production has the most death losses (not culled)?

36. Which phase of production has the most sows euthanized?

37. Is there one season that has greater sow losses than the rest of the year?

38. Have you noticed that culling/mortality rates or reasons for culling/mortality have changed over the past 5-8 years?

39. When recording sow deaths, how often are necropsies (autopsies) done?

40. What observations are common on dead sows (check all that apply)

    a. Injury
    b. Poor body condition
    c. Shoulder sores
    d. Skin Colour
    e. Other (please specify)

41. What is the average body condition score (BCS) of all sows in the herd?

42. What percentage of sows would you consider being BSC 2 or below?

43. What management changes have been implemented in the past 5-8 years? Describe any significant changes in sow management.

44. Are replacement gilts purchased and brought in, or produced on-farm?

    45. What criteria are used when selecting replacement gilts? (check all that apply)

    a. Teat number/quality
    b. Leg conformation
    c. Foot conformation
    d. Growth rate (ADG)
    e. Temperament/behavior (please specify)
    f. Size
    g. Body condition
    h. Foot conformation
    i. Breeding values
    j. Other (please specify)

46. What criteria must gilts meet before breeding? (check all that apply)

    a. Age (specify breeding age must be met)
    b. Body size (specific body weight must be achieved)
    c. Body condition (an ideal body condition must be achieved)
    d. Previous estrus cycle
    e. Other (please specify)

47. What is the average parity of your herd?

48. What percentage of the sow herd is parity 3 or greater?

49. What is the average parity at culling?

Appendix B – Sow Survey: Summary Version

Province: ______________________ Date:________________________________

Researchers: ___________________ Barn manager:________________________

1. How many sows are in your herd? _______

2. What is the disease status of the herd? (check all that apply)

   a) PRRSv b) Circovirus (PCV2) c) PEDv d) Mycoplasma e) *Streptococcus suis* f) Other

3. What type of housing is used in gestation?

4. Are there larger gestation stalls available to accommodate larger sows?

5. Average litter performance for the past 4 months:

   a. Average number of total born piglets per litter?

   b. Average number of total born alive per litter?

   c. Average number of total stillborn piglets per litter?

   d. Average number of total mummies per litter?

6. What is the average annual replacement rate for sows (percentage)?

7. What is the average number of non-productive days (NPD) per sow per year? [NPD/Sow/Year]

8. In the past year: what is the most common reason for sow removals (including culling, euthanasia, and deaths) on your farm?

9. What percent of sows die annually on-farm (not culled)?

10. Which phase of production has the most death losses (not culled or euthanized)?

11. Have you noticed that culling/mortality rates or reasons for culling/mortality have changed over the past 5-8 years?

12. When recording sow deaths, how often are necropsies (post-mortem) done?

13. What observations are common on dead sows (check all that apply)

    a) Injury b) Poor body condition c) Shoulder sores d) Skin Colour e) Other

14. What is the average body condition score (BCS) of all sows in the herd?

15. What management changes have been implemented in the past 5-8 years? Describe any significant changes in sow management.

Appendix C – Research Summary

Research Summary – Risk Factors for Sow Mortality

Summer/Fall 2020

Researchers:

- Jennifer Brown, Research Scientist- Ethology, Prairie Swine Centre,

University of Saskatchewan, Phone: 306 667-7442,

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- Cristina Prade Ramos, MSc Student, Dept. of Animal and Poultry Science,

University of Saskatchewan, Phone: 437 971-5942,

Email: crp647@mail.usask.ca

1. Introduction

Sow death losses are costly to producers and are reported to be increasing. Sow death reports are inconsistent and are often combined with culling numbers. For this reason, there is a need to better understand what is causing higher mortality and culling rates. Reducing sow losses will produce economic benefits by reducing replacement costs and increasing sow lifetime productivity. Additional benefits include reduced biosecurity risk, and improved sow welfare and staff morale. Necropsies are a common diagnostic tool and can increase the accuracy of information related to sow mortality by helping to identify unexpected health events.

2. Purpose of the study

The goal of this project is to gain a better understanding of factors affecting sow mortality and culling rates on Canadian farms, identify causal factors, and provide management recommendations to producers to increase sow retention and longevity.

3. Data collection

Two researchers will visit the barn. Data collection will take approximately six hours, only one hour of this time will be needed with the farm/production manager to collect sow and management information. The remainder of the time will be spent in observing sows in gestation, breeding, and farrowing, and conducting necropsy procedures if dead or recently euthanized sows are available. Biosecurity protocols for each barn will be obtained prior to the visit and will be strictly followed by project personnel.

Depending on farm size, up to a maximum of 100 sows will be observed at each site with roughly half in gestation and half in farrowing. For each sow observed we will record: parity, stage of gestation, production records, presence of body lesions, gait score/lameness assessment, hoof condition, body condition score, and general behaviour. For sows in stalls or farrowing crates, lameness will be assessed by asking the sow to stand using a handling board or shaker paddle and observing weight bearing.

Any sows present in the farm that have died within 24hrs will be considered for necropsy. If no dead sows are present, we will request that up to 1 sow per farm, that are identified as being in poor health and not suitable for transport be euthanized by the producer during the farm visit and necropsy will be performed on-site.

A decision tree consisting of major health issues contributing to sow death will be used to guide the necropsy procedures, and results will be documented using data sheets and photographs. Necropsy training will be provided to any barn staff interested in learning the procedure as this can support more reliable information on mortality causes and lead to improved management practice.

4. Results

The results of this research will be distributed to the swine industry and each participating farm will receive a copy of the final project report. Although absolute confidentiality cannot be guaranteed, every effort will be made to ensure that the information collected for this study is kept entirely confidential and no barns will be identified. Results of this study are intended for publication in scientific journals and presentation at related conferences and workshops, the identities of participating farms and producers will be kept anonymous.

5. Follow-up

Producers will be contacted by phone or email within 4 to 6 months of the farm visit to obtain an update on culling and mortality observations that have occurred since the farm visit.

This study is conducted by the Prairie Swine Centre and the University of Saskatchewan; and is funded by Agriculture and Agri-Food Canada through Swine Innovation Porc, with assistance from provincial pork organizations.

We appreciate your support and willingness to assist in this research. The results will provide important information to improve sow management and productivity. If you have any questions, please contact Jennifer Brown.

Thank you for participating in this study!

Appendix D – Animal Owner Consent Form

UNIVERSITY OF SASKATCHEWAN

Animal Research Ethics Board (AREB)

ANIMAL OWNER CONSENT FORM

CONSENT FORM FOR ANIMAL OWNERS

You have been invited to enter your sow barn in a research project entitled **On-farm evaluation of risk factors for sow mortality and culling**. Please read this form carefully, and feel free to ask questions you might have.

Researchers:

Jennifer Brown, Research Scientist- Ethology, Prairie Swine Centre,
University of Saskatchewan, Phone: 306 667-7442,
Email: jennifer.brown@usask.ca
Cristina Prade Ramos, MSc Student, Dept. of Animal and Poultry Science,
University of Saskatchewan, Phone: 437 971-5942,
Email: crp647@mail.usask.ca

Funding Sources: Swine Innovation Porc, Agriculture and Agri-Food Canada

Purpose and Objective of the Study: The goal of this project is to gain a better understanding of factors affecting sow mortality and culling rates on Canadian farms. The goal is to identify causal factors and provide management recommendations to producers to increase sow retention and longevity.

Knowledge Transfer: Findings of this work will be distributed to the swine industry through presentations given at pork industry meetings, articles in popular industry magazines (eg. Better Pork, National Hog Farmer) and at scientific meetings. Your farm will be given a copy of the final project report. In all reports, the results will be presented in summarized form by province: no barns will be identified, and all participants will remain anonymous.

Potential Benefits: Participation in this study will allow producers to see where they stand in relation to other herds and provinces, and will provide tips on necropsy procedures and potential management problems related to sow health. This study will produce important knowledge on factors influencing sow mortality and culling rates/reasons in the Canadian swine herd. The results will provide a scientific basis for management recommendations to optimize sow longevity, and will benefit producers by reducing costs for replacements and increasing sow lifetime performance.

Description of the Procedures: The study will take place in commercial sow barns in Canada. A total of up to 40 barns will be visited between May 1 and October 30, 2020. Data collection for each visit will take approximately 6 hours. Approximately 1 hour will be needed with the farm/production manager to collect sow and management information. All biosecurity protocols including 48-72h down time between barn visits will be followed by project personnel. Biosecurity protocols will be shared prior to the farm visit.

A sample of 20 farms with high mortality and 20 farms with low mortality rates will be selected for evaluation. Depending on farm size, up to a maximum of 100 sows will be observed at each site in gestation, breeding, and farrowing, and conducting necropsy procedures if dead or recently euthanized sows are available (Maximum sample size = 40 farms x 100 sows = 4000 sows). For each sow observed we will record parity, stage of gestation, production records, presence of body lesions, gait score/lameness assessment, hoof condition, body condition score, and general behavior. For sows in stalls or farrowing crates, lameness will be assessed by asking the sow to stand using a handling board or shaker paddle, and observing weight bearing.

Any sows present that have died within 24hrs will be considered for necropsy. If no dead sows are present, we will request that up to 1 sow per farm that are identified as being in poor health and not suitable for transport be euthanized by the producer during the farm visit and necropsy performed on-site. A decision tree consisting of major health issues contributing to sow death will be used to guide the necropsy procedures, and results will be documented using data sheets and photographs. Necropsy training will be provided to barn staff interested in learning the procedure.

Potential Risks and Discomforts: Due to multiple barns being visited there is a potential risk to barn biosecurity. All biosecurity protocols including 48-72h down time between visits, new clothing, new recording sheets for each visit, use of clean rental cars and autoclaving of any materials that are reused will be followed by project personnel. Biosecurity protocols including parking location and use of booties will be discussed prior to the farm visit. No farms with active PEDv will be visited.

Financial Implications: There will be no cost to you for entering your animals in this study. You will not be charged for any of the procedures performed for the study's purposes. All unrelated costs for diagnosis, management and treatment of your animals are your responsibility. You will receive no reimbursement for entering your animals in this study.

Confidentiality: While absolute confidentiality cannot be guaranteed, every effort will be made to ensure that the information collected for this study is kept entirely confidential. Your name or that of your farm will not be attached to any information nor mentioned in any study report, nor be made available to anyone except the research team. Results of this study are intended for publication in scientific journals and presentation at related conferences and workshops, but your identity or that of your farm will not be revealed.

Data Storage: All research materials will be stored in the Prairie Swine Centre under lock-and-key for a period of 5 years post publication minimum as per the U of S Responsible Conduct of Research Policy, see: https://policies.usask.ca/documents/Responsible_Conduct_Research_Policy__Procedures.pdf

Voluntary Participation: Your animal's participation is voluntary, and you may withdraw your animals/farm from the research project for any reason, at any time, without penalty of any sort. If you do not wish to participate, you do not have to provide any reason for your decision. If you withdraw your animals from the research project any data collected during their enrollment in the study will be retained for analysis.

Questions: If you have any questions concerning the research project, please feel free to ask at any point; you are also free to contact the researchers at the numbers provided if you have other questions. This research project has been approved on ethical grounds by the University of Saskatchewan Animal Research Ethics Board. Any questions regarding the ethical conduct of this research may be addressed to that committee through the Research Ethics Office (306-966-7928). Participants from outside of Saskatoon may call toll free 1-888-966-2975.

Consent to Participate: Include the following statements: Please read and initial the following statements to signify your agreement and sign below.

______I have read or have had the consent form read to me and I understand the consent form.

______I have had an opportunity to ask questions and my/our questions have been answered.

______I freely consent to entering my animal(s) in this study.

______I have been told that a signed and dated copy of this Consent Form will be given to me for my records.

______I am at least 18 years of age and am the legal owner of the animals or am authorized to make decisions regarding these animals on the owner's behalf.

Signature of Owner or Agent Date

Signature of Individual conducting the Consent Process Date

Research Results: If you would like a copy of the research results from this study please include your contact information.

Email address: ____

Address:____

Postal code:____

Appendix E – Observations of Live Sows. Sows in gestation and farrowing rooms will be scored using the CQE PigCARE Animal Based measures for BCS, Lameness, and Injury scores (CPC 2018b).

UNIVERSITY OF SASKATCHEWAN

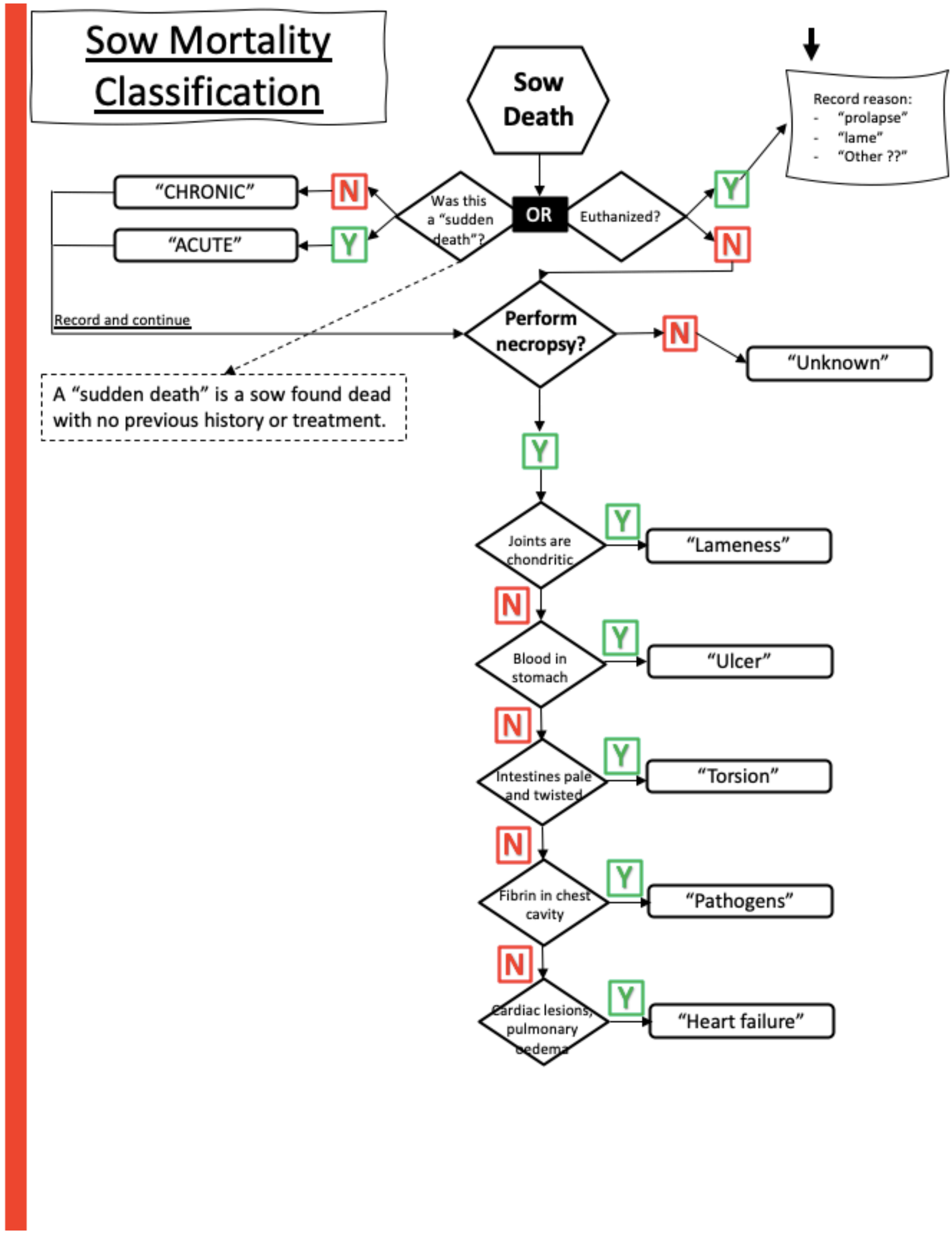
Company name: Province:

Phone: E-mail:

Form completed by: Date:

Sow ID	Parity	Stage of gestation	BCS	Lameness Score	Injury Score	Notes

Appendix F – Sow necropsy decision tree



Sow necropsy decision tree: Diagnostic descriptions

Pathological findings expected for the main sow necropsy diagnoses:

- **Trauma:**
    - Hematomas
    - Wounds
    - Broken bones
- **Skin** (Straw et al, 2006):
    - Colour changes
    - Pruritus
    - Lesions
- **Lameness:**
    - Arthritis
    - Osteochondrosis
    - Foot lesions
    - Swollen joints
- **Ulcer**
- **Abdominal organs** (Straw et al, 2006):
    - Torsions: gastric, splenic, and hepatic
    - Dilation: gastric
- **Pathogens**: Pruritis, abscesses, fibrotic tissue
- **Heart failure**:
    - Characterized pathoanatomically by an acute pulmonary oedema and passive congestion of lungs and liver with absence of gross and microscopic findings suggestive of other diseases (Engblom et al, 2008)
    - Presence of lesions such as cutaneous cyanosis; transudate in the cavities; cardiac chamber changes (Straw et al, 2006)
    - Can be associate with high temperatures, heavier sows, and peripartum period (Straw et al, 2006)
- **Urinary tract** (Straw et al, 2006):
    - Cystitis-pyelonephritis: the amount of aqueous humor urea concentration is higher in sows who died of this cause than in those that died of other causes - collect with a syringe.
- **Respiratory tract** (Straw et al, 2006):
    - Rhinitis: catarrhal inflammation of the nasal – Causes: infection, ammonia, dust, foreign bodies (collect fluid if present)
    - Pneumonia: inflammatory processes caused by different pathogens
    - Pleuritis: fibrotic adherence
- **Reproductive tract** (Straw et al, 2006):
    - Milking problems: mastitis and agalactia
    - Uterine prolapses
    - Vaginal prolapses
    - Vulvar discharges: purulent or blood-tinged. Cystitis and pyelonephritis usually in sows at any stage and vaginitis, metritis specially after farrowing or breeding

Appendix G. Sow Necropsy Recording Sheet

Date:________________Province:____________ Study ID: _____________

Barn name:__________________ Barn location: ____________________

Person conducting necropsy: _______________________________________

Sow info: Age/parity: ____________________Stage: __________________

Sow ID: ____________________ (days of gestation/days of lactation)

Date & time of death: __________________________

Date & time of necropsy: _______________________

Treatment history: ____

Body length: _________ Body condition score: _____

Gross external findings: ____

Dental condition: ____

Necropsy:

Sow death was ☐ACUTE or ☐CHRONIC

Cause of death: ________________________ ☐Unknown

Presence of parasites: Y or N; If Y, describe parasite and location.

Tissues collected:

☐Brain ☐ Skin ☐ Lung ☐Heart ☐ Liver ☐ Kidney ☐ Intestines ☐ Stomach

☐Joints ☐Uterus ☐Ovaries ☐ Other:______________________________