RISK FACTORS FOR PIGLET MORTALITY IN DANISH ORGANIC SOW HERDS

LENA RANGSTRUP-CHRISTENSEN

PhD THESIS · SCIENCE AND TECHNOLOGY · 2017

AARHUS UNIVERSITY

RISK FACTORS FOR PIGLET MORTALITY IN DANISH ORGANIC SOW HERDS

LENA RANGSTRUP-CHRISTENSEN • PHD THESIS • 2017

RISK FACTORS FOR PIGLET MORTALITY IN DANISH ORGANIC SOW HERDS

LENA RANGSTRUP-CHRISTENSEN

PhD THESIS · SCIENCE AND TECHNOLOGY · 2017

AARHUS UNIVERSITY

Department of Animal Science
Blichers Allé 20
postboks 50
8830 Tjele

Tryk: www.digisource.dk
ISBN: 978-87-93148-30-7

Supervisors

Jan Tind Sørensen (main supervisor)

Professor, Head of Research Unit, Epidemiology and Management, Department of Animal Science, Aarhus University, Denmark.

Lene Juul Pedersen (co-supervisor)

Senior Scientist, Behaviour and Stress Biology, Department of Animal Science, Aarhus University, Denmark.

Assessment committee

Jan Værum Nørgaard (chair of the committee)

Senior Scientist, Animal Nutrition and Physiology, Department of Animal Science, Aarhus University, Denmark.

Emma Baxter

Senior Researcher, Animal & Veterinary Sciences, Animal behaviour & Welfare, Scotland's Rural College, Scotland.

Olli Peltoniemi

Professor, Department of Production Animal Medicine, Faculty of Veterinary Medicine, University of Helsinki, Finland.

Preface

The following PhD dissertation is submitted to fulfil the requirements for the degree of Doctor of Philosophy at the Department of Animal Science at Aarhus University, Denmark. The research presented in this PhD thesis has been conducted from June 2014 until August 2017 at the Department of Animal Science, Epidemiology and Management. The research was part of the research project 'VIPiglet' and was funded by the VIPiglet project and the PhD School GSST, Aarhus University.

Acknowledgements

I would like express my gratitude for the all the support and encouragement I have received over the past three years.

Sincere thanks to my supervisors Professor Jan Tind Sørensen and Senior scientist Lene Juul Pedersen for your support, constructive criticism and most of all for your unfailing enthusiasm throughout the entire project.

I would like to thank all the participating herd owners and their employees for their hard work and dedication. I has been a real pleasure working with all of you.

Thanks to research technician Pia Haun Poulsen for planning the start-up of the study and for being a talented and fun necropsy assistant. Thanks to the EMA group for fun and interesting discussions and for all the help and inspiration I have received. I have enjoyed your company immensely.

Special thanks to my two PhD-partners-in-crime: Sarah-Lina - for all your support and feedback, and for all our interesting conversations about whatever topic. Victor - for being the best office roommate imaginable. Thank you for the countless Café zinho/Pingado/Café com leite you have made me. Most of all, thank you for sharing your thoughts on life and cows with me.

Finally, a great thanks to the nearest and dearest of all people, to the best of friends Astrid and Jacob, to Margrethe my always helpful and generous neighbour, to my loving and supportive family especially my superhero-sister Tania, and to Jan for relentless encouragement, patience, and for being loveable.

List of Content

1 List of scientific papers

Paper I

Rangstrup-Christensen, L., Krogh, M.A., Pedersen, L.J., Sørensen J.T.

Sow level risk factors for stillbirth of piglets in organic sow herds.

Published, Animal 2017

Paper II

Rangstrup-Christensen, L., Krogh, M.A., Pedersen, L.J., Sørensen J.T.

Sow level risk factors for early piglet mortality and crushing in organic outdoor production.

Published, Animal 2017

Paper III

Rangstrup-Christensen, L, Schild, S.L.A., Pedersen, L.J., Sørensen J.T.

Causes of preweaning mortality in organic outdoor sow herds.

Submitted to Research in Veterinary Science, October 2017

Papers I and II are reproduced with the permission of the publisher.

2 Summary

High piglet mortality is a considerable problem in Danish organic pig production where it has been estimated that approximately one third of all piglets die before seven weeks of age. The high preweaning mortality has a great negative impact on both piglet welfare and herd economy. Concerns about animal welfare is a key motivator for consumers to purchase organic products and consumers particularly value ‘animal welfare’ and display a positive attitude towards paying for this issue. The majority of the deaths occurs within the first week *post-partum* (*pp*) with stillbirth, crushing and starvation being the most common causes. Little is known about potential risk factors for preweaning mortality in the Danish organic pig production and thus, further research is an essential prerequisite for lowering the preweaning mortality.

Therefore, the overall objective of this thesis was to determine causes of preweaning mortality and to identify risk factors for stillbirth and early piglet mortality within the Danish organic pig production.

An observational study was performed in nine Danish organic sow herds over a 1-year period from June 2014 to May 2015. The herd size ranged from 80 to 910 productive sows per year. All farrowings within the nine herds throughout the study period were included in the study. The data collection comprised of two parts: (1) A detailed recording of dead /alive piglets together with information about the sows in the farrowing field and (2) *Post-mortem* (*pm*) examinations on a subsample of dead piglets collected from selected sows. Collection of piglets was done once in each season throughout the 1-year study period. The stock personnel working in the herds performed the recordings of mortality in the farrowing field and collected dead piglets for *pm* examinations. Piglets were kept frozen at the farm and thawed prior to *pm* examinations, which were conducted by a trained pathologist.

The results of the study are described in three scientific papers included in this thesis. The objective of paper I was to identify sow-level risk factors for stillbirth in organic Danish sow herds. Data was analysed using regression analysis to evaluate parity, sow body condition, season, and total born litter size as risk factors for stillbirth. The results showed a significant interaction between sow body condition and parity. In primiparous sows, an increase in body condition from thin to normal and from normal to fat increased the probability of stillbirth. In sows with more than four parities, an increase in sow body condition from thin to normal and from normal to fat lowered the probability of stillbirth. Additionally, a significant effect of season was found, with an increased probability of stillbirth during summer (May to August) compared with the remaining part of the year. Lastly, a non-linear effect of litter size was confirmed, where an increase of total born litter size resulted in an increased probability of stillbirth.

The objective in paper II was to identify sow-level risk factors for early mortality and crushing in organic Danish sow herds. A negative binomial regression analysis was performed to evaluate parity, sow body condition, season, live-born litter size, and stillborn littermates as risk factors for mortality from parturition until castration (3 - 5 days *pp*). A regression analysis was performed to evaluate parity, sow body condition, season, live-born litter size, and stillborn littermates as risk factors for crushing from parturition until castration (3 - 5 days *pp*). The results showed that one or more stillborn littermates, being born during the summer, high parity, and sow body condition significantly increased the risk of mortality from parturition until castration. Moreover, the study found that the risk of being crushed increased significantly with increasing litter size and parity of the sow.

The objective of paper III was to determine the cause of death by necropsy on a subsample of dead piglets and to evaluate the effect of sow parity and season on the proportions of the identified causes of mortality. In total, 2672 piglets were necropsied. It was found that the majority of the live-born necropsied piglets died of crushing (77 %) and starvation (10 %). Moreover, 81 % of live-born necropsied piglets died within 4 days *pp* and half of these piglets had a body weight of less than 1 kg at the time of death. Crushed piglets dying within four days *pp* were a heterogeneous group consisting of both heavy piglets with full stomachs and piglets with a low body weight and empty stomachs. The proportion of crushed piglets were affected by parity and season, where fewer piglets were crushed during summer compared to the remaining part of the year, and more piglets were crushed by multiparous sows compared to first parity sows. Moreover, the proportion of *pre-partum* stillbirths was higher in autumn compared to the remaining part of the year and in multiparous sows compared to first parity sows. Finally, it was shown that the average total preweaning mortality was to 29.5 % (ranging from 21.4% to 39.9 %between herds) within the study population.

Based on the results presented in this thesis, it is concluded that increasing litter size, high parity, sow body condition, and being born during summer are all risk factors for pre-weaning mortality within the Danish organic pig production. The large variation in total preweaning mortality between the herds indicates that it is possible to achieve a lower piglet mortality in the future and that the Danish organic pig production and a high piglet mortality is not inevitably synonymous.

3 Danish summary (Sammendrag)

Høj pattegrisedødelighed er et stort problem i den danske økologiske svineproduktion, hvor det estimeres at hver tredje pattegris dør inden fravænning ved syv uger. Dette medfører et økonomiske tab for producenterne og har samtidig en negativ betydning for pattegrisenes velfærd. Den høje pattegrisedødelighed har også betydning for de forbrugere, der køber økologisk svinekød, da de ofte bekymrer sig om dyrevelfærd og gerne vil betale for et højere niveau af dyrevelfærd. De fleste pattegrise, der dør inden fravænning, dør allerede inden for den første uge efter farring, hvor dødsfødsler, klemning og sult er de mest almindeligste dødsårsager. Der er generelt en begrænset viden om hvilke risikofaktorer, der har betydning for pattegrisedødeligheden i den danske økologiske svineproduktion. Opnåelse af denne viden er derfor vigtig for at kunne nedbringe pattegrisedødeligheden.

Det overordnede formål med afhandlingen var at fastslå årsager til samt at identificerer risikofaktorer for pattegrisedødelighed i den danske økologiske sobesætninger.

Der blev lavet et observationelt studie som involverede ni danske økologiske sobesætninger gennem en etårig forsøgsperiode fra juni 2014 til maj 2015. Besætningernes størrelse varierede fra 80 årssøer til 910 årssøer og alle farringer fra de ni besætninger i forsøgsperioden var inkluderet i forsøget. Indsamlingen af data var opdelt i to dele 1) detaljerede registreringer af døde og levende pattegrise igennem diegivningsperioden samt oplysninger om soens huld og læg nummer og 2) obduktioner af et udpluk af døde pattegrise fra udvalgte søer. Pattegrisene blev indsamlet over fire gange, en gang i hver sæson. Registreringerne af dødeligheden i faremarken samt indsamlingen af pattegrise til obduktion blev foretaget af ansatte på besætningerne. Pattegrisene blev opbevaret på frost i besætningerne og blevet tøet op forud for obduktionerne, som blev udført af en erfaren veterinær patolog.

Resultaterne fra studiet er præsenteret i tre videnskabelige artikler. Formålet med artikel I var at identificere so-baserede risikofaktorer for dødsfødsler i danske økologiske sobesæt-ninger. Data blev analyseret via en regressionsanalyse for at evaluerer lægnummer, soens huld, sæson og kuldstørrelse som risikofaktorer for dødsfødsler. Der blev fundet en signifikant vekselvirkning mellem soens paritet og huld. Det betød, at der i førstelægssøer blev påvist en øget sandsynlighed for dødsfødsler i fede søer sammenlignet med tynde søer. Det modsatte gjorde sig gældende hos ældre søer med mere end fire læg. I disse søer blev der påvist en øget sandsynlighed for dødsfødsler i tynde søer sammenlignet med fede søer. Der blev ligeledes påvist en signifikant effekt på sandsynligheden for dødsfødsler ved at være født om sommeren sammenlignet med resten af året. Afslutningsvis blev der fundet en ikke-lineær effekt af en stigning i den totale kuldstørrelse på sandsynligheden for at være dødfødt.

Formålet med artikel II var at identificere so-baserede risikofaktorer for tidlig dødelighed og klemning i danske økologiske sobesætninger. Data blev analyseret via en regressions-analyse for at evaluerer soens læg og huld, sæson, kuldstørrelsen (levendefødte grise) samt dødfødte kuldsøskende som risikofaktorer for dødelighed og klemning i perioden fra far-ring indtil kastration (3 – 5 dage efter faring). Resultaterne viste en signifikant øget risiko for at dø mellem farring og kastration for grise født i kuld med en eller flere dødfødte kuld-søskende, ved stigende læg og huld hos soen samt ved at være født om sommeren. I tillæg hertil sås en øget risiko for klemning hos grise født af ældre søer og grise født i store kuld.

I artikel III var formålet at undersøge dødsårsager hos pattegrise fra udvalgte søer samt at evaluerer effekten af soens læg og sæson på andelen af dødsårsager. Dødsårsagerne blev fastslået ved obduktion og i alt blev 2672 pattegrise obduceret. Størstedelen af de levende-fødte obducerede pattegrise døde af klemning (77 %) eller sult (10 %). 81 % af de levende fødte obducerede pattegrise døde inden for de første fire levedøgn og halvdelen af disse havde en kropsvægt på under 1 kg på dødstidspunktet. Klemte pattegrise, der døde inden for de første fire levedøgn, var en heterogen gruppe bestående af både store kraftige patte-grise med fyldte maver samt små undervægtige pattegrise med tomme maver. Andelen af klemte pattegrise blev påvirket af soens læg samt af sæson således at andelen af klemte pattegrise var lavere om sommeren sammenlignet med resten af året samt at andelen af klemte pattegrise var større i multi-lægs søer sammenlignet med første lægs søer. Ligeledes var andelen af pattegrise døde før faringen højere om efteråret sammenlignet med resten af året samt i multi-lægs søer sammenlignet med første-lægs søer. Afslutningsvis, blev det påvist at den gennemsnitlige pattegrisedødelighed fra farring til fravænning i alle besætningerne var 29.5 % med en variation mellem besætningerne på 21.4 % og 39.9 %.

Ud fra resultaterne præsenteret i denne afhandling kan det konkluderes, at en stigning i kuldstørrelse, soens huld og lægnummer samt at være født om sommeren alle er risikofaktorer for pattegrisedødelighed i den danske økologiske svineproduktion. Den store variation af den totale pattegrisedødelighed, som blev påvist mellem besætningerne, indikerer at det er muligt at nedbringe dødeligheden i den danske økologiske sobesæt-ninger. Ligeledes viser resultaterne fra besætningen med den laveste dødelighed, at det er muligt at producere økologiske svin i Danmark uden at dødeligheden overstiger det gennemsnitlige niveau i den danske konventionelle svineproduktion.

4 Introduction

In the Danish organic pig production about every third piglet die before weaning (Sorensen and Pedersen, 2013). The level of piglet mortality exceeds the level observed in Danish conventional pig production (Jessen, 2016) and in organic and outdoor pig productions in other European countries (Berger et al., 1997, Wientjes et al., 2012, KilBride et al., 2014). First and foremost, the high preweaning mortality poses a threat to the welfare of the piglets as dying may involve elements of suffering and so a high preweaning mortality constitute an animal welfare problem. Consumers of organic products are concerned about animal welfare and the confidence in a high level of animal welfare is a key motivator for consumers to purchase organic products (Harper and Makatouni, 2002). Secondly, preweaning mortality negatively affects herd economy. A substantial amount of resources such as feed and labour are invested in sows in the gestation and farrowing unit. The return of this investment, in the form of surviving piglets, is lower when the preweaning mortality is high. Furthermore, consumers particularly value ‘animal welfare’ as an important ethical standard and exhibit a positive willingness-to-pay for this issue (Zander and Hamm, 2010) thereby adding another economic incentive to lower the preweaning mortality.

Organic agriculture comprises four ethical principles; that is the principle of care, the principle of ecology, the principle of health and the principle of fairness (Anonymous, 2017a). These principles were framed by Organics International (IFOAM) and all emphasise the importance of sustainability within the organic production system. The impaired animal welfare and the loss of resources the dead piglets constitutes, contradicts the principles.

The majority of the existing knowledge on sow level risk factors for preweaning mortality originate from studies performed under conventional indoor production conditions and the limited number of studies concerning outdoor systems have been performed in systems differing from the Danish outdoor production. Therefore, the risk factors may have a different impact and magnitude when studied in Danish commercial outdoor sow herds. Large scale studies containing a substantial number of farrowings, are required in order to define not only which risk factors are important for preweaning mortality but also the magnitude of and interactions between these risk factors. Such a study will furthermore enable us to quantify how much the mortality can be lowered by reducing the risk factors in question.

Therefore, the overall aim of this thesis was to identify risk factors for and causes of piglet mortality within commercial Danish organic sow herds. This was achieved by performing an observational study including a substantial number of farrowings throughout a one-year period. Mortality causes were determined by *post-mortem* examinations.

5 State of the Art

This section will present the current knowledge on piglet mortality risk factors together with causes and prevalence of piglet mortality. Knowledge generated in outdoor organic production settings is scarce and thus, research on conventional indoor-housed, both crated and non-crated sows and piglets will be included. First, a brief introduction of the organic pig production in Denmark with emphasis on sows and piglets will be given.

5.1 Organic pig production in Denmark

Danish organic sow herds are certified by the Danish veterinary and Food Administration according to EU Council regulation (EC) No. 834/2007 and current Danish legislation: LBK no. 21 of 04/01/2017. In addition to the legislation an industry agreement on organic pig production exists between different stakeholders within organic pig farming. This agreement adds further standards to the production of organic pork in Denmark (Anonymous, 2008).

In 2016, the number of productive organic sows per year in Denmark increased by 28% to 8180 sows compared to 2015 (Anonymous, 2017b). Despite this substantial increase in organic pig production, which has been constantly increasing since the mid-nineties (Früh *et al.*, 2014), only ~1 % of all slaughtered pigs in Denmark in 2015 were organic. The major differences between organic and conventional pig production in Denmark is summarised in Table 1.

The majority of sows used in the organic production are Danish Landrace/Danish Yorkshire crossbreeds serviced with Danish Duroc boars originating from Danavl's breeding program (Früh et al., 2014). In order to thermoregulate when the average daytime temperature exceeds 15°C, animals on pasture have access to a wallow and animals kept indoors have access to cooling by water sparkling. According to the new industry agreement, with effect from 1 January 2018 animals in the farrowing field must have access to shaded area during the summer months (Anonymous, 2017c).

All animals have access to *ad libitum* roughage. An outer fence surrounds all pastures to keep the animals in and predators and intruders out.

Table 1. Selected husbandry practices Danish organic and conventional farrowing sows and piglets.

Sows	***Organic***	***Conventional***
Farrowing	Outside in huts	Inside in crates
Nest building material	Straw bedding/grass	A handful of straw
Feed	Cereals/Roughage	Cereals
Occupational materials	Pasture/straw bedding	A handful of straw
Flooring	Pasture/straw bedding	Solid/slatted
Breeds	Danavl Landrace-Yorkshire	Danavl Landrace-Yorkshire
Piglets		
Surgical castration, no anaesthesia	Yes	Yes
Tail docking and teeth clipping	No	Yes
Iron injection	No	Yes
Age at weaning	6 – 8 weeks	3 – 4 weeks

(Früh et al., 2014)

Gestation field

Gestating sows are kept in groups and must have access to pasture from April 15th to November 1st whenever weather conditions permit it (Anonymous, 2017d). The gestating sows are either kept indoors in deep litter with access to an outdoor enclosure or on pasture with access to shelter, typically a hut with straw bedding housing several sows, the latter arrangement being most common.

Farrowing field

Sows farrow outdoor all year around and are moved to the farrowing field 10 to 14 days prior to parturition. Sows are kept in individual paddocks of varying size (approximately 350 m^2) with access to a farrowing hut (~ 4 m^2) with deep straw bedding. The most commonly used type of hut is an insulated A-hut fitted with door flaps during winter. After parturition, litter equalisation and standardisation are often performed to uniform litter size between sows and minimise weight variation between piglets within the litter. Most commonly, these procedures are done within two days *post-partum (pp)* but might take place later in the preweaning period as well. In large herds, two-step nurse sows are sometimes used to handle surplus new-born piglets as described by Baxter et al. (2013). Piglets are kept within the hut e.g. by use of a fender (Figure 1, top left) until 10 - 21 days *pp*. This measure is to keep piglets from getting lost in the farrowing field and to protect them from predators. After removal of the fender, piglets roam freely in large packs throughout the entire farrowing field. Male piglets are castrated 2 - 7 days *pp* without any use of anaesthetics but with systemically administrated analgesia. Tail docking and teeth clipping is not permitted and piglets are not injected with a prophylactic iron. Piglets are weaned at an average age of 49 days. Pictures from a standard farrowing field are presented in Figure 1.

Weaning and fattening unit

Weaners (from weaning at 7 weeks of age until 30 kg) and fatteners (30 kg until slaughter) are kept in indoor pens consisting of a resting area with a deep litter and an activity area with solid and partial slated flooring. Each pen has an outdoor area (a concrete run) with solid and partial slated floors. The indoor space allowance for weaners and fatteners is 0.6 m^2/pig and 0.8 – 1.3 m^2/pig, respectively. Pigs are delivered to slaughter when reaching a live weight of around 110 kg (Sorensen et al., 2011).

Figure 1. Pictures from a standard Danish farrowing field.
Top left: Sow in individual hut prior to farrowing. The fender is placed in front of the entrance to keep piglets near the hut. Top right: Sow nursing new-born piglets. Bottom: Overview of a farrowing field after removal of the fender. Piglets roam freely and interact with piglets from other litters. In the bottom left part of the picture, two wallows can be seen.

5.2 Piglet mortality

This section provides an overview of the current knowledge on the prevalence and causes of stillbirth and live-born mortality in piglets.

The preweaning piglet mortality in Danish organic sow herds is high, both compared to the Danish conventional production system and in organic production systems in other countries. The most recent reports on piglet mortality in Danish organic sow herds are from 2007 and 2008 including 1200 litters from seven herds where the mean total preweaning mortality was 33 %, ranging from 25 % to 40 % between herds (Sorensen and Pedersen, 2013). By contrast, mean total preweaning mortality reported in Danish conventional sow herds in the same period (2007/2008).was 23.4 %. At the time of the present study (20145), the mean total preweaning mortality in Danish conventional herds was 21.5 % (Jessen, 2016). In commercial outdoor-housed sows in England in 2003/2004 live-born mortality by farm ranged from 5 % to 24 % with a mean of 13.5 %. In a French study on crated sows conducted from 2004 to 2014 the total preweaning mortality was 21 % (Pandolfi et al., 2017).

5.2.1 Stillborn piglets

The percentage of stillborn piglets have been found in recent studies to range between 5.1 % and 7.5 %. In a study by KilBride et al. (2012) the percentage of stillborn piglets recorded by farmers was 6.5 % across housing systems. In the same study, it was found that the risk of stillbirth was significantly lower in outdoor-housed sows compared to sows housed in farrowing crates, which is in accordance with Baxter et al. (2009) who found that 5.1 % of piglets born by sows housed outdoors were stillborn. In a Danish study by Damm *et al.* (2005) performed on indoor loose-housed sows, 6.5 % of piglets were stillborn. The stillborn piglets in the two later studies were diagnosed by *post-mortem* (*pm*) examination. In a study on crated sows in Belgium 7.5 % of piglets were stillborn and 48 % of litters had one or more stillborn piglets (Vanderhaeghe et al., 2010b). The latter study was in agreement with Le Cozler et al. (2002) who reported stillborn piglets in 43 % of the litters within three French experimental herds.

Sprecher et al. (1974) classified stillbirths into two categories based on the time of death. Type I includes deaths that occur before the end of gestation and is most commonly attributed to infectious causes and placental insufficiency. Type II includes animals dying during parturition and is often associated with non-infectious causes such as intra uterine asphyxia and dystocia. Of all piglets classified as stillborn, type I accounts for 10 % and type II for 75 %. The remaining 15 % of piglets are not truly stillborn but die immediately after birth (Leenhouwers et al., 1999) and share physical appearance with type II piglets and can only be distinguished from one another by *pm* examinations. Piglets that are not truly stillborn present the same disease ethology as type II piglets and thus preventative methods to reduce stillbirths can be applied to both groups. This distribution of piglets into type I and II is consistent with another study by Leenhouwers et *al.* (2003) and with reported figures from conventional Danish sow herds (Thorup, 2017).

KilBride et al. (2014) and Leenhouwers et al. (1999) have demonstrated a positive but undesirable relationship between stillbirth and preweaning mortality of live-born piglets in both outdoor-housed, indoor loose sows and crated sows. Thus, besides being a direct cost due to loss of stillborn piglets, the underlying causes may affect live-born preweaning mortality. The association can be explained by the correlation between stillborn piglets and dystocia negatively affecting the viability of live-born piglets. In addition, stillborn piglets might be associated with illness of the sow negatively influencing her capacity to nurse and to be attentive towards her piglets, consequently increasing piglet mortality and in particular crushing (Spicer et al., 1986).

5.2.2 Live-born piglets

The majority of live-born preweaning mortality occurs early in lactation.

In the study by Sorensen and Pedersen (2013), 12.6 % of live-born piglets died within 3 to 7 days *pp* accounting for approximately 65 % of the total live-born preweaning mortality. This is slightly less than what was seen by Wientjes et al. (2012) who found that 79 % of preweaning live-born deaths in organic loose-housed sows occurred within the first 7 days *pp*. Accordingly, 84 % of live-born mortality in loose-housed sows in England occurred within the first 7 days *pp*. Mortality occurring during the first 7 days of life is often referred to as early piglet mortality and preweaning mortality is used about mortality occurring throughout lactation.

The majority of live-born preweaning mortality is caused by crushing and starvation. In a large study in outdoor-housed sows in England using farmer-recorded mortality, 74 % of live-born mortality was caused by crushing (KilBride et al., 2012). This is in accordance with studies where the cause of death was determined by *pm* examinations. Thus, Edwards et al. (1994) found that 72 % of live-born mortality were due to crushing and 16 % were starved in outdoor-housed sows. Marchant et al. (2000) found that crushed and starved piglets from indoor loose-housed sows accounted for 75 % and 19 % of live-born mortality up to 7 days *pp*, respectively. The reverse distribution of crushed and starved piglets was seen in a study on indoor loose-housed sows where crushed and starved piglets accounted for 28 % and 34 %, respectively (Westin et al., 2015). However, in the latter study crushed piglets also showing signs of starvation were grouped with starvation as the primary cause of death. In a large study including 955 necropsied piglets age 0 – 4 days of age from Danish commercial crated sows crushing, starvation and low-viability accounted for, 47 %, 18 % and 18 % respectively.

Low-viability of piglets is a risk factor for both starvation and crushing. Small and hungry piglets with poor growth spend more time near a standing and sitting sow increasing the risk of crushing (Weary et al., 1996). Emaciated piglets that are not crushed by the sow while attempting to feed will possibly die of starvation later in lactation. Hence, though crushing is often the ultimate cause of death a combination of low viability and starvation are often predisposing factors. The risk factors for low-viability in piglets are presented in more detail in section 5.3.1.

5.3 Sow level risk factors

This section provides an overview of the current knowledge about sow level risk factors for stillbirth and preweaning mortality. These risk factors are often closely linked and the causality can in some cases be difficult to establish.

5.3.1 Litter size

The sow lines used in both conventional and organic farming in Denmark are typically Danish Landrace-Yorskshire (LY) crossbred from DanAvl with a high genetic potential to produce large litters (Su et al., 2007). In 1992, the number of total born piglets was included in the breeding program for Danish Landrace and Yorkshire sows, resulting in a considerable increase in both number of total born piglets and in piglet mortality. In 2004 the selection criterion was changed to number of piglets alive at day five *pp* (LS5) aiming at diminishing the unfavourable correlation between total born litter size and mortality. The attempt was somewhat successful in the sense that live born litter size is currently still increasing with approximately 0.3 live born piglets per litter per year, while number of stillborn piglets per litter seems to have stagnated at 1.7 (Jessen, 2016). In conventional Danish sow herds in 2015 the mean total born litter size was 17.6 of which 1.7 were stillborn (Jessen, 2016). The total born litter size of Danish sows are larger than what has been reported in other countries. In a Swedish study from 2009 the total litter size was ~14.5 (Westin et al., 2015) and in a recent Scottish study by Baxter et al. (2015) an average total litter size of 12.8 was reported.

Increasing litter size is a well-known risk factor for stillbirth and the association has been demonstrated in previous studies in various production systems (Fraser et al., 1997, Leenhouwers et al., 1999, Vanderhaeghe et al., 2010b, KilBride et al., 2012, Hales et al., 2014). Canario et al. (2006) demonstrated a non-linear significant effect of litter size, where piglets from small and large litters had a greater risk of stillbirth compared to piglets born in intermediate sized litters with 12 piglets. The association between a high number of total born piglets and type II stillbirth is partly believed to be due to prolonged parturition which is elaborated in section 5.3.4. A large litter size potentially leads to intra-uterine crowding consequently increasing the within litter weight variation between piglets (litter heterogeneity), the proportion of small piglets with a low birth weight (LBW) and immature piglets suffering from Intra Uterine Growths Retardation (IUGR) (Foxcroft et al., 2006, Quesnel et al., 2008). Both LBW and IUGR piglets are more susceptible to death during parturition (Leenhouwers et al., 1999, Knol et al., 2002, Canario et al., 2006, Pedersen et al., 2011a). IUGR piglets are characterised by having a disproportional body shape expressed as the relationship between weight and length of piglets[1] (Bauer et al., 1998). IUGR piglets have not reached their intra uterine growth potential suggesting immaturity providing an additional disadvantage for post-natal survival on top of a low birth weight. Even though the magnitude of challenges faced by LBW and IUGR is not entirely comparable, henceforward the term LBW will be used without distinguishing between LBW and IUGR piglets.

Large litters are a risk factor for early piglet mortality both in conventional and organic indoor production (Wientjes et al., 2012, Hales et al., 2014 and 2015a) and are associated with the challenges faced by LBW piglets (Tuchscherer et al., 2000, Quiniou et al., 2002, Pedersen et al., 2011a). Piglet viability (the ability to survive) is associated with piglet vitality, also referred to as piglet vigour (Baxter et al., 2008, Vasdal et al., 2011), meaning that the more vital and vigorous piglets possess a better chance of survival. Hypoxia during parturition is a major risk factor for low *pp* vitality and viability (Herpin et al., 1996). This effect is further pronounced in LBW piglets compared to heavier littermates. In addition, LBW piglets are more prone to suffer from hypothermia due to a poor thermoregulatory ability (Herpin et al., 2001) and thus LBW piglets are not well adapted to the extra uterine life (Herpin et al., 1996). Consequently, LBW piglets are less vigorous when competing at the udder increasing the risk of starvation making them weak and less responsive to sow movements increasing the risk of crushing (Pedersen et al., 2011a).

During the first 24 h *pp*, piglets compete to gain access to a functional teat, which they will occupy throughout lactation. In large litters, more piglets fight for the same teats, and

[1] Measured by Ponderal Index (PI): weight (kg)/CTR $(m)^3$ or Body Mass Index (BMI): weight (kg)/CTR $(m)^2$

competition is therefore greater (Andersen et al., 2011). LBW piglets have a disadvantage to their heavier littermates during the establishment of a teat order and are therefore at greater risk of suffering from both insufficient colostrum intake and starvation. A reduced colostrum uptake compromise piglet thermoregulation, intestinal development and immunity (Devillers et al., 2011). The two latter problems result in an increased susceptibility to disease (Tuchscherer et al., 2000, Pedersen et al., 2011a). In addition, hungry piglets are more prone to crushing because they spend more time close to the sow (Weary et al., 1996). LBW piglets usually have a low weight at weaning (Milligan et al., 2002, Panzardi et al., 2013) suggesting that the competitive disadvantage of being small remains throughout the lactation period.
If the litter size exceeds the number of functional teats, management interventions such as fostering of piglets by nurse sows or access to milk supplement are necessary in order to ensure adequate feeding of all piglets. Risk factors for piglet mortality linked to cross fostering is presented in section 5.4.3.

5.3.2 Sow body condition

The effect of sow body condition on the risk of stillbirth has been investigated with varying results. A positive association between a high body condition score and stillbirth was reported by Le Cozler et al. (2002) which could be explained by excessive amounts of adipose tissue surrounding the birth canal providing a physical obstruction in the pelvic region at parturition predisposing a prolonged farrowing. In agreement with this, Oliviero et al. (2010) found significantly longer farrow duration and higher stillbirth rate in sows with a back fat level > 17 mm compared to sows with back fat level < 17 mm. The opposite effect has also been demonstrated, where thin sows have a greater risk of getting stillborn piglets compared to normal and fat sows, measured by back-fat level (Maes et al., 2004, Vanderhaeghe et al., 2010b). It has been suggested that the main source of energy in sows approaching farrowing is the internal body reserves such as fat and muscle. Therefore, it seems possible that sows with a low back-fat level at the end of gestation are lacking the energy to complete parturition potentially leading to an increased duration of farrowing, in turn increasing the risk of stillbirth (Oliviero et al., 2009). In other studies, no association between sow body condition (visually scored) and stillbirth was established (Lucia et al., 2002, Borges et al., 2005). The different outcome of the above mentioned studies might be explained by the different methods used to assess sow body condition since it has previously been demonstrated that there is a poor to moderate correlation between measuring back-fat levels and performing a visual scoring of the body condition (Young et al., 2001, Maes et al., 2004). In addition, differences in breed and housing/production system could also explain some of the disagreement.

It has been shown that an increase in body weight of the sow increased the risk of *pp* death (Wulbers-Mindermann et al., 2002, Oliviero et al., 2010). This suggests that heavy sows have difficulties laying down and turning around slowly, resulting in a potential higher risk of piglet crushing. A positive correlation between lameness and a high body condition score (visually scored) has been seen in Danish organic sow herds (Knage-Rasmussen et al., 2014). In an experimental study with inducing lameness in sows, sows moved more quickly through the standing to lying transition when lame compared to periods with no lameness (Roca et al., 2016). Alterations in the laying behavior of lame sows could cause increased piglet mortality due to crushing.

5.3.3 Parity

Sow parity is a well-known risk factor both in regard to increasing number of stillborn piglets and preweaning mortality as reviewed by Vanderhaeghe et al. (2013) and Muns et al. (2016). High parity has been associated with an increased risk of stillbirth (Zaleski and Hacker, 1993, Leenhouwers et al., 1999, Vanderhaeghe et al., 2010b) which is confirmed in both conventional and organic Danish sows (Hales et al., 2015b; Thorsen et al., 2017). Litter size is reported to increase with increasing parity, peaking at parity 3-5 and subsequently reaching either a plateau or slowly decline in later parities (Koketsu et al., 1999, Quesnel et al., 2008). Additionally, older sows have less heterogeneous litters with a larger proportion of LBW piglets than first and second parity sows (Damgaard et al., 2003, Quesnel et al., 2008). Whether this is an effect of parity per se or if this is associated with the effect of parity on litter size is not evident. However, Wientjes et al. (2012) showed that the proportion of stillborn piglets and the number of light piglets, together with litter heterogeneity, increased with increasing parity in organic indoor-housed sows independently of litter size, suggesting that litter uniformity is also partly affected by parity as such, independent of the effect of litter size.

The increase of stillbirth with increasing parity has also been suggested to arise from a reduced uterine muscle tone in older sows possibly resulting in a prolonged parturition. This is in agreement with Vanderhaeghe et al. (2010b) who found that manual birth assistance (vaginal palpation) was more frequent in sows of parity three and above compared to first and second parity sows.

In the study by Wientjes et al. (2012) high prolific organic sows with parity above four had a significantly higher early piglet mortality compared to sows with lower parities, and

Hales et al. (2014) showed that early piglet mortality was lower in first parity sows compared to older sows housed indoors in both pens and crates. As described above, there is a positive relationship between parity and litter size (Weber et al., 2009, Hales et al., 2014) and between litter size and piglet mortality (Baxter et al., 2009, Hales et al., 2015a). Thus, the risk factors associated with increasing litter size could also explain some of the effect of parity on piglet mortality. Increasing parity is correlated to increasing age of the sow and some of the effect of parity could be explained by age and/or production exhaustion. In a study by Vasdal and Andersen (2012) it was found that less than half of the functional teats were accessible to suckle during the important colostrum period. This effect was more pronounced in older sows due to sub-functional udder morphology, making it difficult for piglets to reach teats even though the sow is lying in lateral recumbency during lactation, resulting in an insufficient ingestion of colostrum by piglets, potentially increasing piglet mortality. Increased age could also affect leg health and mobility making a sow less agile and potentially altering her reaction to squeals from crushed piglets.

5.3.4 Duration of farrowing

Both parity, sow body condition and increasing litter size are, as mentioned previously, associated with prolonged duration of farrowing. The farrowing duration of Danish indoor-housed crated sows average 7 h (Hales et al., 2015b) and 7.5 h in Danish organic sows (Thorsen et al., 2017), both figures considerably longer than what is reported elsewhere. Oliviero et al. (2010) and Mainau and Manteca (2011) concluded that farrowings exceeding 5h and 3-4h respectively, should be considered as prolonged. Farrowing duration is shorter in loose sows compared to crated sows (Oliviero et al., 2010, Hales et al., 2015b). This difference can be explained by the positive effects of exercise such as reduced constipation (obstructing the birth canal) and increased fitness of sows resulting in more stamina during parturition. Providing sows with abundant nest building material reduces the duration of farrowing when comparing sows with no or little nest building material (Westin et al., 2015). Access to suitable nesting material increases the release of oxytocin and enhances calmness during parturition, factors which are both beneficial to the duration of farrowing (Thodberg et al., 2002, Yun et al., 2013).
Prolonged farrowing has been associated with an increased risk of stillbirth in both Danish organic sows (Thorsen et al., 2017) and in crated sows (van Dijk et al., 2005, Hales et al., 2015b). The causality of the association between risk of stillbirth and prolonged farrowing has been questioned. However, Rootwelt et al. (2012) demonstrated an increased risk of

stillbirth and being born with a broken umbilical cord (the latter in both stillborn and live-born piglets) if a piglet was born in the last third of a litter. This suggests that prolonged time spent in the birth canal is a risk factor for premature rupture of the umbilical cord, with a subsequent increased risk of dying of hypoxia before delivery (van Dijk et al., 2005, Rootwelt et al., 2012). This is in accordance with Le Cozler et al. (2002) who found that 80 % of stillborn piglets were born during the second half of parturition. The consequences of a prolonged farrowing with risk of piglets suffering from hypoxia subsequently affecting their viability and thus preweaning mortality, have been elaborated in section 5.3.1. During a long parturition, sows will have a lower (if any) feed and water intake, resulting in energy depletion. This might negatively affect the ability to control movements (stand and laying) imposing a risk of crushing on piglets. However, Thorsen et al. (2017) did not find any association between early maternal behaviour related to risk of crushing and length of farrowing in Danish organic sows, indicating that the major risk factor of prolonged parturition for *pp* death may be related to reduced piglet viability. Besides the direct effect of a prolonged parturition on piglet viability, it potentially affect the sow's health and productivity lowering the piglets' chance of survival.

5.4 External risk factors

This section presents a brief introduction to external and management factors such as ambient temperature and strategies to handle surplus piglets affecting stillbirth and preweaning mortality. The possibilities of control for these factors can however be limited within the outdoor organic pig production.

5.4.1 Temperature and season

In an outdoor production system, options to control ambient temperatures are limited. During summer months, sows have access to a wallow and often the only shaded area in the paddock will be the hut. During winter, door flaps are placed in front of the hut opening to prevent draft and the amount of straw in the hut is increased. Sows are sensitive to high ambient temperatures due to their lack of self-thermoregulation. Thus heat stress occurs when ambient temperatures exceed their thermo-neutral zone reported to be around 12 - 20°C (Black et al., 1993, Bloemhof et al., 2013) if they are not given the possibility to thermoregulate by behaviour, e.g. seeking up cooler areas. Heat stress is known to be related to problematic farrowings, most likely due to the inhibitory effect of stress on oxytocin (reveiwed by Lawrence et al., 1997). This consequently leads to an increased farrowing duration and longer inter birth intervals between piglets (Oliviero et al., 2008), the latter also being a risk factor for stillbirths in indoor crated and loose sows (van Dijk et al., 2005, Pedersen et al., 2006, Rootwelt et al., 2012). In two studies performed on crated sows in commercial herds, it was found that temperatures above 22°C were significantly associated with more stillbirths compared to temperatures below 22°C (Odehnalova et al., 2008, Vanderhaeghe et al., 2010a). A seasonal difference in number of stillborn piglets has also been demonstrated in indoor-housed crated sows by Wegner et al. (2014) where numbers of stillborn piglets were higher during summer and autumn compared to winter. However, the later study did not find a significant effect of temperature and humidity.

Season and ambient temperature also affect preweaning mortality. In the study by Wegner *et al.* (2014), increasing temperatures for up to 7 days *pp* reduced preweaning mortality. New-born piglets thrive at temperatures above 30°C (Black et al., 1993). It is therefore likely that any adverse effect of high ambient temperatures on piglet survival is due to potential heat stress in sows rather than the temperature negatively affecting the piglets directly. High ambient temperature has a negative effect on milk production with a decrease in milk production with temperatures above 25°C (Quiniou and Noblet, 1999), potentially leading to piglet mortality. During the first days *pp* it has been shown that Danish organic sows spend most of their time inside the hut together with the piglets and that, during this period, they use the wallow less frequently compared to later in gestation (Schild et al., 2016), potentially leading to an increased risk of heat stress during periods of high ambient temperatures. Sows suffering from heat stress could also be expected to be less attentive towards their piglets, performing more risky behaviors and increasing the risk of crushing piglets.

Weber et al. (2009) found an effect of season on preweaning mortality in indoor-housed sows which was higher during summer than winter but lowest in spring and autumn.

As previously described new-born piglets have poor thermoregulatory ability and are therefore sensitive to low ambient temperatures which is negatively related to piglet survival (Tuchscherer et al., 2000). Protecting piglets from hypothermia during periods with low ambient temperatures could potentially lower preweaning mortality. In the outdoor production, this is mainly achieved by providing extra straw bedding, using insulated huts and by placing a flap in front of the door to prevent draft. Straw bedding provides an insulating and warm microclimate aiding the maintenance of normal body temperature and thus lowering the postnatal temperature drop in new-born piglets, increasing their chances of reaching the udder and ingesting colostrum (Pedersen et al., 2016). The use of insulated huts and door flaps were found to have a protective effect, lowering preweaning mortality in outdoor-housed litters in England (KilBride et al., 2014).

However, the protective effect of insulated huts was not found in other studies (Edwards et al., 1995; Johnson and McGlone, 2003). The reason for this difference could be that huts in the two latter studies had sufficient bedding to prevent heat loss. Berger et al. (1997) found that pre-weaning piglet mortality in outdoor production systems was higher in late autumn and early winter in France, but does not present any possible explanation behind the association.

5.4.2 Supervision and birth assistance during parturition

Several studies have investigated farrowing supervision and manual birth assistance as risk factors for stillbirth and preweaning mortality.

Manual birth assistance in form of vaginal palpation is associated with the proportion of stillborn piglets (Vanderhaeghe et al., 2010b), which is somewhat expected since manual birth assistance is performed on sows suspected to suffer from dystocia. Supervision of farrowings gives the stock personnel the opportunity to dry piglets and to help them to the udder, potentially lowering mortality. However, there is some disagreement about whether or not supervision is a protective factor for piglet mortality. Le Cozler et al. (2002) found that the proportion of litters without stillborn piglets increased from 46 % when no supervision was performed compared to 66 % when the entire litter was observed and assisted if necessary. Vanderhaeghe et al. (2010a) found that occasional supervision of farrowing at herd level was associated with a higher occurrence of stillborn piglets compared to herds with full time supervision.

An increased management effort around parturition in Norwegian loose-housed sows with the farmer being present at 80 – 100 % of farrowings, drying and massaging piglets, split suckling in combination with being in contact with sows more than twice every day significantly increased piglet survival (Rosvold et al., 2017). Both the results from Vanderhaeghe et al. (2010a) and Rosvold et al. (2017) suggest that correct supervision might be beneficial for piglet survival.

The risk of stillbirth has been found to be higher during daytime farrowings compared to overnight farrowings (Vanderhaeghe et al., 2010b, Pandolfi et al., 2017). In the two studies no farrowing supervision took place overnight and during the day, sows might get disturbed and stressed by the normal working routines in the farrowing unit. This suggests that sows benefit form a quiet farrowing environment.

Correct supervision and birth assistance could have a positive effect on mortality but unfortunately, these options are of limited practical use in an outdoor production setting.

5.4.3 Cross fostering

Cross fostering refers to the action of moving piglets from the birth sow to a foster sow. Cross fostering of piglets is a widely used management tool in Danish conventional and organic sow herds to handle large litters with regard to both surplus piglets and the weight variation between piglets described earlier.

If the number of piglets in a farrowing batch does not exceed the number of functional teats, cross fostering is used to even out litter sizes between sows so that all sows nurse piglets corresponding to their number of functional teats. In addition, piglets from several litters are often moved in order to standardise piglet size within the litter so that large piglets are grouped with large piglets and small piglets are grouped with small piglets. The latter is done to help LBW piglets to gain access to a functional teat by lowering the competition from larger siblings. If the number of piglets in a farrowing batch exceeds the number of functional teats, nurse sows can be used to nurse surplus piglets until weaning. A nurse sow is a sow receiving piglets after weaning of her own piglets. For a further detailed description of different cross-fostering strategies and the practical implementation of nurse sows please refer to the review on the subject by Baxter *et al.* (2013).

In 2014, it was estimated that 17 % of sows in a farrowing unit in conventional Danish sow herds were nurse sows (Sorensen and Pedersen, 2015). Nurse sows are used in the Danish organic production system, but the extent of it is not known.

Despite the benefits of providing all piglets with the opportunity to gain access to a functional teat throughout lactation and providing LBW piglets a less competitive environment away from heavier littermates, cross-fostering imposes some risks potentially increasing piglet mortality. The recommended best practise of fostering new-born piglets is to do it between 12 and 24h *pp* and no later than 48h *pp*. Supporting this, cross-fostering of piglets after 24h *pp* has been found to be a risk factor for piglet mortality in outdoor-housed sows in England (KilBride et al., 2014). If piglets are moved before 12h *pp* there is an increased risk of inadequate or no intake of colostrum, potentially compromising piglet survival. In addition, moving piglets between litters means that teat order has to be re-established increasing stress and fights at the udder, subsequently increasing the risk of facial abrasions (reviewed by Rutherford et al., 2013). Moreover, sows are more prone to terminate suckling if piglets fight at the udder (Pedersen et al., 2011b). It is not permitted to clip or grind the teeth of organic piglets in Denmark, which might further increase these problems.

Piglets being fostered to a nurse sow at 4-7 days *pp* will probably face less teat fights since the entire litter is often moved in unity and piglets will take position of the same teat as they occupied at the birth sow. However, piglets are at risk of suffering from hunger and hypothermia before the sow accepts the new litter. This could possibly be worsened in organic litters since it is not permitted to fixate organic sows in Denmark, potentially prolonging the acceptance period. Moreover, the energy demand of 4-7 days old piglets is still increasing, whereas the milk production of a nurse sow around day 21 of lactation is at a maximum milk yield. Thereafter, milk production plateaus with a risk of not being able to meet the energy demands of the new litter all through to weaning (reviewed by Baxter et al., 2013). With a preweaning period of 7 weeks in Danish organic production, this issue might be more pronounced. Internal biosecurity is violated when piglets are being moved between litters and sows, and with a potential transmission of pathogens between litters affecting health and survival of piglets.

Due to the extensive manner of outdoor organic farming, risk factors highlighted in this section might have a different effect and magnitude in outdoor-housed sows compared to conventional crated sows.

6 Objective and hypotheses

The risk factors and causes of piglet mortality in Danish commercial organic sow herds have not previously been investigated. Previous studies performed in conventional production setting and in organic production systems in other countries have identified parity, season, litter size and sow body condition as risk factors for stillbirth. In addition to the above mentioned risk factors, stillborn littermates have been shown to be associated with mortality of live-born piglets.

The risk factors could potentially be of differing importance and magnitude when evaluated in a less extensive setting, such as the outdoor organic production system. Across production systems, starvation and crushing have been identified as the major cause of piglet mortality. Identification of both the causes and risk factors of piglet mortality is necessary in order to implement preventative measures to lower mortality in the future.

Therefore, the overall objective of this thesis is to identify risk factors and causes for piglet mortality within the commercial Danish organic pig production. This is performed in an observational study, including a substantial number of farrowings throughout a one-year period. Mortality causes will be determined by *pm* examinations.

The three following hypotheses were investigated:

1. Summer season, increased litter size, high parity and body condition of the sow are risk factors for stillbirth in Danish organic sow herds (paper I).

2. Season, increased litter size, high parity, body condition of the sow and stillborn littermates are risk factors for 1) piglet mortality from parturition until castration (3 - 5 days *pp*) and 2) crushing of live-born piglets in litters with mortality from parturition until castration (3 - 5 days *pp*) (paper II).

3. Season and parity of the sow affect the proportion of identified causes of mortality based on *pm* examinations during a one-year period (paper III).

7 Study design and population

In the follow section, a description of the study population and study design is presented.

7.1 Study population

The study was performed in nine commercial Danish organic pig herds of variable size ranging from 80 to 910 productive sows per year. The study population comprised of all farrowing sows and piglets within each herd over a one-year period. The nine herds were not randomly selected but included in the project based on their interest in the outcome of the study. Furthermore, willingness and ability to take on the extra workload associated with participating in the study was a precondition. The target population constituted of productive sows and their piglets from Danish organic commercial sow herds. During the study period, the total number of productive sows in Danish commercial organic sow herds amounted to around 6 000 of which 3 105 were included in the study population. The nine study herds constituted one third of all organic certified sow herds with a minimum of 50 productive sows per year.

7.2 Study design

The study was purely observational and performed in nine commercial Danish organic sow herds during a one-year period from June 2014 to May 2015.

The study comprised of two parts: 1) Recordings of piglet mortality from parturition until weaning in all litters in the nine study herds throughout the study period and 2) Necropsy on a subsample of dead piglets collected once every season in all nine study herds.

Upon insertion into the farrowing field, the sow identification number, together with her parity and body condition score, was recorded. At the first check-up after parturition, alive piglets were counted and the number of stillborn piglets and piglets that died *pp* was recorded. The piglets were counted again at castration (2 - 7 days *pp*), at vaccination or removal of the fender (10 - 21 day *pp*) and at weaning (49 days *pp*). If piglets were moved between sows for litter equalisation/standardisation or euthanised during the preweaning period it was also recorded. All above mentioned recordings were performed by the stock personnel working in the farrowing field.

Necropsies were done on a subsample of dead piglets sampled from one farrowing batch in each herd once in every season. After collection, piglets were frozen and thawed prior to the *pm* examinations which were performed at the farms by an experienced pathologist (the undersigned). In herds with farrowing batches of more than 30 sows, piglets were collected from 25 sows. The 25 sows, from whom piglets were collected, were selected upon insertion into the farrowing field. Number of gilts included mimicked the percentage of gilts in the herd. The stock personnel selected both gilts and older sows randomly. In herds with farrowing batches of less than 30, piglets were collected from all sows.

8 Methodological considerations

This section will present the methodological considerations and decisions made during the planning, implementation and execution of the study. Detailed descriptions on the methods and materials used are presented in the three research papers and will not be elaborated further.

8.1 Observational study

In order to investigate the importance and magnitude of risk factors for piglet mortality within a commercial organic production setting, the study was performed as a purely observational study. The observational study design provides the opportunity to evaluate the relevance of the risk factors when influenced by the noise of "real life" such as different management strategies and routines. The strength of this is that generated results have a high external validity and reflect the real life situation in which they were investigated (Ersbøl and Toft, 2004). However, using this method, options to control the factors under investigation are limited and randomisation and balancing of groups are not possible. This entails a large variation within the study population, meaning that many observations, together with variation of both outcome and explanatory variables, are necessary in order to obtain significantly valid results. Furthermore, the outcome can be influenced by confounding between routines and management decisions not standardised between herds and the risk factors of interest potentially obscuring the true effect of the risk factor in question.

8.2 Selection of study herds

Herds were included, as previously described, based on their interest in the study outcome and their ability to take on the extra workload associated with participation in a labour-intensive study during a one-year period. In addition, selection was made to mimic the diversity of commercial organic sow herds in Denmark in the study population, as the aim was to gather knowledge representative for the entire target population. Therefore, the nine herds included in the study vary greatly both in regard to size and management strategies. Five herds were included in the study as partners in the VIPiglet project and the four herds recruited as the remaining herds were paid a one-time salary of 10.000 DKK (£1335) for their participation. Herd characteristics and management information are presented in Appendix I.

8.3 Motivation and communication

When doing an observational study in a commercial herd where data collection is performed by the staff, the quality of the data is highly dependent on the staff's ability and willingness to perform it correctly. Therefore, it was of great importance to keep the motivation of all participants high throughout the entire study period so that collecting of dead piglets and recording of piglet mortality were done satisfactorily, even on cold and rainy days. To accommodate this, emphasis has been put on building and maintaining a good relationship with all stock personnel involved in the project. The purpose was to create an environment where participants would be comfortable asking questions if instructions were unclear and to come forward if errors occurred. Communication with and to the herd owners was done by phone, e-mail and SMS. All visits and collection of piglets were planned well in advance and were announced by e-mail and confirmed by a phone call two days later. The herd owners were reminded 24 hours before visits, either by e-mail, phone or SMS depending on their preferred means of communication. Phone calls were logged and a summary containing the main decisions were sent to the herd owner afterwards. The procedures regarding communicating about visits and planning of piglet collection were adjusted over time to meet the individual herd owners' needs.

All herds were visited at least five times during the study period, once at the start-up of the mortality recordings and four times when dead piglets were necropsied. During the necropsy visits, it was prioritised to either eat lunch or drink coffee with herd owners and staff both to evaluate and discuss the project and data collection but also to show a personal interest in the everyday life of the farm. In addition, necropsies were demonstrated to all interested staff and interesting or important pathological findings were presented and discussed in a relaxed atmosphere. The purpose and relevance of all recordings were explained and discussed together with the possibilities of using the generated results in their future daily work at the farms. Furthermore, feedback on the progress of the project and preliminary results were presented and discussed at the last necropsy visit. The aim of continuously discussing both necropsies and purpose of recordings with the staff was to give them ownership and an understanding of the usability of the study and the results obtained from it and to get them personally interested in the outcome. The intention behind this was that, by elevating their commitment to the project, it would help generate more reliable recordings. The project handed out all utilities used for data collection such as plastic bags for dead piglets, pens, booklets for mortality recordings etc. Since the working routines varied between the herds and collection of data was performed outdoors all year round, different herds had different needs regarding these utilities. Again, deliberate effort was put into accommodate these needs in order to facilitate and ensure the quality of the collected data.

8.4 Method of recording

The intention was to introduce a method of recording mortality in the farrowing field that did not interfere with management routines within the farm. The implementation of the data collection had to be feasible and not be a burden during daily work routines. These considerations were taken into account when deciding upon methods to collect data. The recordings on sows and piglets from the farrowing field were initially planned to be written in small pocket-sized booklets. Prior to the decision to go with this method of data collection, it was discussed with all the herd owners involved in the study whether it would be possible to obtain the desired information directly from the management software used in the herds. However, only information on sow parity and number of piglets born and weaned was available in the software. Therefore, in order to make it possible to use the recordings from the management software, additional recordings would have to be incorporated into the software, which was not within the scope of the project. Alternatively, information already available from the software could be used in combination with extra recordings done on the side. This idea was discussed with the participants but abandoned due to concerns about increased risk of missing recordings if split into two parts. All herd owners were invited to participate in a workshop prior to the start-up of the study to provide input and suggestions on how to design the actual booklet to be used for the recordings. It was agreed upon that the recordings would be connected to the time line of sow (from entry into the farrowing field and until weaning). In this manner, all activities within the farrowing filed was linked to a sow. Alternatively, recordings could be connected to the date with information of all activities performed on a daily basis. The “sow alternative” was chosen in cooperation with the participants as it was assumed the most feasible solution. Based on input from the workshop the booklet was designed. However, in spite of their involvement in the design process, due to practical reasons some found it difficult to get used to the booklet and implement it into the daily routines in the farrowing field. In these cases, individual solutions were thought of to meet the specific needs in the herds, while assuring that all data was still being collected correctly. Therefore, the original booklet was used in four herds whereas two herds used special designed information sheets fitting their working routines better, and the remaining three herds gathered information in the manner they did prior to start of the study period, later transferring recordings into the booklets. An English version of the booklet was designed for herds with foreign employees. Details about data collection in individual herds are presented in Appendix I and examples on mortality recordings performed in the various ways explained above are shown in Appendix II.

8.5 Recordings from the farrowing field

The various data collected on sows and piglets from the farrowing field are shown in Table 1. With every entry made in the booklet/recording sheet, the date of the observation was noted. Note that at farrowing, both number of dead and alive piglets were recorded. At subsequent recordings only the number of alive piglets was recorded. A description of the criteria and definitions of variables marked with a § in Table 2 are provided in Appendix III.

Not all recordings were performed identically between the farms. Stock personnel were not asked to change how to count piglets at first check-up *pp* or whether or not they wrote plus or minus when piglets were moved between litters, since these entries could be adjusted after the end of data collection. The reason behind this was that fewer errors would occur if recordings were performed in a manner that was familiar and logical to the stock personnel.

The body condition of the sows was visually scored using a scale modified from Hollinger et al. 2015 with three levels to differentiate between thin, normal and fat sows. Previous studies have found poor (Young et al., 2001) and moderate (Maes et al., 2004) correlations between back fat thickness measured by ultrasound scanning and visual scoring of sow body condition. This could indicate that the sow body condition score obtained in the present set-up, is not solely a measure of whether a sow is thin, normal or fat but also includes information on her muscle mass and size. The advantage of using ultra-sound scanning of back-fat thickness to assess the body condition of sows, would be that any demonstrated effect of the risk factor would be better attributed to whether or not the sow actually was thin, normal or fat without including muscle mass and size. However, none of the participating herds used ultrasound scanning of sows as a tool to assess sow body condition, and implementing the method in the daily work routines as part of the project was not practically feasible. Alternatively, ultrasound scanning of sows could have been performed by research staff. This being a very labour-intensive task considering the number of sows included in the study population, that approach was not realistic.

Table 2. Overview of recordings made in the farrowing field

Sow moved into farrowing field	Date	
	Hut no.	
	Sow no.	
	Parity no.	
	§Lameness (0-1)	
	§Body condition (2-4)	
Farrowing	Farrowing, date	
	1. check-up after farrowing, date	
	#All live-born piglets	
	Small alive piglets (max 21 cm)	
	§Stillborn piglets	
	Dead after farrowing (live-born)	
	Euthanised piglets	
Until castration	¤Litter equalisation+/-	
Gilts	No. of functional tits	
Castration	Castration, date	
	No. of piglets	
	Euthanised piglets after counting	
	¤Litter equalisation +/-	
Removal of fender/ Vaccination	Date	
	No. of piglets	
	¤Litter equalisation +/-	
Weaning	Date	
	No. piglets weaned	
Disease, sow	Date	
*1 = MMA, 2 = mastitis 3 = locomotor problems 4 = other	*Disease	
	Antibiotics yes/no	

§: Descriptions of the different categories are presented in detail in Appendix III. #: In two herds, number of piglets alive at first check-up *pp* was noted. ¤: Total number of piglets removed or added to the litter. Number of piglets added to a litter was marked with a plus (+) and piglets removed from the litter were marked with a minus (-). In one herd, this was opposite where piglets added to a litter were marked with a minus (-) and piglets removed from the litter were marked with a plus (+).

Previous studies have shown that the vast majority of preweaning mortality occurs during the first weak *pp*. Sorensen and Pedersen, 2013 found that 12.6 % of live-born piglets die within 3 to 7 days *pp* accounting for approximately 65 % of the total live-born preweaning mortality in seven Danish organic sow herds. This is in accordance with Wientjes et al. (2012) who found that 79 % of pre-weaning live-born deaths in organic indoor-housed sows occur within the first 7 days after parturition. In the present study, piglets were counted at first check-up *pp* and at weaning and additionally at day 3 – 5 *pp* and again between day 10– 21 *pp*. The two additional rounds of counting were added to gather detailed information in the period where the majority of the mortality was expected to occur and the piglets were still confined within the hut. At weaning, the number of piglets in a hut could not with certainty be linked to the sow because of piglets mixing between litters within the farrowing field. These two latter rounds of recordings were not initially part of the normal work routines within the herds. Therefore, in order to facilitate data collection and to minimise occurrences of missing data, these additional recordings of piglets were performed in coherence with standard working routines involving the piglets, such as castration and vaccination/removal of the fender.

Prior to the start of the data collection, all observers were carefully instructed in how to perform the recordings, how to distinguish between live-born and stillborn piglets and how to use the gait and body condition scoring system. A detailed description of the instruct-tions are given in Appendix III. Guidance and practical instructions were done in the farrowing field to test and adjust the observers' ability to perform the recordings correctly.

8.5.1 Cross fostered piglets

In all participating herds, litter equalisation and standardisation were widely used. An example on how to record piglets being moved between litters is illustrated in Table 3.

Table 3. Recording of piglets being moved between litters.

Sow Id	Parity	Date-far	Live born	Stillborn	Dead *pp*	Equalised*	Date-cast	Alive
1527	1	26 June	13	1	1	+2 +1	30 June	14

*: Number of piglets moved to or from the litter from parturition until castration. In total 14 piglets were born, of which one was stillborn and one died *pp* before first check-up. At the first check-up *pp*, 12 piglets were alive. Piglets were then added to the litter twice between first check-up and castration. At castration four days *pp*, 14 piglets were alive and thus, one piglet had died between first check-up and castration.

NB: To simplify, only relevant recordings from the booklet is included in this example.

When using this method of recording, it was not possible to know if a dead piglet found within a hut was actually the biological offspring of this particular sow or if it had been cross-fostered into the litter. Dead piglets were always linked to the sow by whom it was found dead. This approach on recording litter equalisation and standardisation was chosen due to practical limitations. Individual tagging of live-born piglets to identify which piglets were moved between litters was not practically possible and thus, as explained above, distinguishing if a dead piglet was fostered or born into a litter was not possible. In addition, no exact date of removal/adding of piglets from/to the litter was recorded. If tagging of individual piglets had been practically feasible, information on whether a piglet was cross-fostered (by equalisation or standardisation) or not could have been included into the analyses as a risk factor for individual piglet mortality.

Cross-fostering was not included as a risk factor in the current study, since in most cases the procedure is confounded with litter size. Therefore, cross-fostering was expected to explain some of the same effect as litter size since piglets would only be fostered in and out of litters if they were either too large or too small.

In the four largest herds, second step nurse sows were routinely used to handle new-born surplus piglets. No herds used one step nurse sows, and in the following description there will be no distinguishing between one or two step nurse sows. Figure 2 show how the piglets are being moved between sows when nurse sows are used.

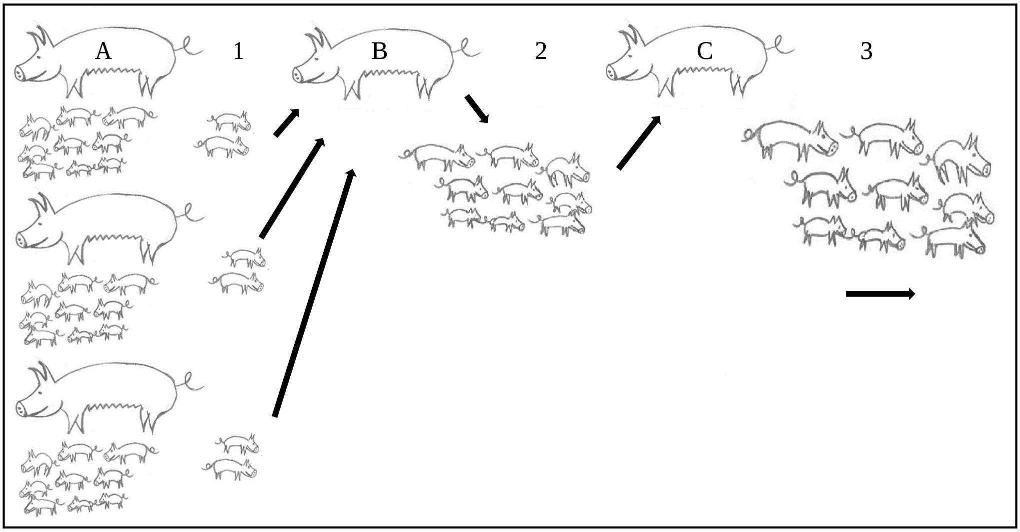


Figure 2. New-born surplus piglets (1) from litters (A) are being collected. A well-performing sow (B) is selected as nurse sow. She will nurse the collected new-born surplus piglets until weaning. Her biological litter (2) which is approximately one week old is moved to the interim sow (C). Her biological litter is between 6-7 weeks old and is weaned. She will nurse her new litter (2) until weaning.

The method of recording nurse and interim sows is shown in Table 4. This approach ensured that piglets were only counted once per recording round.

Table 4. Example of recording of interim and nurse sows.

Sow Id	Parity	Date-far	Live-born	Date-cast	Alive	Date-vac	Alive	Date-wean	Alive
*1729	1	26-jun	12	29-jun	12	N/A	N/A	N/A	N/A
¤1729	N	06-jul	12	09-jul	12	27-jul	12	08-sep	11
#1704	I	06-jul	12	N/A	N/A	20-jul	10	18-aug	7

*A well performing sow number 1729 selected as a nurse sow. Her piglets are moved at 11 days of age (between castration and vaccination/removal of fender) to sow number 1704. There is no recording of piglets at vaccination/removal of fender or at weaning. ¤ New entry of sow 1729 in the booklet/recording sheet with the number of added surplus new-born piglets noted under "Live-born" and the date she received them noted under "Date-far". The piglets were counted again at castration, at vaccination/removal of fender and at weaning. # 1704 is the interim sow and receives 12 piglets 11 days old from sow 1729 (prior to this, 1704 weaned her own piglets at ~ 49 days of age). The piglets were counted at castration when they stayed with sow 1729 and thus were counted next at vaccination/removal of fender and at weaning when staying with sow 1704. Interim sows were marked with "I" as parity and nurse sows were marked with "N" as parity.
NB: To simplify, only relevant recordings from the booklet is included in this example.

Prior to analysing the risk factors for live-born mortality from parturition until castration (paper II), all nurse sows were removed from the data and not included in the analyses. The reason for the exclusion of nurse sows and their foster litters was that the majority of variables to be tested as risk factors (stillborn littermates, live-born litter size and parity) were not comparable to the variables from the remaining sows.
Alternatively, if the piglets from these foster litters were to be included in an analysis of mortality risk factors from parturition until castration, it could be done using the entire farrowing batch as the analytical unit instead of the litter. This was not believed a feasible method to investigate sow-level risk factors.
All piglets from both birth sows, nurse sows and interim sows are included in calculations of total preweaning mortality (total born and live-born). This was possible, because it was performed at farrowing batch-level with no identification of risk factors on sow-level.

8.6 Necropsy

Necropsies were done at the farm, all equipment used was brought along, and all herds were given a 390-litter freezer (-12 to -18°C) to store collected piglets. Necropsies were performed by the same trained veterinary pathologist[2] throughout the study period with the aid of an assistant. Time spent on each farm varied between 6 and 16 hours depending on the amount of collected material. Since necropsies were performed over a one-year period, there could be a risk of drifting in the use of terms and diagnoses over time, meaning that a piglet examined in the beginning of the period would risk not to be assessed the same way if examined again further on into the study period. To minimise this risk, several steps were initiated prior to the start-up of necropsies. A well-defined standardised protocol was used during all post mortem examinations aiming at securing consistency in the collected data, both between herds and throughout the study period. The full protocol is presented in detail in Appendix IV. Prior to preparation of the protocol, the Laboratory for Pig Diseases in Kjellerup, Denmark was visited to attend *pm* examinations of piglets from conventional Danish pig herds. Afterwards, the design of the protocol to be used in the present study was discussed. The laboratory is a commercial lab owned by the Danish Agriculture & Food Council performing diagnostic *pm* examinations on Danish pigs and have a caseload of ~3800 pigs per year of which ~2900 are piglets (Salomonsen, personal communication, 2017). Furthermore, veterinary pathologist Charlotte Mark Salomonsen from Laboratory for Pig Diseases joined one necropsy session in the autumn 2014 to discuss the use of the protocol, diagnoses and causalities.

Dead piglets were macroscopically examined without any use of histology or other diagnostic tools to identify specific disease agents. This approach was implemented based on the overall aim of the study which was to investigate the overall causes of preweaning mortality over a one-year period and not to provide details about disease agents and aetiology. Dead piglets were, as described above, stored at -12 to -18°C at the herd and thawed prior to the *pm* examinations. Freezing of carcasses prior to necropsies might alter the tissue, potentially complicating diagnostic work. However, since the current study was aiming at providing an overall categorisation of the causes of piglet mortality and not a detailed pathological anatomical diagnosis for each piglet, freezing of piglets was not believed to affect the outcome of the study significantly. This is accordance with Vaillancourt and Martineau (1988) who found that results of macroscopic examinations of previously frozen piglets relate well to the results obtained on unfrozen piglets.

[2] Undersigned - five years' work experience in veterinary pathology of various species

An alternative strategy concerning the necropsies could have been to use a commercial diagnostic laboratory such as the Laboratory of Pig Disease, Kjellerup, Denmark to perform the necropsies. An advantage of this would be their high level of expertise. However, the increased cost as a result of this strategy would result in less included piglets potentially lowering the power of the study. In addition, it would not be possible for the same pathologist to perform the necropsies throughout the entire study period. Furthermore, the possibility to interact with the stock personnel while performing the necropsies at the farms would be lost.

8.7 Statistical analyses

In the following section, reasoning behind the choice of statistical model used in paper I is explained. In addition, the reasoning behind the construction and usage of the LTR variable from paper II will be explained. The final statistical models and the included variables together with their mathematical notations are presented in detail in each of the papers and will not be elaborated further here.

8.7.1 Paper I

The relationship between the outcome variable, the proportion of stillborn piglets within litter, and the explanatory predictors was analysed using a logistic analysis with the logit transform as the link function (glm function in R).

Initially, it was attempted to analyse the data using a Poisson regression model, however the data did not fulfil the model assumptions. The data showed over-dispersion with a dispersion parameter > 3 which could be explained by 60% of the observed litters containing no stillborn piglets. The idea was discussed of using a zero-inflated Poisson regression model. However, such a model relies on the assumption that the observed data derives from two different latent processes: 1) one that provides the true Poisson distributed data and 2) one that provides the extra zeroes. It was not believed reasonable to assume that the counts of stillborn piglets arise from two different types of sows. Based on these initial considerations, the logistic regression model used was thought to give the best fit. Woodward (2005) describes the logistic regression approach in detail.

The data analysed include approximately 1500 sows with two litters and 2000 sows with one litter. In the model, the sow was not included as a random effect. The “sow effect” would explain most of the variation in the data because it would not be possible to separate sow from litter in the model. In addition, data being observational from an ongoing commercial production setting, a large element of unobserved management decisions highly influenced whether or not a sow had the possibility to produce the next litter. The effect of neglecting the correlation between litters produced by the same sow was examined by running the analysis with a reduced dataset including only one randomly selected litter per sow. The parameter estimates and P-values were similar to the estimates and P-values from the analyses on the full data set. Based on that, it was decided to analyse the full data set and present these results.

The herd was included in the model as a fixed effect. The reasoning behind this approach was the limited number of herds, making it questionable if the herds in the study could be considered a random sample of the population of Danish organic pig herds. In addition, the data included one large herd that would influence the estimation of the variance component disproportionately.

8.7.2 Paper II

Two statistical analyses were used in paper II 1) A negative binomial regression analysis and 2) A logistic analysis.

Model 1

The relationship between the outcome variable, number of dead piglets within litter from parturition until castration and the explanatory predictive variables were analysed with a negative binomial regression analysis using the glm.nb function with a log-link in R (MASS-package).

Prior to onset of the analysis a variable called live-time-risk (LTR) was constructed by multiplying number of live-born piglets to number of days from parturition until castration. The log (LTR) was used as the offset of the model. The days from parturition until castration varied between litters leading to a different exposure among litters, and the LTR variable was constructed to account for this. Live-born litter size was included in LTR and thus, could not be included as an independent continuous variable as it would explain some of the same effects as LTR. As described in section 8.5.1 information about time of death or time of removal/adding of individual piglets was not available and thus not included in the calculation of the LTR.

Had this information been available and included in the calculation of LTR, the LTR would be adjusted every time a piglet died or were being removed/added to a litter. In that case, a more suitable approach would be to perform a survival analysis.

Model 2

In model 2, a logistic analysis is used to model the probability of at least one piglet in litters with mortality being diagnosed as crushed from parturition until castration within each litter.

A dichotomous outcome variable was used describing whether at least one piglet was diagnosed as crushed in litters with mortality. 1 = crushed piglets in the litter and 0 = no crushed piglets in the litter. Following this, no time of exposure was relevant since what was modelled was whether a crushed piglet was present or not within a litter. Thus, LTR was not included in model 2. Instead live-born litter size (LS), along with the quadratic live-born litter size (LS^2), were included as continuous variables.

9 Papers

This section holds three scientific papers submitted during the PhD project.

9.1 Paper I

Sow-level risk factors for stillbirth of piglets in organic sow herds

L. Rangstrup-Christensen*, M.A. Krogh, L.J. Pedersen and J.T. Sørensen

Department of Animal Science, Aarhus University, DK-8830, Tjele, Denmark

*Contact for correspondence and request for reprints, Lena Rangstrup-Christensen.

E-mail: lena.rangstrup@anis.au.dk

Published in Animal 2017,11:6, pp 1078-1083 (doi: 10.1017/S1751731116002408).

Animal (2017), **11**:6, pp 1078–1083 © The Animal Consortium 2016
doi:10.1017/S1751731116002408

animal

Sow-level risk factors for stillbirth of piglets in organic sow herds

L. Rangstrup-Christensen†, M. A. Krogh, L. J. Pedersen and J. T. Sørensen

Department of Animal Science, Aarhus University, DK-8830 Tjele, Denmark

(Received 21 June 2016; Accepted 13 October 2016; First published online 24 November 2016)

In Danish organic pig production, one-third of total born piglets die before weaning, and stillbirth has previously crudely been estimated to account for 27% of the total preweaning mortality. The objective of this study was to evaluate season, litter size, parity and body condition of the sow as risk factors for stillbirth in nine commercial Danish organic pig herds. The study was conducted over a 1-year period, and the data included registrations on 5170 farrowings with 82 906 total born piglets. The average number of total born piglets per litter was 16.0, and the number of stillborn piglets per litter was 1.1. A significant effect of season was seen with an odds ratio for stillbirth of 1.15 during summer (May to August) compared with the remaining part of the year. A non-linear effect of litter size was seen where an increase in litter size from 11 to 16 resulted in an odds ratio of stillbirth of 1.11. An increase in litter size from 16 to 21 resulted in an odds ratio of stillbirth of 1.45. A significant interaction between body condition and parity was present. In first parity sows, an increase in body condition score from 2 (thin) to 3 (moderate) and from 3 to 4 (fat) increased the probability of stillbirth with an odds ratio of 1.23 and 1.36, respectively. In sows with parity above 4, an increase in body condition score from 2 to 3 and from 3 to 4 decreases the probability of stillbirth with an odds ratio of 0.68 and 0.79, respectively. In conclusion, increasing litter size and being born during the summer months of May to August were found to be risk factors for stillbirth. Furthermore, an interaction between body condition and parity showed that thin sows with parity above 4 had a substantially increased risk of stillbirth compared with normal and fat sows with parity above 4. In contrast, for parity 1 sows risk of stillbirth was increased in fat sows.

Keywords: stillbirth, organic pig production, body condition, parity, litter size

Implications

Stillbirth is believed to be a multifactorial problem, and little is known of the risk factors affecting the occurrence of stillborn piglets in organic pig production. In the current study, it was found that thin sows with parity above 4 had a substantially increased risk of stillborn piglets compared with normal and fat sows with parity above 4. This study is the first large-scale observational study performed to identify risk factors for stillbirth in Danish organic pig production. A better understanding of the causes of stillbirth will potentially help decrease piglet mortality and improve animal welfare in the future.

Introduction

The total piglet mortality in Danish organic pig production is high with an estimated average of 33% of total born piglets dying before weaning (Sorensen and Pedersen, 2013). Consumers expect a high level of animal welfare in organic pig production (Zander and Hamm, 2010). High piglet mortality is, therefore, a major problem for further development of organic pig production, as it affects both farm economy and animal welfare. In a study performed in 2007/08 in seven Danish organic sow herds, an approximation on stillbirths was done using results from two independent studies estimating that 9% of total born piglets were stillborn and thus accounting for 27% of the total preweaning mortality (Sorensen and Pedersen, 2013). This is in accordance with a study by Baxter *et al.* (2011) who found that stillbirths accounted for 22% to 30% of the total preweaning mortality in sows housed under outdoor conditions in England. A positive relationship between stillbirth and preweaning mortality of live-born piglets has been demonstrated by Leenhouwers *et al.* (1999) and Kilbride *et al.* (2014). Besides being a direct cost due to loss of stillborn piglets, the underlying causes may affect live-born preweaning mortality. Stillbirth in commercial pig production is a multifactorial problem (Vanderhaeghe *et al.*, 2013), and there is a need for identifying important risk factors and possible interactions to help organic pig farmers improve management around parturition and culling. Vanderhaeghe *et al.* (2010a) showed

† E-mail: lena.rangstrup@anis.au.dk

an association between an increase in litter size and an increase in stillborn piglets, and Canario *et al.* (2006) showed a non-linear effect of litter size on the probability of stillbirth with an increase in risk of stillbirth in small and large litters. An important factor influencing stillbirth is parity of the sow (Zaleski and Hacker, 1993; Leenhouwers *et al.*, 1999; Vanderhaeghe *et al.*, 2010a). A study by Wientjes *et al.* (2012) showed that the proportion of stillborn piglets increased with parity in organic sows which has also been demonstrated in conventional Danish pig herds (Hales *et al.*, 2015). A positive association between a high body condition score (BCS) and stillbirth was reported by Le Cozler *et al.* (2002) and Maes *et al.* (2004), whereas other studies did not find this association (Lucia *et al.*, 2002; Borges *et al.*, 2005). In a study by Vanderhaeghe *et al.* (2010a), it was found that thin sows with back fat levels beneath 16 mm at the end of gestation have an increased risk of stillbirth compared with sows with back fat levels between 16 and 23 mm. Temperatures above 27°C to 30°C negatively affect the productivity of sows, and a temperature between 18°C and 23°C is usually recommended in farrowing units. A survey by Vanderhaeghe *et al.* (2010b) showed that the risk of stillbirth increased with temperatures above 22°C at parturition.

In outdoor production systems, options to provide manual birth assistance, supervise parturition and control ambient temperature are limited. Identification of risk factors for stillbirth in an organic commercial setting is, therefore, important for development of best practical management procedures in order to decrease stillbirths. The objective of this study is to evaluate summer season, litter size, parity and body condition of the sow as risk factors for stillbirth in nine commercial Danish organic pig herds.

Material and methods

The study was performed over a 1-year period in nine commercial Danish organic pig herds of variable size ranging from 80 to 910 productive sows per year.

In total, nine herds were included in the project based on their interest in the outcome of the study and were not randomly selected. Willingness and ability to take on the extra workload associated with participating in the study was a precondition. During the time period of the study, the total number of productive sows in Danish commercial organic pig herds amounted to around 6000 of which approximately half were included in the study.

Study design

The study was an observational prospective study including all farrowings in the nine herds throughout a 1-year period from June 2014 until May 2015. One herd collected data from July 2014 until June 2015. All recordings were conducted by the producers and their employees. Depending on the herd size, the number of observers in each herd varied from one to five people. All observers were carefully instructed in how to perform the registrations and how to distinguish between live-born and stillborn piglets before the start of the data collection. Guidance and practical instructions were done in the farrowing unit to test and adjust the observers' ability to perform the registrations correctly. During the 1-year period, the farms were visited five times, and procedures regarding registrations were discussed continuously to assure the quality of the collected data.

Animals and housing

The majority of the sows were Danish Landrace–Yorkshire (LY) crossbred from DanBred and farrowed outdoors all year around. During gestation, sows were typically kept in three separate groups according to their size: small sows and gilts, medium-sized sows and larger older sows. In small herds, all sows were kept in the same group. Housing of the gestation groups was either on pasture with access to shelter or indoors on deep straw bedding with access to an outdoor enclosure. Sows were moved into the farrowing unit 10 to 14 days before expected date of parturition and kept in individual paddocks of varying size (approximately between 270 and 450 m^2) with a hut (~4 m^2) with deep straw bedding. In one herd, two to four huts, each containing one sow, were situated in the same paddock. The sows were not restrained at any time during their stay in the farrowing field.

Registrations

Upon transfer of each sow to the farrowing unit, the sow number, parity and BCS were recorded. The date of parturition was recorded along with the number of piglets that were live-born, stillborn and live-born dead. The registrations on live-born dead piglets are not included in the analysis. As previously stated, the observers in all nine herds were instructed in distinguishing stillborn from live-born piglets before the start of the registrations. A wide and uncontracted umbilical cord, in combination with the presence of cabbed hoofs with no sign of wear or intact or partial intact fetal membrane covering the piglet, was defined as sufficient evidence of the piglet being stillborn. The BCS scale was modified from the scale available at ProPig (Holinger *et al.*, 2015), and the categories were defined as follows: (2) thin – ribs, backbone and hip bones are obvious or easily detected with pressure, (3) moderate – ribs, backbone and hip bones are barely visible or are barely felt with firm pressure, (4) fat – ribs, backbone and hip bones cannot be seen or felt when firm pressure is applied, or fat deposits are clearly visible. The description was supplemented by pictures to emphasize the visible differences between the groups.

Statistical analysis

The relationship between the outcome variable, the proportion of stillborn piglets within litter, and the explanatory predictors presented below was analyzed with a logistic analysis with the logit transform as the link function using the GLM function in R. For the model fitted, a strategy with a backward elimination of variables was applied using the deviance test with a significance level of 5% to exclude the variables and interactions. During sequential backward elimination, the parameter estimates for the model were accessed to evaluate model stability and to detect possible confounders.

Herd was included as a factor with nine levels, one for each herd. This approach was chosen because of the limited number of herds, making it questionable if the herds in the study could be considered a random sample of the population of Danish organic pig herds. Also, the data included one large herd that would influence the estimation of the variance component disproportionately. Season was included as a factor with two levels: summer (May to August) and the remaining part of the year (September to April). Parity was included as an ordinal variable (1 to >4) with both first- and second-order term. Body condition score of the sow was included as a factor with three levels: 2 = thin, 3 = moderate, 4 = fat. Total born piglets was included by a new variable created as the grand mean centered total born (cLS). This, along with the quadratic grand mean centered total born (cLS^2), was included as a continuous variable. Total born were included in this manner to increase the speed of convergence and stability in the parameter estimates and to facilitate the interpretation of the intercept. In the statistical analysis, sow was not included as a random effect. The effect of neglecting the correlation between litters within sow has been examined by analyzing a reduced data set including only one litter (randomly selected) per sow. The parameter estimates and *P*-values were similar to the parameter estimates and *P*-values from the analysis on the full data set and therefore the analysis was done on the latter.

The initial full model included the following variables and interactions: herd, season, parity, parity^2, BCS, cLS, cLS^2 and parity × BCS, parity × cLS and BCS × cLS.
The model analysis relies on these assumptions
Let y_i = observed number of stillborn piglets in litter i
We now consider y_i as a realization of the random variable Y_i that can take the values $\{0, 1, 2, 3, \ldots, n_i\}$. Then Y_i is binomial with parameters π_i and n_i. That is $Y_i \sim \text{Bin}(n_i, \pi_i)$. This provides the stochastic basis for the model. Then assume that the logit of the underlying probability (π_i) can be described by a linear function of the predictive variables. So what we model here is the probability of stillbirth within each litter.

The final reduced model was as follows:

$$\text{logit}(\pi_i) = \beta_0 + \beta_1 \, Herd_i + \beta_2 \, Season_i + \beta_3 \, parity_i + \beta_4 \, BCS_i + \beta_5 \, cLS_i + \beta_6 \, cLS_i^2 + \beta_7 \, parity \times BCS_i$$

Model assumptions were checked by plots of Pearson's residuals against the predictive values.

Results

The data included registrations from 5980 farrowings of which 810 were subsequently removed because of insufficient quality of the registrations. The order and the criteria of the removal of observations are shown in detail in Table 1.

Table 1 *Exclusion criteria of observations*

Exclusion criteria	Number of observations
Missing value total born	9
Invalid observations body condition	5
Missing value parity	232
Missing value date of parturition	6
Missing value sow number	17
Number of live-born dead larger than live-born	6
Missing value body condition	535
Final number of observations	5170

Invalid observations, missing values and nursing sows were removed from the data set before analysis.

The distribution between the nine herds of the 5170 farrowings included in the analysis is shown in Table 2. No stillborn pigs occurred in 2901 litters (56%). One herd (herd 1) differed markedly in size from the rest of the herds, contributing approximately one-third of the total number of observations and having almost twice as many observations as the second largest herd. The smallest herd contributed 108 observations.

The proportion of first parity sows varied from 20% to 35% between the herds, and the proportion of sows with parity above 4 ranged from 2% to 35%. In total, 59% to 100% of the sows had moderate body condition (score 3), 0% to 40% were thin (score 2) and 0% to 13% were fat (score 4). Sows from herd two were all given a BCS of 3. The farrowings were distributed evenly throughout the year with a variation between the herds of 19% to 42% of farrowings occurring during the summer months (May to August). During the 1-year study period, there were 82 906 piglets (both live-born and stillborn) giving an average total litter size of 16.0 ranging from 13.4 to 17.2 within the nine herds. On an average, 1.1 piglets/litter were stillborn with a range of 0.7 to 1.9 between the herds. Table 3 summarizes the parameter estimates, standard errors and the *P*-values of the level of significance of the logistic analysis.

The logistic analysis showed a significant effect of season with an increase of the probability of stillbirth during the summer months (May to August) compared with the remaining part of the year with an odds ratio of 1.15. A non-linear effect of litter size was seen where an increase in litter size from 11 to 16 resulted in an odds ratio of stillbirth of 1.11. An increase in litter size from 16 to 21 resulted in an odds ratio of stillbirth of 1.45. This effect was greatest in litters of 17 and above. Table 4 presents an overview of the odds ratios of stillbirth. A significant interaction between parity and body condition was found. In first parity sows, an increase in BCS from 2 to 3 and from 3 to 4 increased the probability of stillbirth with an odds ratio of 1.23 and 1.36, respectively. In sows with parity above 4, an increase in BCS from 2 to 3 and from 3 to 4 decreased the probability of stillbirth with an odds ratio of 0.68 and 0.79, respectively. The interaction between body condition and

Table 2 *Characteristics of the study herds and the percentage of sows, stratified by herd, in different categories of body condition score, parity and season of farrowing*

			Body condition (%)			Parity (%)					Season (%)	
Herds	Litter size	Farrowings (*n*)	2	3	4	1	2	3	4	>4	0	1
1	16.0	1481	4	83	13	24	21	16	13	27	66	34
2	17.2	714	0	100	0	21	14	15	17	33	68	32
3	16.3	763	5	93	2	34	27	25	12	2	58	42
4	17.0	714	10	79	11	35	26	13	11	15	62	38
5	15.1	322	1	90	10	31	30	14	11	13	72	28
6	14.6	454	21	74	5	34	16	20	18	12	67	33
7	15.6	482	7	86	7	30	14	17	19	20	66	34
8	13.4	108	0	98	2	24	10	10	22	33	81	19
9	14.7	132	40	59	1	20	14	17	13	35	63	37

Litter size = number of total born piglets (live-born + stillborn piglets).
Body condition: 2 = thin, 3 = moderate and 4 = fat.
Season: 1 = summer (May to August) and 0 = remaining part of the year (September to April).

Table 3 *Parameter estimates from the logistic analysis describing the effects of the explanatory variable on the probability of a piglet being stillborn*

Explanatory variables	Estimate	SE	*P*-value (deviance test)
Intercept	−3.90	0.144	
Herd			<0.001
2	0.44	0.041	
3	−0.30	0.054	
4	0.49	0.042	
5	0.22	0.065	
6	−0.07	0.064	
7	−0.37	0.063	
8	−0.25	0.127	
9	0.31	0.090	
Season			<0.001
1	0.14	0.029	
Body condition			0.1171
3	0.36	0.146	
4	0.80	0.243	
Parity	0.35	0.044	<0.001
Litter size (centered)	0.05	0.004	<0.001
Quadratic litter size	0.01	0.001	<0.001
Body condition × parity			<0.001
Body condition 3 × parity	−0.15	0.044	
Body condition 4 × parity	−0.28	0.062	

Litter size = number of total born piglets (live-born + stillborn piglets).
Quadratic litter size = quadratic grand mean centered litter size.
Season: 1 = summer (May to August) and 0 = remaining part of the year (September to April).

parity and the effect on the probability of stillbirth are shown in Figure 1.

Discussion

The sow lines used in both conventional and organic farming in Denmark are Danish LY crossbred from DanBred with a high

Table 4 *Selected odd ratios (ORs) for stillbirth of piglets*

Explanatory variables	OR	95% CI
Litter size		
Increase from 11 to 16	1.11	[1.05; 1.18]
Increase from 16 to 21	1.45	[1.40; 1.50]
Season		
0 : 1	1.15	[1.09; 1.22]
Body condition × parity		
Increase from 2 to 3 at parity 1	1.23	[1.02; 1.48]
Increase from 2 to 3 at parity >4	0.68	[0.55; 0.84]
Increase from 3 to 4 at parity 1	1.36	[1.00; 1.86]
Increase from 3 to 4 at parity >4	0.79	[0.70; 0.89]

Season: 1 = summer (May to August) and 0 = remaining part of the year (September to April).

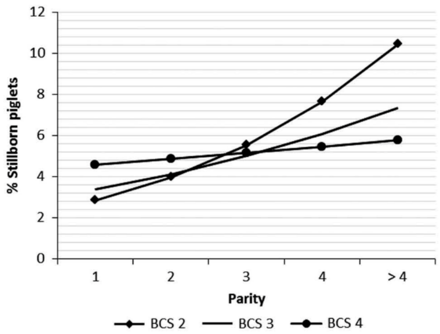


Figure 1 The percentage of stillborn piglets for each body condition score (BCS) stratified on parity. Thin first parity sows have a lower proportion of stillborn piglets compared with fat first parity sows. On the contrary, fat sows with parity above 4 have a lower proportion of stillborn piglets compared with thin sows with parity above 4. BCS where 2 = thin, 3 = moderate and 4 = fat. The percentage was calculated using the parameter estimates from the logistic analysis (Table 3).

genetic potential to produce large litters (Su *et al.*, 2007) which is a well-known risk factor for stillbirth (Lucia *et al.*, 2002; Hales *et al.*, 2014). The average of 16.0 total born piglets per litter in the present study is lower than the average number of total born piglets of 17.6 seen in commercial conventional Danish sow herds in 2015 (Olsen, 2016). In the present study, the average number of stillborn piglets was 1.1 piglets/litter, which is less than 1.7 reported from the conventional Danish production in 2015 (Olsen, 2016). A reason for these differences could be that dead organic piglets, compared with conventional piglets, have greater risk of disappearing in the time span from parturition until the first check-up, thereby reducing the number of total born piglets. The number of total born piglets in some of the herds included in the present study resembles the average number of total born piglets of 17.6 seen in commercial conventional Danish sow herds in 2015. Thus, it is reasonable to assume that the difference between the average of 16.0 total born piglets found in this study compared with the average of 17.6 in the Danish conventional production is not due to genetic factors, but relies more on the difference in management procedures and housing in the two production systems.

The association between litter size and stillbirth is well known and has been demonstrated in previous studies (Fraser *et al.*, 1997; Leenhouwers *et al.*, 1999; Hales *et al.*, 2014). A non-linear significant effect of litter size was found in the present study, which is in accordance with the findings of Canario *et al.* (2006). The association between a high number of total born piglets and stillbirth is believed to be due to prolonged parturition resulting in a higher risk of hypoxia in the piglets and, thereby, also a higher risk of stillbirth (Herpin *et al.*, 1996). The lower number of stillborn piglets per litter could, besides the risk of dead piglets disappearing (predation, getting lost in the straw bedding, eaten by the sow, etc.), also be attributed to the fact that organic sows have greater possibilities to nest build and exercise before parturition which have previously been associated with a decrease in the risk of stillbirth (Oliviero *et al.*, 2008 and 2010). The percentage of stillborn out of total born piglets was 7.0% which is in accordance with other studies where piglets were necropsied, both in a conventional and organic production setting (Damm *et al.*, 2005; Baxter *et al.*, 2009; Wientjes *et al.*, 2012). Stillbirths can be classified into two types based on the time of death (Sprecher *et al.*, 1974). Type I include deaths that occur before the end of gestation and is most commonly attributed to infectious causes. Type II includes deaths during parturition and is often associated with non-infectious causes such as dystocia and intrauterine asphyxia. Of all piglets classified as stillborn, type I accounts for 10% and type II accounts for 75%. The remaining 15% of piglets are not truly stillborn, but die immediately after birth (Leenhouwers *et al.*, 1999) and share physical appearance with type II piglets. They can only be distinguished from type II piglets by *postmortems*. These piglets that are not truly stillborn present the same disease ethology as type II piglets and, therefore, preventive measures to reduce stillbirths can be applied to both groups. In this study, the categorization of a piglet as being stillborn was done by the producers, and the quality of the data was, therefore, highly dependent on their ability to distinguish between stillborn and dead live-born piglets. It has been demonstrated that 9% of piglets classified as stillborn by producers were found at necropsy to have been live-born (inflated lungs) (Vaillancourt *et al.*, 1990). Therefore, Vaillancourt *et al.* (1990) emphasize that causes of mortality assessed by producers should be interpreted with caution. However, the producers in the Vaillancourt *et al.* (1990) study were not instructed in the recognition of stillborn piglets before the beginning of data collection. In the present study, producers and employees were carefully instructed and received practical guidance in the correct classification of stillborn piglets before the study period and it is, therefore, believed that the classification has been performed with sufficient accuracy. Also, the fact that the level of stillborn piglets in the present study was similar to the level found in studies where the piglets were necropsied (Damm *et al.*, 2005; Baxter *et al.*, 2009; Wientjes *et al.*, 2012) indicates that stillborn piglets were correctly categorized in the present study. Because of the large study population and practical limitations, it was not possible to collect valid information about inter-observer differences and include it in the analysis.

The risk of stillbirth was higher during the summer months (May to August) compared with the remaining part of the year with an odds ratio of 1.15. This is in accordance with Vanderhaeghe *et al.* (2010b) where an association was found between stillbirths and ambient temperatures at parturition above 22°C in the farrowing unit and Odehnalova *et al.* (2008) showing an increase in stillbirths with temperatures >28°C. As all the organic sows from this study were housed in outdoor huts, possibilities to control the ambient temperature were limited. According to The Danish Meteorological Institute, the summer months (June to August) of 2014 in Denmark had an average temperature of 16.8°C which is 1.6°C higher than the normal average for those months (Cappelen, 2014). It is, therefore, reasonable to assume that the increase in stillbirths during the summer months could be explained by high ambient temperatures at parturition. An effect of body condition was seen which is in accordance with other studies (Le Cozler *et al.*, 2002; Maes *et al.*, 2004; Vanderhaeghe *et al.*, 2010a). In the present study, the effect of body condition interacted with the effect of parity. Increasing parity is a well-known risk factor for stillbirths (Zaleski and Hacker, 1993; Leenhouwers *et al.*, 1999; Wientjes *et al.*, 2012). The interaction between body condition and parity in the present study showed that being thin compared with being fat increases the risk of stillbirth in sows with parity above 4. This is in accordance with the results of Vanderhaeghe *et al.* (2010a) who found that thin sows have a higher risk of getting stillborn piglets. On the other hand, the present study also showed that fat parity 1 sows have an increased risk of stillbirth compared with thin and normal parity 1 sows. This is in accordance with common knowledge of farmers to avoid fat gilts. The increased risk of stillbirth could be explained by excessive amounts of adipose tissue surrounding the birth canal providing a physical obstruction in the pelvic region at parturition potentially resulting in a prolonged farrowing, which is a well-known risk factor for stillbirth (Oliviero *et al.*, 2010). When interpreting parity, it is important to be aware that sows with high parity have been selected by the producer to continue in the production because of their performance in the preceding parities and are, therefore, not a randomly selected group. A low BCS in old sows might suggest an underlying problem such as disease or production exhaustion increasing the risk of stillbirth.

Conclusion

The study showed that being born during the summer months (May to August) and a litter size of more than 17 piglets are risk factors for stillbirth in nine organic pig herds in Denmark. An interaction between body condition and parity was present showing that thin sows with parity above 4 had a substantially increased risk of stillbirth compared with normal and fat sows with parity above 4. In contrast, for parity 1 sows risk of stillbirth was increased in fat sows compared with thin parity 1 sows.

Acknowledgment

The authors would like to thank technician Pia Haun Poulsen for planning the start-up of the study and all herd owners and their employees for their dedication and hard work during the 1-year study period.

References

Baxter EM, Jarvis S, Sherwood L, Farish M, Roehe R, Lawrence AB and Edwards SA 2011. Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. Applied Animal Behavioural Science 130, 28–41.

Baxter EM, Jarvis S, Sherwood L, Robson SK, Ormandy E, Farish M, Smurthwaite KM, Roehe R, Lawrence AB and Edwards SA 2009. Indicators of piglet survival in an outdoor farrowing system. Livestock Science 124, 266–276.

Borges VF, Bernardi ML, Bortolozzo FP and Wentz I 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine 70, 165–176.

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

Cappelen J 2014. Vejret i Danmark – Sommer 2014. Retrieved on 16 June 2016 from http://www.dmi.dk/vejr/arkiver/maanedsaesonaar/201402/vejret-i-danmark-sommeren-2014/.

Damm BI, Pedersen LJ, Heiskanen T and Nielsen NP 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Applied Animal Behavioural Science 92, 45–60.

Fraser D, Phillips PA and Thompson BK 1997. Farrowing behaviour and stillbirth in two environments: an evaluation of the restraint-stillbirth hypothesis. Applied Animal Behavioural Science 55, 51–66.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal 8, 113–120.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2015. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality. Journal of Animal Science 93, 4079–4088.

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

Holinger M, Edwards S, Illmann G, Leeb C, Milsova M, Prunier A, Rudolph G and Früh B 2015. Fertility. Improving health and welfare of pigs – a handbook for organic farmers, pp. 7–26. Research Institute of Organic Agriculture, Frick, Switzerland.

Kilbride AL, Mendl M, Statham P, Held S, Harris M, Marchant-Forde JN, Booth H and Green LE 2014. Risks associated with preweaning mortality in 855 litter on 39 commercial outdoor pig farms in England. Preventive Veterinary Medicine 117, 189–199.

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

Leenhouwers JI, van der Lende T and Knol EF 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243–253.

Lucia T, Correa MN, Deschamps JC, Bianchi I, Donin MA, Machado AC, Meincke W and Matheus JEM 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. Preventive Veterinary Medicine 53, 285–292.

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

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

Oliviero C, Heinonen A, Valros A, Halli O and Peltoniemi OAT 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Animal Reproduction Science 105, 365–377.

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

Olsen O 2016. Landsgennemsnit for produktivitet i svineproduktionen 2015 Notat nr. 1611. Retrieved on 16 June 2016 from http://vsp.lf.dk/~/media/Files/PDF%20-%20Publikationer/Notater%202016/Notat_1611.pdf.

Sorensen JT and Pedersen LJ 2013. Status, årsager og udfordringer i forhold til løsning af forhøjet dødelighed hos økologiske pattegrise DCA rapport 021. Aarhus University, Tjele, Denmark.

Sprecher DJ, Leman AD, Dziuk PD, Cropper M and Dedecker M 1974. Causes and control of swine stillbirths. Journal of the American Veterinary Medical Association 165, 698–701.

Su G, Lund MS and Sorensen D 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. Journal of Animal Science 85, 1385–1392.

Vaillancourt JP, Stein TE, Marsh WE, Leman AD and Dial GD 1990. Validation of producer-recorded causes of preweaning mortality in swine. Preventive Veterinary Medicine 10, 119–130.

Vanderhaeghe C, Dewulf J, de Kruif A and Maes D 2013. Non-infectious factors associated with stillbirth in pigs: a review. Animal Reproduction Science 139, 76–88.

Vanderhaeghe C, Dewulf J, De Vliegher S, Papadopoulos GA, de Kruif A and Maes D 2010a. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Animal Reproduction Science 120, 78–83.

Vanderhaeghe C, Dewulf J, Ribbens S, de Kruif A and Maes D 2010b. A cross-sectional study to collect risk factors associated with stillbirths in pig herds. Animal Reproduction Science 118, 62–68.

Wientjes JGM, Soede NM, van der Peet-Schwering CMC, van den Brand H and Kemp B 2012. Piglet uniformity and mortality in large organic litters: effects of parity and pre-mating diet composition. Livestock Science 144, 218–229.

Zaleski HM and Hacker RR 1993. Variables related to the progress of parturition and probability of stillbirth in swine. The Canadian Veterinary Journal 34, 109–113.

Zander K and Hamm U 2010. Consumer preferences for additional ethical attributes of organic food. Food Quality and Preference 21, 495–503.

9.2 Paper II

Sow-level risk factors for early piglet mortality and crushing in organic outdoor production

L. Rangstrup-Christensen*, M.A. Krogh, L.J. Pedersen and J.T. Sørensen

Department of Animal Science, Aarhus University, DK-8830, Tjele, Denmark

*Contact for correspondence and request for reprints, Lena Rangstrup-Christensen.

E-mail: lena.rangstrup@anis.au.dk

Published in Animal 2017, in press (doi: 10.1017/S1751731117002178).

Animal, page 1 of 9 © The Animal Consortium 2017
doi:10.1017/S1751731117002178

animal

Sow level risk factors for early piglet mortality and crushing in organic outdoor production

L. Rangstrup-Christensen[†], M. A. Krogh, L. J. Pedersen and J. T. Sørensen

Department of Animal Science, Aarhus University, DK-8830, Tjele, Denmark

(Received 11 May 2017; Accepted 24 July 2017)

Piglet mortality is a major problem in organic pig production affecting both farm economy and animal welfare. Knowledge is scarce on the risk factors of piglet mortality in Danish commercial organic pig production. The objectives of this study were to evaluate season, litter size, parity, sow body condition and stillborn littermates as risk factors for early piglet mortality and crushing of liveborn piglets from parturition until castration at day 3 to 5 postpartum (pp). The study was conducted over a 1-year period in nine commercial Danish organic pig herds practicing outdoor farrowing all year round. Data included recordings on 3393 farrowings with 50 284 liveborn piglets of which 14.8% died before castration. A subset of the dead piglets were collected and necropsied to identify crushed piglets. The average number of liveborn piglets per litter was 14.8 (SD = 3.7) and the average time from parturition until castration was 4.1 (SD = 1.7) days. A negative binomial regression analysis was used to model the effect of the predictive variables on the early piglet mortality accounting for different time periods from parturition to castration. An increase in maternal body condition score (BCS) and parity significantly increased the risk of dying between parturition and castration. Early mortality was found to be lowest during spring (March to May) and highest during summer (June to August). Being born into a litter with one or more stillborn littermates increased the risk of early mortality. The risk factors for crushing of piglets were evaluated using a logistic analysis. A significant effect of parity and litter size was found where the odds of at least one piglet in a litter with mortality was diagnosed as crushed increased with increasing parity and litter size. In conclusion, being born during summer (June to August), high parity and maternal BCS and stillborn littermates were found to be risk factors for piglet mortality between parturition and castration. In addition, parity and increasing litter size were found to be risk factors for crushing of piglets in litters with mortality.

Keywords: piglet mortality, organic production, crushing, parity, season

Implications

Piglet mortality constitutes a major problem in outdoor organic pig production. The vast majority of mortalities occur within the 1st week after parturition, and a substantial proportion of piglets are crushed to death by the sow. In the current study we identified high parity, fat sows, stillborn littermates and being born during the summer as risk factors for early piglet mortality. Furthermore, large litter size and high parity were identified as risk factors for crushing. Better management of sow body condition, heat exposure and breeding strategies towards smaller litters are possible ways to decrease piglet mortality in the future.

Introduction

High piglet mortality is a major problem in organic pig production affecting both farm economy and animal welfare. In the Danish organic pig production, sows farrow outside in small A-shaped farrowing huts, and weaning takes place after 7 weeks of lactation. This system provides sows with several potential beneficial conditions allowing them to exercise and perform behaviours that the sow is highly motivated to do, such as rooting and nest building, and providing an isolated and quiet environment around parturition. In spite of this, an excessive mortality is reported compared with the outdoor production in other countries such as Sweden (Wallenbeck *et al.*, 2009) and England (KilBride *et al.*, 2014) and to the conventional indoor production in Denmark (Jessen, 2016). A small study including 835 farrowings performed in 2007 and 2008 in seven Danish organic sow herds (Sorensen and Pedersen, 2013) revealed that 12.6% of liveborn piglets die within 3 to 7 days *postpartum* (*pp*) accounting for ~65% of the total liveborn pre-weaning mortality. This is in accordance with Wientjes *et al.* (2012) who found that 79% of pre-weaning liveborn deaths in organic loose-housed sows occur within the first

[†] E-mail: lena.rangstrup@anis.au.dk

7 days after parturition. The most prevalent cause of death in outdoor-housed sows is crushing by the sow, accounting for between 61% (Roehe *et al.*, 2009) and 74% (KilBride *et al.*, 2012) of the pre-weaning mortality. Large litters are a well-known risk factor for early piglet mortality both in conventional and organic production (Wientjes *et al.* 2012; Hales *et al.*, 2014 and 2015). The risk of piglets suffering from asphyxia after a long farrowing has been associated with larger litter size in conventional production (Herpin *et al.*, 1996). To date, a few studies have been performed to investigate the influence of the body condition of the sow on early piglet mortality. A study by Oliviero *et al.* (2010) found that the duration of farrowing was longer in sows with a higher back-fat thickness, which could negatively influence the piglet's chance of survival after parturition. It has been shown that an increase in BW of the sow increased the risk of piglet mortality (Wulbers-Mindermann *et al.*, 2002; Oliviero *et al.*, 2010) and that litters with an increased number of stillborn piglets also had a higher pre-weaning mortality of the liveborn piglets (Leenhouwers *et al.*, 1999). The parity of the sow has previously been shown to influence piglet mortality with increased parity, resulting in increased early piglet mortality (Wientjes *et al.*, 2012; Hales *et al.*, 2014). Season and ambient temperature have also been shown to affect piglet mortality. Berger *et al.* (1997) found that pre-weaning piglet mortality in outdoor production systems was higher in late autumn and early winter in France, and Wegner *et al.* (2014) found that increasing temperature at the day of parturition reduced pre-weaning mortality in an indoor production system.

Most of the current knowledge on sow level risk factors for piglet mortality originate from studies performed in conventional indoor production systems or from outdoor production systems that differ from the Danish outdoor production by using sows with a markedly smaller litter size. The risk factors might have a different impact and magnitude when investigated in a Danish outdoor production system. Large studies performed in a commercial outdoor setting, including a substantial number of farrowings, are needed in order to determine not only which risk factors are important but also their magnitude and how much, in terms of lower mortality, is gained by reducing these risk factors.

The objectives of this study were to evaluate season, litter size, parity, sow body condition and stillborn littermates as risk factors for (1) early mortality of liveborn piglets and (2) crushing of piglets in nine commercial Danish organic sow herds. Early piglet mortality is defined as liveborn piglets dying within the period from parturition until castration at day 3 to 5 *pp* (mean = 4.1; SD = 1.7).

Material and methods

The study was performed in nine commercial Danish organic sow herds during a 1-year period. Herds were organically certified by the Danish veterinary and Food Administration according to EU Council regulation (EC) No. 834/2007 and current Danish legislation: LBK no. 21 of 04/01/2017. The herds were not randomly selected but included in the project based on their willingness to take on the extra workload involved in data collection and on their specific interest in the study outcome. The size of the herds varied from 80 to 910 productive sows per year. In the study period, the total number of productive sows in the organic production in Denmark amounted to ~ 6000 of which around 3105 were included in the present study. The nine study herds constituted one third of all organic certified sow herds with a minimum of 50 productive sows per year.

Study design

The study was an observational prospective study performed from June 2014 to May 2015 in eight herds. One herd only collected data from July 2014 to May 2015. The data collection consisted of two parts: (1) A detailed recording of dead/alive piglets together with information about the sows in the farrowing unit and (2) Collection of dead piglets for necropsy from selected sows once in every season during the 1-year study period. The owner or the staff working in the herd performed both recordings and collection of dead piglets. The number of observers varied from one to five different persons, depending on the size of the herd. All observers were carefully instructed in how to register sow information correctly and count dead/alive piglets, perform the recordings, distinguish between stillborn and liveborn dead piglets and collect dead piglets, before the study period. Training, including practical instructions and demonstrations, was done in the farrowing unit to test, and if necessary adjust, the observers' ability to perform the recordings correctly. The herds were visited five times during the study period, and the procedures regarding recordings were continuously validated in order to assure the quality of the collected data.

Animals and housing

The sows in the study were Danish Landrace – Yorkshire (LY) crossbreeds (DanAvl). Sows were artificially inseminated with semen from DanAvl boars of which 80% to 90% were Duroc and 10% to 20% were Yorkshire or Landrace. During gestation, sows were kept in groups according to their size: small sows (mostly parity 1 and gilts), medium-sized sows and larger and older sows. In smaller herds, all sows were kept in one big group throughout gestation. Housing of gestating sows was either indoors on straw bedding with access to an outdoor enclosure or on pasture with access to a large shared hut with deep straw bedding. During gestation, the sows were fed restricted (2.5 to 3.5 kg/sow per day of a commercial gestation diet (~13 MJ ME/kg)). Daily allowance depended on sow body condition, management strategies and ambient temperature. All sows had *ad libitum* access to grass, straw or other similar roughage. All sows farrowed outdoors all year round. Sows were moved from the gestation group into the farrowing unit 10 to 14 days before expected parturition and were kept in individual paddocks of variable size (approximately between 270 and 450 m^2) containing a single hut (~4 m^2) with deep straw bedding and a fender to keep piglets from roaming freely outdoors. The piglet area outside the hut was ~1 m^2, and the fender was removed 10 to 14 days *pp*. In one herd, two huts were kept in each paddock. Sows were not fixated or restricted, at any time, during their stay in the farrowing unit in any of the nine herds. Reproduction in the herds was planned in order to cluster farrowings in groups of sows with expected farrowing date within 5 to 7 days. The interval between the groups was most commonly 3 weeks, and the number of sows in each farrowing group ranged from 15 to 100 between the study herds.

Recordings in the farrowing unit

Upon transfer to the farrowing unit, the sow identification number, body condition score (BCS) and parity were recorded. At the first check-up after parturition (0 to 24 h *pp*), the date of parturition was recorded along with the number of piglets that were liveborn, stillborn and liveborn that died *pp*. Alive piglets in the litter were counted once again, most often at castration. In some litters, castration took place at the first check-up after parturition. This being the case, piglets were counted a few days later. The time interval between parturition and the second counting varied from day 1 to day 10 (mean = 4.1; SD = 1.7) *pp*. Throughout the paper, the second counting of piglets will be referred to as having taken place at castration.

The number of piglets removed or added to a litter was recorded. The number of dead piglets within each litter from parturition until castration was calculated in the following manner: the number of liveborn piglets at parturition plus the number of piglets added to the litter from other sows minus number of piglets removed from the litter and given to other sows minus number of piglets alive at castration. Dead piglets at the first check-up after parturition were separated into stillborn piglets and liveborn that died *pp*. Stillborn piglets were macroscopically distinguished from liveborn piglets based on specific criteria. A piglet with intact cartilaginous tips on the hoofs without sign of wear in combination with the presence of a wide and uncontracted umbilical cord or intact or partially intact foetal membrane covering the piglet was classified as stillborn. If none of these signs were present, the piglet was classified as liveborn dead.

The BCS scale used on the sows was divided into three categories and modified from the scale described by Holinger *et al.* (2015). The categories were defined as follows: thin – ribs, backbone and hip bones are obvious or easily detected with pressure; normal – ribs, backbone and hip bones are barely visible or are barely felt with firm pressure and fat – ribs, backbone and hip bones cannot be seen or felt when firm pressure is applied, or fat deposits are clearly visible. In addition to the written description, pictures and drawings were provided as a visual aid to elaborate the differences between the three groups.

Sampling of dead piglets

Dead piglets were collected from around 25 sows during four separate time periods (once per season) in each herd: in total, around 100 sows in each herd.

In herds with more than 25 sows per farrowing group, the sows from whom to collect piglets were selected before parturition. The number of gilts to include was based on the percentage of gilts in the entire herd. Multiparous sows were included based on their gestation group so that one third of the sows were selected from each of the three gestation groups. The goal was to include sows representing each parity group. Sows from each gestation group were randomly distributed between the individual farrowing pens. After moving sows into the farrowing field, the observers marked the huts with sows for piglet sampling. This ensured that the sampled sows were not scattered throughout the entire farrowing field and thus making collection of piglets practically possible. In smaller herds with less than 25 sows per farrowing group, piglets were collected from all sows.

Postmortem examinations

Postmortem examinations were performed on a subset of the study population (all dead piglets in all nine farms). Dead piglets were sampled four times (summer, autumn, winter and spring) during the same 12-month period as the mortality recordings explained above were performed. Dead piglets were bagged together with a note stating the sow number, date and whether the piglet was euthanized (including the reason for euthanasia) or found dead. The observers were instructed to collect all dead piglets or remnants of piglets from the 25 sows with no regard to the state of decomposition or missing body parts. Piglets were kept frozen and were thawed before *postmortem* examinations, which were all conducted at the farms by the first author who has expertise in pathology. Piglets were diagnosed to have died from sow-inflicted injuries (crushed, trampled or savaged) if they were crushed with subcutaneous blood-tainted oedema or had other visible signs of trauma, such as internal bleedings, broken ribs or crushed skulls. The term crushed piglets will hence throughout the paper be used to describe all piglets that died of sow-inflicted injuries. Only piglets that died before castration were included in the present study.

Statistical analyses

Negative binomial regression analysis of risk factors for number of dead piglets. The relationship between the outcome variable: number of dead piglets within litter from parturition until castration and the explanatory predictive variables presented below were analysed with a negative binomial regression analysis using the glm.nb function with a log-link in R using the MASS-package.

A variable called live-time risk (LTR) was constructed by multiplying number of liveborn piglets to number of days from parturition until castration. The number of days at risk and the size of the litters varied, leading to a difference in exposure between litters. Information about time of death or time of removal or adding of individual piglets was not available and thus not included in the calculation of the LTR. The log (LTR) was used as the offset of the model to account for the differences of time at risk and litter size between litters.

Herd is included in the model as a factor with nine levels, one for each herd. The BCS of the sow was included as a factor with three levels: thin, normal and fat. Season was included as a factor with four levels: summer (June to August), autumn (September to November), winter (December to February) and spring (March to May). Parity was included as a factor with three levels: parity 1, parity 2 to 4 and parity >4. Stillborn piglets (still) were included as a dichotomous factor: 0 = no stillborn piglets and 1 = at least one stillborn piglet in the litter.

The initial full model included the following variables and interactions: herd, BCS, parity, still, season and BCS × parity, BCS × still, BCS × season, parity × still, parity × season, still × season.

The model analysis relies on these assumptions:

Let y_i = number of dead piglets in litter$_i$. Since y_i is a realisation of the random variable y_i that takes the values of 0,1,2,3 …. y_i can then be modelled as negative binomial as $y_i \sim \text{Negbin}(\pi, \kappa)$ and variance Var $(y_i) = \pi + (\pi^2/\kappa)$. The observed number of dead piglets in litter i (y_i) is distributed as an underlying mortality rate π and with a dispersion parameter κ.

For the model fitted, a strategy with a backward elimination of variables was applied using the deviance test with a significance level of 5% to exclude interactions and variables. During sequential backward elimination, the parameter estimates for the model were accessed to detect possible confounders and to evaluate model stability.

The final reduced model was as follows:

$$\log\left(\frac{y_i}{LTRi}\right) = \beta_0 + \beta_1\text{herd} + \beta_2\text{parity} + \beta_3\text{BCS} + \beta_4\text{season} + \beta_5\text{still}$$

$$\Downarrow$$

$$\log(y_i) - \log(\text{LTR}_i) = \beta_0 + \beta_1\text{herd} + \beta_2\text{parity} + \beta_3\text{BCS} + \beta_4\text{season} + \beta_5\text{still}$$

$$\Downarrow$$

$$\log(y_i) = \beta_0 + \beta_1\text{herd} + \beta_2\text{parity} + \beta_3\text{BCS} + \beta_4\text{season} + \beta_5\text{still} + \log(\text{LTR}_i)$$

Logistic analysis of risk factors for crushing of piglets. Data used for analysing the risk factors for crushing of piglets consisted of mortality recordings from litters containing necropsied piglets combined with the results of the *postmortem* examinations. Thus, all litters containing necropsied piglets were included with information about presence of crushed piglets in the litter.

A dichotomous outcome variable was used describing whether at least one piglet was diagnosed as crushed in litters with mortality. 1 = crushed piglets in the litter and 0 = no crushed piglets in the litter. The relationship between the outcome variable and the explanatory predictors listed below was analysed with a logistic analysis with the logit transform as the link function using the glm function in R. The explanatory variables: herd, parity, season, stillborn piglets, and BCS was included in the model as described for the negative binomial regression analysis. In addition, liveborn litter size (LS), along with the quadratic liveborn litter size (LS^2), was included as continuous variables.

The initial full model included the following variables and interactions: herd, parity, still, season, BCS, LS, LS^2, and parity × BCS, season × parity, season × still, parity × LS, still × LS, parity × still, BCS × LS.

The model analysis relies on these assumptions:

Let y_i = observation of at least one crushed piglets in litter i.

We now consider y_i as a realisation of the random variable y_i that can take the values 0 or 1. Then y_i is binomial with parameters π_i and n_i. That is $y_i \sim \text{Bin}(1, \pi_i)$. This provides the stochastic basis for the model. Then assume that the logit of the underlying probability (π_i) can be described by a linear function of the predictive variables. Therefore, what we model is the probability of at least one piglet in litters with mortality is diagnosed as crushed from parturition until castration within each litter. For the model fitted, a strategy with a backward elimination of variables was applied using the deviance test with a significance level of 5% to exclude interactions and variables. During sequential backward elimination, the parameter estimates for the model were accessed to detect possible confounders and to evaluate model stability.

The final reduced model was:

$$\log it(y_i) = \beta_0 + \beta_1\text{parity}_i + \beta_2\text{LS}_i$$

Model assumptions were checked by plotting the Pearson's residuals against the predictive values.

Results

Mortality recordings: negative binomial regression analysis

The data included recordings from 5175 farrowings. A total of 120 farrowings were removed due to missing recordings of the date of castration, and 17 farrowings were removed because the number of piglets alive at castration was missing. The remaining 5038 farrowings were performed by 3434 sows of which 1938 sows were included with one litter, 1388 sows were included with two litters, and 108 sows were included with three litters. All sows with more than one litter were identified, and one litter from each of these sows was randomly selected to be included in the analysis. This was done to eliminate the correlation between litters produced by the same sow and in total 1604 farrowings were removed. In addition, 41 litters with LTR = 0 were removed before analysis. Thus, the analysis included 3393 farrowings from 3393 sows. In these litters a total of 53 911 piglets were born of which 6.7% were stillborn and 14.8% of liveborn piglets died within the study period from parturition until castration. The average number of total born and liveborn piglets per litter was 15.9 (SD = 4.2) and 14.8 (SD = 3.9), respectively. The distributions of number of dead piglets per litter, number of days from parturition until castration and LTR are presented in Table 1.

Table 1 *The mean, median and 1st and 3rd quartile of dead piglets per litter, days from parturition until castration and live-time risk (LTR)*

	Mean	Median	1st quartile	3rd quartile
Dead piglets per litter	2.2	1	0	3
Days from parturition until castration	4.1	4	3	5
LTR	60.5	57	39	78

LTR: live-time risk calculated as number of liveborn piglets multiplied by number of days from parturition until castration.

The negative binomial regression analysis showed a significant effect of herd, season, BCS, parity and the presence of stillborn piglets in the litter on the number of dead piglets from parturition until castration. None of the tested interactions significantly affected the outcome. The result from the negative binomial regression analysis is presented in Table 2.

The analysis showed a significant effect of BCS with greatest risk of dying when born by a fat sow. A significant effect of parity was found with differences between all three parity groups with the greatest risk of mortality in the oldest sows. The effect of being born into a litter with one or more stillborn piglets provided a 1.28 times greater risk of dying compared with litters with no stillborn piglets. A significant effect of season was present with the lowest risk of mortality during spring and the highest risk during summer. Pairwise comparisons of the differences between all categories of BCS, parity and season together with the confidence intervals are illustrated in Figure 1.

To illustrate possible mortality outcome, two examples are given in Table 3 with different combinations of the risk factors.

Table 2 *Estimates from the negative binomial regression analysis describing the effects of the explanatory variables on the relative risk of a piglet being born alive and dying between parturition and castration*

Explanatory variable	Estimate	SE	*P*-value (dev. test)	Relative risk [95% CI][#]
Intercept	−3.82	0.113		
Herd			<0.001	
1	0	0		
2	0.30	0.071		1.35 [1.18; 1.55]
3	0.12	0.068		1.13 [0.99; 1.29]
4	0.04	0.071		1.03 [0.90; 1.19]
5	0.46	0.087		1.58 [1.33; 1.87]
6	−0.10	0.083		0.90 [0.77; 1.06]
7	0.27	0.078		1.30 [1.12; 1.52]
8	0.14	0.146		1.15 [0.86; 1.52]
9	0.28	0.134		1.33 [1.02; 1.72]
Body condition			<0.001	
Thin	0.00	0.000		
Normal	0.13	0.091		1.14 [0.95; 1.36]
Fat	0.27	0.118		1.31 [1.04; 1.65]
Parity			<0.001	
1	0.00	0.000		
2 to 4	0.37	0.050		1.44 [1.31; 1.59]
>4	0.49	0.065		1.64 [1.44; 1.86]
Stillborn			<0.001	
0	0.00	0.000		
1	0.25	0.044		1.28 [1.18; 1.40]
Season			<0.001	
Summer	0.00	0.000		
Autumn	−0.04	0.059		0.96 [0.86; 1.10]
Winter	−0.15	0.058		0.86 [0.77; 0.97]
Spring	−0.30	0.059		0.74 [0.66; 0.83]

[#]The relative risk is of early mortality compared with the category of the variable used as the intercept with an estimate of zero.

Crushed piglets: logistic analysis

In total, 3304 piglets from 839 litters were collected for *postmortem* inspection of which 325 piglets were discarded due to a high level of decomposition or missing body parts. The remaining 2979 piglets were collected from 818 litters, and crushing by the sow was the final cause of death in 1376 piglets (46%). In all, 286 litters were removed from the data due to insufficient information either about the sow (parity, BCS, sow identification number, liveborn piglets, etc.), the piglets (date of death or castration) or because mortality in the litter occurred after castration. In the remaining 532 litters, mortality due to crushing by the sow occurred in 395 (74%) of the litters. In 137 litters, only mortality due to other reasons than crushing occurred. The proportion of sows of parity 1, 2 to 4 and >4 were 20%, 58% and 22%, respectively. The distribution of observations between summer, autumn, winter and spring were 27%, 25%, 23% and 25%, respectively.

In first parity sows, 56% of the litters had crushed piglets. In sows with parity 2 to 4, 77% of the litters had crushed piglets, and in litters from sows of parity above four, 84% of the litters had crushed piglets. Mean liveborn litter size was 13.9 (SD = 4.4) in litters with no crushed piglets and 15.8 (SD = 3.8) in litters with crushed piglets.

The logistic analysis showed a significant effect of parity where the odds of at least one piglet in a litter with mortality was diagnosed as crushed increased with increasing parity. A linear effect of liveborn litter size was seen where the odds of at least one piglet in a litter with mortality was diagnosed as crushed increased with an odds ratio of 1.11 with an increase of liveborn litter size by one piglet. None of the tested interactions was found to significantly affect the outcome. The results of the logistic analysis together with odds ratios are presented in Table 4

Discussion

This study showed a clear effect of parity on risk of mortality with older sows being more at risk of high mortality than younger sows, which is in accordance with previous studies. Wientjes *et al.* (2012) showed that highly prolific organic sows with parity above four had a significantly higher early mortality compared with sows with lower parities, and Hales *et al.* (2014) showed that early piglet mortality was lower in first parity sows compared with older sows housed indoors in both pens and crates. Earlier studies on organic sows housed

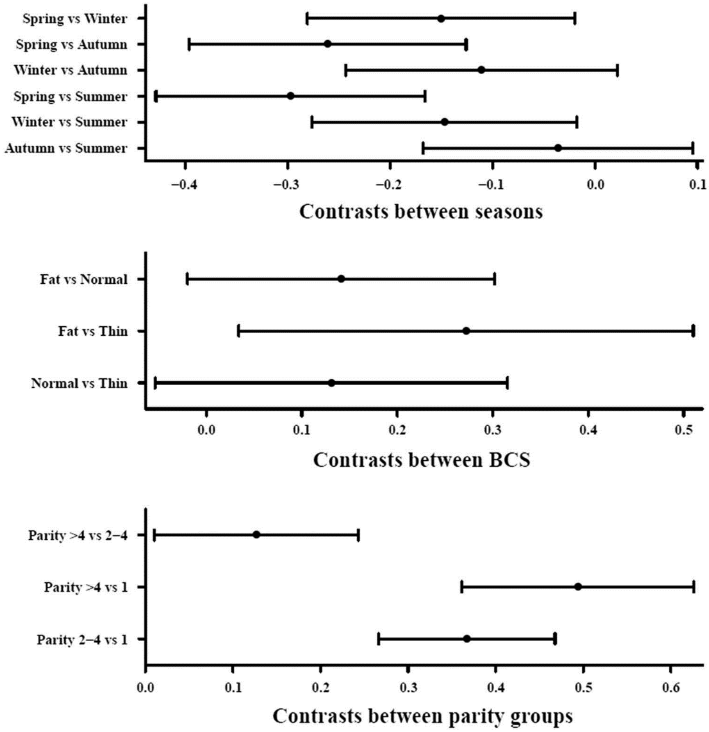


Figure 1 Pairwise comparisons of differences between the estimates of the various levels of the explanatory variables and the 95% confidence intervals of the differences. The estimates describe the effect of the explanatory variables on the relative risk of a piglet being born alive and dying before castration. Numbers on the *x*-axes are the differences between the estimates from the categories of the explanatory variables shown on the *y*-axes. Confidence intervals including zero equal no significant difference between variables shown on the *y*-axes. Top figure: Pairwise comparisons of differences between all four seasons included in the model. Middle figure: Pairwise comparisons of differences between the three categories of body condition score (BCS) included in the model. Bottom figure: Pairwise comparisons of differences between the three categories of parity included in the model.

Table 3 *Combinations of the estimates illustrating possible piglet mortality outcome*

Example	Parity	BCS	Season	Stillborn	e^ (sum estimates)	MLS, 4 days[¤]	MLS3+, 4 days[#]
1	1	Thin	Spring	No	0.02	1.14 piglets	1.37 piglets
2	>4	Fat	Summer	Yes	0.07	4.25 piglets	5.11 piglets

BCS = body condition score; MLS = mean litter size.
The examples include the intercept and a constructed estimate for an average herd.
[¤]MLS: mean litter size of 14.8 × 4 days (median time at risk).
[#]MLS3 +: mean litter size of 14.8 + 3 piglets × 4 days (median time at risk).

outdoors (Wientjes *et al.*, 2012) and indoor crated and loose sows (Weber *et al.*, 2009; Hales *et al.*, 2014) show a positive relationship between parity and litter size and between litter size and piglet mortality (Baxter *et al.*, 2009; Hales *et al.*, 2015). In the present study, the number of total born piglets was not directly included in the statistical analysis as a predictive variable but was only taken into account by the offset LTR and by the dichotomous variable stillborn piglets being correlated to litter size. Thus, increased litter size with increasing parity may partly explain the parity effect. In a study by Vasdal and Andersen (2012) it was found that less than half of the functional teats were accessible to suckle during the important colostrum period. This effect was more pronounced in older sows due to sub-functional udder morphology, making it difficult for piglets to reach teats even if the sow is lying in lateral recumbancy during lactation, resulting in an insufficient ingestion of colostrum by piglets, consequently increasing piglet mortality. When

Table 4 *Parameter estimates from the logistic analysis and odd ratios describing the effect of the explanatory variables on the risk of at least one piglet in a litter with mortality being diagnosed as crushed*

Explanatory variable	Estimate	SE	*P*-value (dev. test)	Odds ratio [95% CI]
Intercept	−1.11	0.399		
Parity			<0.001	
1	0.00	0.000		
2 to 4	0.73	0.244		2.08 [1.29; 3.35]#
>4	1.30	0.327		3.67 [1.96; 7.10]¤
Liveborn litter size				
Increased by 1 piglet	0.10	0.026	<0.001	1.11 [1.05; 1.16]*

#The odds ratio of at least one piglet in a litter with mortality being crushed when comparing parity two to four sows to parity 1 sows.
¤The odds ratio of at least one piglet in a litter with mortality being crushed when comparing parity >4 sows to parity 1 sows.
*The odds ratio of at least one piglet in a litter with mortality being crushed when increasing liveborn litter size with one piglet.

interpreting the effect of parity in a commercial production setting it is important to be aware of the selected culling of sows where farmers only permit sows assumed fit for farrowing to remain in production. The sow lines used in organic farming in Denmark are Danish Landrace-Yorskshire (LY) crossbred (DanAvl) with a high genetic potential to produce large litters (Su *et al.*, 2007). In the present study, the average of total born and liveborn piglets per litter was 15.9 (SD = 4.2) and 14.8 (SD = 3.9), respectively. This is less than what is seen in the Danish conventional production system where the number of total born piglets is 17.6 on average, and the number of liveborn piglets was 15.9 in 2015 (Jessen, 2016). This difference could be due to the increased risk of liveborn dead piglets from an organic production system disappearing (predation, getting lost in the straw bedding or being eaten by the sow) before the first check-up after parturition and thereby lowering the observation of total born piglets.

The present study showed increased risk of piglet mortality in fat sows, which is in accordance with an earlier study on indoor and outdoor loose-housed sows (Wulbers-Mindermann *et al.*, 2002). A high BCS has previously been shown to be associated with prolonged farrowing (Oliviero *et al.*, 2010) with an increased risk of piglets late in the birth order suffering from hypoxia at birth, rendering them less viable with an increased risk of dying later in lactation (Herpin *et al.*, 2001).

Litters with one or more stillborn piglets had higher mortality compared with litters with no stillborn piglets. This is in accordance with a study including both outdoor-housed, indoor loose sows and crated sows by Leenhouwers *et al.* (1999) and KilBride *et al.* (2012) showing an increase in mortality in litters with two or more stillborn piglets. Reasons for this association could be that presence of stillborn littermates might be due to dystocia rendering the liveborn piglets less viable. In addition, stillborn piglets might be associated with illness of the sow negatively influencing her capacity to nurse and to be attentive towards her piglets, consequently increasing piglet mortality and in particular crushing (Spicer *et al.*, 1986).

Mortality was highest during summer (June to August), but the mortality rate was also higher during autumn and winter than during spring, being the season with the lowest mortality rate. Sows have a thermal comfort zone around 20°C, whereas piglets thrive at temperatures above 30°C (Black *et al.*, 1993). It is, therefore, likely that the increase in early mortality during the warmer months of June to August is due to potential heat stress in sows rather than the temperature negatively affecting the piglets directly. In the outdoor production system, ambient temperatures cannot be controlled, and sows therefore need to be able to thermoregulate through wallowing. During the first days *pp* it has been shown that sows spend most of their time inside the hut together with the piglets and that, during this period, they use the wallow less frequently compared with later in gestation (Schild *et al.*, 2016), potentially leading to an increased risk of heat stress during periods of high ambient temperatures. High ambient temperature has previously been shown to have a negative effect on milk production with a decrease in milk production with temperatures above 25°C (Quiniou and Noblet, 1999), potentially leading to piglet mortality. In a study by Rangstrup-Christensen *et al.* (2016) it was found that the risk of stillbirth increased during the months of May to August compared with the rest of the year. As discussed previously, the mortality increases in litters with stillborn piglets. As no temperature or humidity recordings were performed, the mentioned causalities are somewhat speculative, and further studies, including behavioural observations and recordings of temperatures and humidity, on the subject are needed to determine which factors are directly involved in the effect of season on early piglet mortality.

Crushed piglets

In accordance with the present study, previous studies have shown that crushing accounts for the vast majority of early piglet mortality in both crated and indoor and outdoor loose-housed sows (Damm *et al.*, 2005; Roehe *et al.*, 2009; KilBride *et al.*, 2012). The significant effect of parity on the odds that at least one piglet in a litter with mortality is crushed could be explained by young sows being smaller in size (not necessary leaner) than older sows. A small sow occupies less of the hut, leaving the piglets more space to withdraw to, while she is lying down and getting up thus decreasing the risk of piglets being crushed. Older sows are larger, with potentially poorer leg health and mobility impairing the sows ability to control lying and react to piglet crushing. In a study by Vieuille *et al.* (2003) comparing behaviour of first and second parity sows housed in outdoor farrowing huts with regard to crushing of piglets, it was found that first parity sows were more responsive to squeals from piglets trapped underneath the sow. Vieuille *et al.* (2003) also found a relationship between crushed piglets and increasing litter size as was the case in the present study. The effect of litter size might be explained by the lack of space in the hut where many piglets might lead to crowding, making it difficult for the sow to lay down on a piglet-free area. In addition, large litters lead to crowding at the udder with a potential reduced milk consumption, resulting in hungry and weak piglets that are more exposed to crushing by the sow. Variation in birth weight within litter increases with litter size (Milligan *et al.*, 2002; Quiniou *et al.*, 2002) and with sow parity (Quesnel *et al.*, 2008). In heterogeneous litters, the number of small underweight piglets are higher (Quesnel *et al.*, 2008). Piglets with a low birth weight have greater risk of suffering from hypothermia (Herpin *et al.*, 2002) and have a longer latency to first suckle than heavier piglets (Pedersen *et al.*, 2011). In addition, small piglets in heterogeneous litters have difficulties obtaining a functional teat when competing with their heavier littermates. Weary *et al.* (1996) found that piglets with poor growth spend more time underneath a sitting and standing sow and thus are more prone to crushing.

Conclusion

The risk of early piglet mortality increased with increasing sow BCS and parity, with being born into a litter with one or more stillborn littermates and with being born during summer, autumn or winter compared to spring. In addition, increasing parity and liveborn litter size increased the probability of piglets being crushed in litters with mortality. Further studies, including behavioural observations and recordings of temperatures and humidity, are needed in order to determine the causal relationships and to suggest methods to prevent high mortality.

Acknowledgements

The authors would like to thank all the participating producers and their employees for their hard work and dedication throughout the 1-year study period. A special thanks to technician Pia Haun Poulsen for help and support during the study period. This work was funded as part of the VIPiglets project under the Organic RDD 2 programme, which is coordinated by International Centre for Research in Organic Food Systems (ICROFS). It has received grants, J.nr. 34009-13-0679, from the Green Growth and Development programme (GUDP) under the Danish Ministry of Food, Agriculture and Fisheries.

References

Baxter EM, Jarvis S, Sherwood L, Robson SK, Ormandy E, Farish M, Smurthwaite KM, Roehe R, Lawrence AB and Edwards SA 2009. Indicators of piglet survival in an outdoor farrowing system. Livestock. Science 124, 266–276.

Berger F, Dagorn J, LeDenmat M, Quillien JP, Vaudelet JC and Signoret JP 1997. Perinatal losses in outdoor pig breeding. A survey of factors influencing piglet mortality. Annales de zootechnie 46, 321–329.

Black JL, Mullan BP, Lorschy ML and Giles LR 1993. Lactation in the sow during heat-stress. Livestock Production Science 35, 153–170.

Damm BI, Pedersen LJ, Heiskanen T and Nielsen NP 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Applied Animal Behavioural Science 92, 45–60.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal 8, 113–120.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2015. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality. Journal of Animal Science 93, 4079–4088.

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

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

Herpin P, LeDividich J, Hulin JC, Fillaut M, DeMarco F and Bertin R 1996. Effect of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067–2075.

Holinger M, Edwards S, Illmann G, Leeb C, Milsova M, prunier A, Rudolph G and Früh B 2015. Improving health and welfare of pigs – a handbook for organic farmers, pp 7–26. Research Institute of Organic Agriculture, Frick, Switzerland.

Jessen O 2016. Landsgennemsnit for produktivitet i svineproduktionen 2015 Notat nr. 1611. Retrieved on 16 November 2016 from http://vsp.lf.dk/~/media/Files/PDF%20-%20Publikationer/Notater%202016/Notat_1611.pdf.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 104, 281–291.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Marchant-Forde JN, Booth H and Green LE 2014. Risks associated with preweaning mortality in 855 litters on 39 commercial outdoor pig farms in England. Preventive Veterinary Medicine 117, 189–199.

Leenhouwers JI, van der Lende T and Knol EF 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243–253.

Milligan BN, Fraser D and Kramer DL 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science 76, 181–191.

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

Pedersen LJ, Berg P, Jorgensen G and Andersen IL 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. Journal of Animal Science 89, 1207–1218.

Quesnel H, Brossard L, Valancogne A and Quiniou N 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal 2, 1842–1849.

Quiniou N, Dagorn J and Gaudre D 2002. Variation of piglets birth weight and consequences on subsequent performance. Livestock Production Science 78, 63–70.

Quiniou N and Noblet J 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. Journal of Animal Science 77, 2124–2134.

Rangstrup-Christensen L, Krogh MA, Pedersen LJ and Sørensen JT 2016. Sow-level risk factors for stillbirth of piglets in organic sow herds. Animal 11, 1078–1083.

Roehe R, Shrestha NP, Mekkawy W, Baxter EM, Knap PW, Smurthwaite KM, Jarvis S, Lawrence AB and Edwards SA 2009. Genetic analyses of piglet survival and individual birth weight on first generation data of a selection experiment for piglet survival under outdoor conditions. Livestock Science 121, 173–181.

Schild S-LA, Rangstrup-Christensen L and Pedersen LJ 2016. Increase sustainability of organic pig production with more vital piglets. In Food futures: ethics, science and culture, pp. 98–104.

Sorensen JT and Pedersen LJ 2013. Status, årsager og udfordringer i forhold til løsning af forhøjet dødelighed hos økologiske pattegrise DCA rapport 021. Aarhus University, Tjele, Denmark.

Spicer EM, Driesen SJ, Fahy VA, Horton BJ, Sims LD, Jones RT, Cutler RS and Prime RW 1986. Causes of preweaning mortality on a large intensive piggery. Australian Veterinary Journal 63, 71–75.

Su G, Lund MS and Sorensen D 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. Journal of Animal Science 85, 1385–1392.

Vasdal G and Andersen IL 2012. A note on teat accessibility and sow parity – consequences for newborn piglets. Livestock Science 146, 91–94.

Vieuille C, Berger F, Le Pape G and Bellanger D 2003. Sow behaviour involved in the crushing of piglets in outdoor farrowing huts – a brief report. Applied Animal Behaviour Science 80, 109–115.

Wallenbeck A, Gustafson G and Rydhmer L 2009. Sow performance and maternal behaviour in organic and conventional herds. Acta Agriculturae Scandinavica: Section A, Animal Science 59, 181–191.

Weary DM, Pajor EA, Thompson BK and Fraser D 1996. Risky behaviour by piglets: a trade off between feeding and risk of mortality by maternal crushing? Animal Behaviour 51, 619–624.

Weber R, Keil NM, Fehr M and Horat R 2009. Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livestock Science 124, 216–222.

Wegner K, Lambertz C, Das G, Reiner G and Gauly M 2014. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. Animal 8, 1526–1533.

Wientjes JGM, Soede NM, van der Peet-Schwering CMC, van den Brand H and Kemp B 2012. Piglet uniformity and mortality in large organic litters: effects of parity and pre-mating diet composition. Livestock Science 144, 218–229.

Wulbers-Mindermann M, Algers B, Berg C, Lundeheim N and Sigvardsson J 2002. Primiparous and multiparous maternal ability in sows in relation to indoor and outdoor farrowing systems. Livestock Production Science 73, 285–297.

9.3 Paper III

Causes of preweaning mortality in organic outdoor sow herds

L. Rangstrup-Christensen, S.-L.A. Schild, L.J. Pedersen and J.T. Sørensen*

Department of Animal Science, Aarhus University, DK-8830, Tjele, Denmark

*Contact for correspondence and request for reprints, Jan Tind Sørensen.

E-mail: jantind.sorensen@anis.au.dk

Submitted for publication in Research in Veterinary Science, October 2017.

Causes of preweaning mortality in organic outdoor sow herds

Lena Rangstrup-Christensen, Sarah-Lina Aagaard Schild, Lene Juul Pedersen and Jan Tind Sørensen*.
Department of Animal Science, Aarhus University, Blichers Allé 20, PO box 50, 8830 Tjele, Denmark

*Corresponding author. Address: Department of Animal Science, Aarhus University, Blichers Allé 20, PO box 50, 8830 Tjele, Denmark. Tel.: +45 871 57925. *E-mail address:* jantind.sorensen@anis.au.dk

Short title: Causes of piglet mortality in organic sow herds

Abstract

The aim of the current study was to 1) identify the causes of preweaning piglet mortality by performing *post-mortem* (*pm*) examinations on a subset of dead piglets from outdoor organic sow herds and 2) investigate the effect of season and parity on the proportions of mortality causes. The study was conducted over a one-year period, and dead piglets were collected for necropsy once during each of the four seasons in nine commercial Danish organic pig herds practicing outdoor farrowing all year round. In total, 2672 piglets were necropsied of which 60 % were live-born but died *post-partum (pp)*, 32 % were stillborn and 8 % were euthanised. Intra-partum deaths (type II stillbirth) accounted for 88 % of stillborn piglets, and these piglets had a statistically and significantly higher BMI than *pre-partum* dead piglets (p-value = 0.006). The proportion of *pre-partum* stillbirths (type I stillbirth) was higher in autumn compared to the remaining part of the year with an odds ratio of 2.4 (95 % CI [1.5;3.6]) and was higher in multiparous sows compared to first parity sows with an odds ratio of 2.3 (95 % CI[1.1;6.1]). Eighty-one percent of necropsied live-born piglets died within four days *pp* of which half had a body weight of less than 1 kg at the time of death. Crushed and starved piglets accounted for 83 % and 9 % of mortalities from zero to four days *pp*, respectively. Thirty-three percent of the crushed piglets (age zero to four days) had not suckled prior to death. The proportion of crushed piglets age zero to four days was lower in summer compared to the remaining part of the year with an odds ratio of 0.6 (95 % CI [0.5;0.9]) and was higher for multiparous sows compared to first parity sows with an odds ratio of 1.7 (95 % CI[1.1;2.6]).
In conclusion, sow parity and season affected the proportion of crushed piglets before four days of age. Furthermore, the group of crushed piglets was heterogeneous and consisted of both heavy well-fed piglets and small piglets with empty stomachs. Thus, management

implementations to lower mortality may differ depending on sow parity, season and individual piglet characteristics.

Keywords
Piglet mortality, crushing, stillbirth, necropsy, organic production

Introduction

Preweaning mortality in the Danish organic pig production is a major concern, consequently leading to poor piglet welfare and economic losses for the farmer. Danish organic sows farrow outdoors all year round in individual huts with a thick straw bedding. Providing sows with the opportunity to perform nest building behavior has been found to reduce the risk of crushing of piglets (Andersen et al., 2005). In addition, straw bedding provides insulation and helps maintain a warm microclimate in the nest, potentially lowering the postnatal temperature drop in new-born piglets. This enhances the piglets' chances of reaching the udder and ingesting colostrum which potentially increases piglet survival. Despite these beneficial conditions around farrowing, preweaning mortality in Danish organic sow herds is high compared to conventional Danish herds (21.5 %) (Jessen, 2016), Dutch organic herds (25.5 %) (Leenhouwers et al., 1999), Swedish organic herds (15.2 %) (Wallenbeck et al., 2009) and English outdoor herds (13.5 %) (KilBride et al., 2014). In a study from 2007/2008 comprising 1200 litters from seven Danish organic sow herds, the mean total preweaning mortality amounted to 33 % ranging from 25 % to 40 % between herds. The Danish organic pig production is characterised by large litters which together with increasing parity previously have been identified as risk factors for stillbirth, piglet mortality and crushing of piglets up to four days *pp* in Danish organic sow herds (Rangstrup-Christensen et al., 2017a and 2017b). The majority of live-born preweaning mortality occurs within the first four days *pp*, and crushing together with starvation are the most frequently reported causes of death across production systems (Edwards et al., 1994, Wientjes et al., 2012, Westin et al., 2015). However, the proportion of piglets dying from crushing compared to piglets dying from other causes differs between both production systems and herds (Weber et al., 2007, KilBride et al., 2012, Pandolfi et al., 2017). Piglets with low viability are slow in reaching the udder and are at greater risk of dying from starvation (Herpin et al., 1996). Furthermore, low viability piglets are less capable of reacting to posture changes in the sow rendering them more susceptible to crushing. In addition, starvation is a risk factor for crushing, and hungry piglets have been found to spend more time near a standing and sitting sow which increases the risk of crushing (Weary et al., 1996).

Knowledge on the causes of piglet mortality in commercial Danish organic sow herds is needed to implement suitable preventive measures to lower preweaning mortality in the future. Therefore, the aim of the current study was to 1) identify the causes of preweaning piglet mortality throughout a one-year period by performing *pm* examinations on a subset of dead piglets from outdoor organic sow herds and 2) investigate the effect of season and parity on the proportions of mortality causes.

Materials and methods

The study was observational and performed in nine Danish organic sow herds during a one-year study period from June 2014 until May 2015. Results on sow level risk factors for stillbirth, crushing and early piglet mortality have previously been published elsewhere (Rangstrup-Christensen et al., 2017a and 2017b). Information on sow parity and recordings of total preweaning piglet mortality from all farrowings in all herds throughout the one-year period (5877 farrowings) are included in the current study.
The nine study herds varied in size from 85 to 910 productive sows per year and were all commercial herds. They were included in the project because of their interest in the outcome of the study. Willingness and ability to take on the extra workload associated with participating in the study was a precondition. The total number of productive organic sows in Denmark during the study period amounted to around 6000 productive sows per year of which 3150 were included in the study.

Animals and housing

All sows in the study herds were Danish Landrace-Yorkshire crossbreds. Danish Duroc boars were used to service 80-90 % of sows, and Danish Landrace or Danish Yorkshire (DanAvl) were used for the remaining sows. Herds practiced batch-farrowing with either two, three or four week intervals. Depending on the management, gestating sows were kept outdoors on pasture with access to a large communal hut with straw bedding or indoors on deep straw bedding with access to an outdoor enclosure. During gestation, sows were fed a restricted (2.5 to 3.5 kg/sow/day of a commercial gestation diet (~13 MJ/DE/kg)). All sows had *ad libitum* access to grass or other similar roughage.
Sows farrowed outdoors all year round and were moved from the gestation unit to the farrowing unit 10-14 days prior to expected date of parturition. Each sow had access to a paddock of variable size (approximately 300 m2) containing a single hut (~4 m2) with deep straw bedding. Until around day 10 *pp*, a fender was placed in front of each hut

providing piglets with an outdoor area of approximately 1 m2 keeping them from roaming freely in the farrowing field. Male piglets were castrated (using local analgesia) at day 2 to 7 *pp*. No tail docking or teeth clipping were performed. Piglets were weaned at seven weeks of age. Piglets were cross-fostered in all herds (without using a standardised procedure) in order to equalise and standardise litters between sows.
In one herd (herd 5), management routines differed markedly from the remaining herds. There was no use of farrowing batches, and farrowings occurred continuously. In the farrowing filed, two sows shared the same paddock but still had individual huts, and piglets were weaned at 10 weeks of age.

Collection of piglets for necropsy
Collection of dead piglets was performed once every season (four rounds) during the study period. Piglets were collected from one farrowing batch in each herd in each season. The four collection periods were: July 2014, September/October 2014, January/February 2015 and April/May 2015. In five herds with farrowing batches with less than 30 sows, piglets were collected from all sows within the batch. In four herds, where farrowing batches exceeded 30 sows piglets were collected from a subset of 25 sows. The 25 sows were selected at transfer to the farrowing field. Gilts were included to mimic the percentage (20-25 %) of gilts in the herd and stock personnel selected older sows randomly.

Necropsies
Dead piglets were bagged and frozen at the farms with an information note stating the sow ear tag number, date and whether the piglet was found dead or euthanised. After each collection period, piglets were thawed, and necropsies were performed at the farm. All necropsies were performed by the same trained pathologist (first author) using a standardised protocol. The following information about each piglet was recorded: weight, crown to rump length (CTR), gender, level of decay, presence of cartilaginous tips on hoofs and stomach content and volume. The ultimate cause of death was recorded together with any contributing causes and general remarks and findings from the *pm* examination (see Table 1). Stillborn piglets were identified by testing if lung tissue sank when suspended in water. In addition, stillborn piglets were evaluated to determine if time of death occurred before or during parturition. Stillborn piglets with general autolysis of internal organs (rendering all organs a homogeneous red brick colour) were classified as having died prior to onset of parturition (type I stillbirth). Stillborn piglets with distinctively different

colours of internal organs with no sign of autolysis were classified as having died during parturition (type II stillbirth). Mummified piglets were not collected for necropsy.

Organisation of collected data

The age of live-born piglets was calculated by subtracting the day of birth from the day the piglet was found dead, and piglets were then divided into three age groups: 0-4 days, 5-10 days and > 10 days. Prior to data processing, the results from the *pm* examinations were grouped according to cause of death. Piglets with partly inflated lungs and intact cartilaginous tips on the hoofs were considered to present the same disease ethology as type II stillborn piglets and were therefore grouped as stillborn type II piglets. A description of the different classifications of causes of death are presented in Table 1.

Table 1. Definitions used to determine the cause of death.

Cause of death	**Description**
Prenatal deaths	
Stillborn type I Dead prior to parturition	Uninflated lung tissue (does not float in water) with autolysis of internal organs.
Stillborn type II Dead during parturition	Uninflated lung tissue (does not float in water) without autolysis of internal organs.
Stillborn type II Dead immediately after parturition	Partly inflated lung tissue and intact cartilaginous tips on the hoofs.
Crushing	Subcutaneous oedema, internal and/or external lacerations and/or fractures.
Starvation/emaciation	Prominent spine and ribs with little or no abdominal and subcutaneous fat in combination with scarce content in stomach and intestines.
Non-viable[#]	Body weight of less than 700 g or larger piglets with amnion fluids/meconium in the stomach. Both with remnants of the cartilaginous tips on hoofs and completely inflated lung tissue with no pathological findings explaining the cause of death.
Infection	
Septicaemia	Enlarged liver, pleuritis or peritonitis; generalised arthritis.
Enteritis	Necrotising proliferative lesions in intestines.
Pneumonia	Consolidated lung tissue, necrotic areas, fibrinous or fibrous pleuritis on the lungs and/or adhesions to the pleura.
Miscellaneous	Miscellaneous occurring diagnoses such as congenital malformations, anaemia and complications form castration.
Unknown	No pathological findings present.
Euthanised	Reported as euthanised by staff.
Not fit for necropsy	Advanced decomposition.

#: Only piglets of zero to four days of age.

Statistical analyses

Logistic analyses

Logistic analyses were used to test for a significant effect of herd, season and parity as explanatory variables on: 1) the proportion of type I stillbirths out of all stillborn piglets where type could be determined, 2) the proportion of starved piglets out of necropsied piglets in zero to four days old piglets and 3) the proportion of crushed piglets out of necropsied piglets in zero to four days old piglets. Explanatory variables with a significance level > 20 % in deviance test were not included in the full model. For the model fitted, a strategy with a backward elimination of variables was applied using the deviance test with a significance level of 5 % to exclude interactions and variables. During sequential backward elimination, the parameter estimates for the model were accessed to detect possible confounders and to evaluate model stability.

Season and parity were included as dichotomous factors in all models to avoid 0 and 1 parametrisation of the predictive estimates.

<u>Model 1 – Stillbirth</u>

A dichotomous outcome variable was used describing whether a stillborn piglet was classified as type I (1) or type II (0). Season was included as a dichotomous factor with autumn (1) and the remaining part of the year (0). Parity was included as a dichotomous factor with first parity sows (0) and multiparous sows (1). Herd was included as a fixed effect. The initial full model included all three variables and their two-way interactions. The final reduced model included parity and season as explanatory variables.

The analysis was performed using the glm function from the stat package in R.

<u>Model 2 – Starvation</u>

A dichotomous outcome variable was used describing whether a piglet was diagnosed to have died from starvation (1) or from other reasons than starvation (0). Season was included as a dichotomous factor with summer (1) and remaining part of the year (0). Parity was included as a dichotomous factor with first parity sows (0) and multiparous sows (1). The initial full model included the two explanatory variables and their two-way interaction. The final reduced model included season as explanatory variable.

The analysis was performed using the glm function from the stat package in R.

Model 3 – Crushing

A dichotomous outcome variable was used describing whether a piglet died from crushing (1) or from other reasons than crushing (0). Season was included as a dichotomous factor with summer (1) and the remaining part of the year (0). Parity was included as a dichotomous factor with first parity sows (0) and multiparous sows (1). Herd was included as a random effect. The initial full model included the fixed effects of parity and season and herd as a random effect. The initial full model was not reduced.
The analysis were performed using the glmer function from the lme4 package in R.

Difference in median and proportions

Difference between median Body Mass Index (BMI) in type I and type II stillborn piglets was analysed using a non-parametric Wilcoxon rank sum test with continuity correction. Difference between median weights in crushed piglets age zero to four days was analysed using a non-parametric Kruskal-Wallis rank sum test.
Sex ratios (males/males+females) were analysed using a 1-sample proportions test with continuity correction.

Results

Preweaning mortality was based on recordings from 5877 farrowings.
One herd (herd 1) differed markedly from the rest of the herds both in size by contributing approximately one fourth of the 5877 farrowings used to calculate preweaning mortality and by a substantial lower preweaning mortality compared to the other herds (21.4 % (herd 1) vs 29.5 % (average)). Herd 2 contributed with a substantially larger amount of necropsied piglets compared to the rest of the herds. Characteristics of the nine herds along with information about preweaning mortality are shown in Table 2.
In total, 3304 piglets were collected from 803 sows in the nine herds. Of these, 325 piglets were discarded prior to necropsy due to advanced decomposition. *Pm* results from 307 piglets were excluded due to insufficient quality of data. In total, 2672 piglets from 698 sows were included of which 844 were stillborn, 1606 died *pp* and 222 were euthanised. From here on, the term piglets dead *pp* only refers to live-born piglets dying unassisted and will not include euthanised piglets.
Only intact piglets with no missing organs or body parts and piglets with no or a minor level of decay are included in presented means and medians of body weight and Body Mass Index [BMI= weight (kg)/CTR $(m)^2$].

Table 2. Presentation of the nine study herds with regard to size, total number of farrowings during the one-year study period, total number of necropsied piglets together with total born, live-born and weaned litter size and preweaning mortality within the nine study herds.

Herd	Size[1]	Parity[2] (%)		Litters[3] (n)	Necropsied piglets[4] (n)	Litter size[5] (n)			Preweaning mortality (%)		
		1	> 1			TB	LB	WLS	SB[6]	LB[7]	TB[8]
1	910	24	76	1594	241	15.8	14.8	12.5	6.5	15.9	21.4
2	360	21	79	727	499	17.2	15.3	11.5	11.2	25.0	33.3
3	550	33	67	968	340	16.7	16.0	11.4	4.0	29.0	31.8
4	345	37	63	752	381	16.9	15.1	11.9	10.4	21.5	29.7
5	200	32	68	335	257	14.8	13.8	8.9	6.7	35.5	39.9
6	275	37	63	564	204	14.8	14.0	11.0	5.0	21.4	25.3
7	270	28	72	559	312	15.5	14.9	11.4	4.6	23.2	26.6
8	85	21	79	131	172	13.5	12.8	9.5	5.5	25.7	27.7
9	110	21	79	227	266	14.7	13.3	10.3	9.0	23.0	30.0
Total[9]	3105	29	71	5877	2672	15.5	14.4	10.9	7.0	24.5	29.5

1: Productive sows per year. 2: Percentages of sows grouped according to parity where 1 = first parity sows and 2 = multiparous sows. 3: Litters from each herd included in the mortality recordings. 4: Number of piglets necropsied from each farm. 5: TB = Total born litter size, LB = Live-born litter size, WLS = Number of weaned piglets per farrowing. 6: Percentage of stillborn piglets = (stillborn/total born)*100. 7: Live-born mortality = ((live-born – weaned)/ live-born)*100. 8: Total born mortality = ((total born – weaned)/ total born) * 100. 9: Litter size and preweaning mortality are given as the mean of the nine herds.

Stillborn piglets

Stillborn piglets accounted for 32 % of all piglets sampled for necropsy. In 11 % of stillborn piglets, the type could not be determined. Piglets categorised into either type I or type II amounted to 752 of which 88 % were type II. The mean body weight of both type I and II stillborn piglets was 1014 g ranging from 280 g to 2350 g, and the mean CTR was 26.7 cm ranging from 17 cm to 35 cm. Type II piglets were found to have a significantly higher median BMI compared to type I piglets (13.6 vs. 12.2 tested using a Wilcoxon rank sum test, p-value = 0.006). The proportion of males was not significantly different to 0.5 (0.53, $X_1^2 = 1.82$, p-value = 0.18). Distribution of gender, mean weight and median BMI of stillborn piglets are shown in details in Table 3.

Table 3. Stillborn piglets presented according to type with distribution of gender, mean weight and CTR and median BMI.

Type	Piglets		Gender[1] (%)		Weight (g)		CTR[2] (cm)		BMI[3]		
	n	%	F	M	Mean	±SE	Mean	±SE	Median	1st qu.	3rd qu.
Type I	92	12	52	48	921	45	26.1	0.37	12.2	11.2	14.7
Type II	660	82	47	53	1024	15	26.7	0.13	13.6	12.0	15.3
Total	752	100	47	53	1014	14	26.7	0.12	13.6	11.7	15.3

1: F = female, M = male. 2: CTR = length of piglet measured from crown to rump.
3: Body Mass Index = BMI [weight (kg)/CTR (m)^2].

The distribution of stillbirth type between seasons and between first parity sows and multiparous sows is shown in Figure 1. The proportion of type I piglets was greater in autumn compared to the remaining part of the year with an odds ratio of 2.4 (95 % CI [1.5;3.6]) and in multiparous sows compared to first parity sows with an odds ratio of 2.3 (95 % CI[1.1;6.1]). No significant difference in proportion of type I stillbirths was seen between herds.

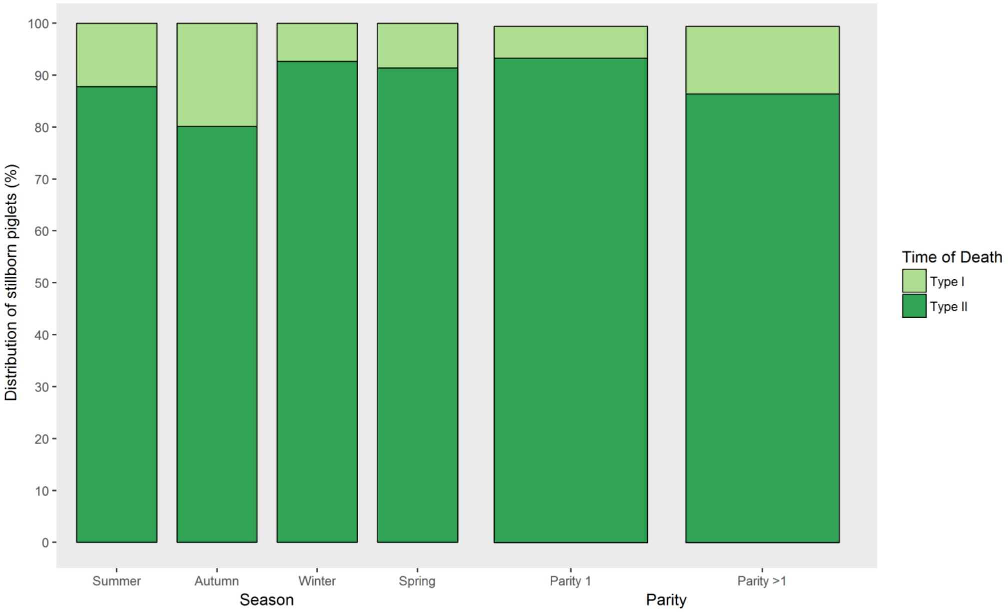


Figure 1. Distribution of type I and type II stillbirths between seasons and parity groups.

Piglets dead pp

Eighty-one percent of the necropsied piglets died between day zero and four *pp*. Crushed and starved piglets accounted for 77 % and 10 % of the necropsied piglets, respectively. Forty-four percent of piglets dying *pp* were female, 47 % were entire males and 9 % were castrated males. The proportion of males (entire and castrated) were significantly different to 0.5 (0.56, X_1^2=21.36, p-value < 0.001).

In total, 1233 piglets were crushed. The proportion of crushed piglets within each of the three age groups were 83 %, 67 % and 24 %, respectively. At the *pm* examinations, starvation, infection and injuries (such as abdominal bleedings due to castration) were considered a contributing factor to crushing in 14 %, 1 % and 1 % of all crushed piglets, respectively. Non-viable piglets accounted for 3 % of piglets dead *pp* of which 58 % had a bodyweight of less than 700 g, 24 % between 700 g and 1 kg and 18 % had a body weight above 1 kg. None of the piglets dying *pp* had abrasions on the carpal joint or lesions in the coronary band.

The distribution of gender and age of piglets dead *pp* together with the parity of the sow stratified by diagnoses are presented in Table 4.

Table 4. Distribution of gender and age of piglets dead *pp* together with parity of the sow stratified on cause of death.

	Piglets		Gender[1] (%)			Age[2] (%)			Parity[3] (%)	
	N	%	F	M	C	0-4	5-10	>10	1	> 1
Crushed	1233	76.8	44	50	5	87	10	3	11	89
Starvation	161	10.0	47	38	13	71	21	8	15	85
Infection	75	4.7	44	12	40	21	21	58	37	63
Unknown	66	4.1	44	26	21	42	9	49	30	70
Non-viable	44	2.7	27	73	-	100	-	-	18	82
Misc. #	27	1.7	37	19	44	56	19	26	15	85
Total	1606	100	44	47	9	81	11	8	14	86

1: F = female, M = male C = castrated male 2: Age of piglets measured in days.
3: 1 = First parity sows, > 1: multiparous sows. #: Miscellaneous diagnoses with a low frequency.

Characteristics of live-born dead piglets stratified on cause of death within each age category are presented in Table 5.

Table 5. Characteristics of piglets dead *pp* divided into age groups and stratified on cause of death.

	Piglets[1]	Gender[2] (%)			Stomach content[3] (%)			Weight (g)		BMI[4]		
Age 0 to 4		F	M	C	Empty	Half	Full	Mean	±SE	Median	1st qu.	3rd qu.
Crushed	1079	44	52	3	33	37	31	1089	13	13.9	12.0	15.3
Starvation	115	50	43	6	85	15	0	770	30	11.3	10.2	13.0
Non-viable	44	27	73	0	89	9	2	787	59	11.8	10.3	12.9
Infection	15	67	33	0	13	27	60	1210	95	13.6	12.5	16.1
Misc. #	15	40	27	33	40	13	47	1279	97	15.8	13.9	17.8
Unknown	28	36	50	11	40	40	20	1161	64	14.6	12.9	15.4
Total	1296	44	52	4	40	33	27	1056	12	13.6	11.7	15.7
Age 5 to 10												
Crushed	123	38	40	20	19	41	40	1536	61	15.9	13.7	19.2
Starvation	33	46	24	27	63	37	0	1045	60	13.2	11.3	14.6
Infection	16	44	12	44	19	44	37	1643	100	17.7	16.2	19.7
Misc. #	5	20	20	60	20	20	60	1916	303	19.6	17.2	21.5
Unknown	6	33	17	17	33	67	-	1680	587	15.3	12.1	17.1
Total	183	39	34	24	28	38	34	1472	48	15.4	13.3	19.1
Age > 10												
Crushed	31	55	7	36	21	41	38	3044	461	20.2	16.8	21.5
Starvation	13	23	31	39	100	0	0	1490	176	14.4	12.5	16.6
Infection	44	36	5	52	21	48	31	3628	317	21.0	19.2	24.1
Misc. #	7	43	0	57	29	57	14	3370	1060	21.5	15.6	26.7
Unknown	32	53	6	31	25	39	36	4901	586	21.8	19.4	24.1
Total	127	44	8	42	31	40	29	3548	236	20.5	17.1	23.7

1: Number of piglets. 2: F = female, M = male C = castrated male (piglets with no available data are not included and thus, rows do not always sum to 100 percent). 3: Piglets with amnion fluids and meconium in stomach (only in piglets age zero to four days) are included in the empty category. 4: Body Mass Index = BMI [weight (kg)/CTR (m)^2]. #: Miscellaneous sporadic occurring diagnoses with a low frequency.

Piglets age zero to four days

Crushed and starved piglets accounted for 83 % and 9 %, respectively, of piglets dying from day zero to day four *pp*. Forty-nine percent had a body weight of less than 1 kg, 36 % between 1 kg and 1.5 kg and 15 % had a body weight above 1.5 kg.

The distribution of the diagnoses on seasons and on first parity sows and multiparous sows is shown in Figure 2. There was a significant effect of summer on the proportion of crushed piglets with a lower proportion of crushed piglets in summer compared to the remaining part of the year with an odds ratio of 0.6 (95 % CI [0.5;0.9]). The proportion of crushed piglets was greater in multiparous sows compared to first parity sows with an odds ratio of 1.7 (95 % CI[1.1;2.6]). There was a significant effect of summer compared to the remaining part of the year on the proportion of starved piglets with an odds ratio of 2.6 (95 % CI [1.8;3.9]). There was no effect of parity on the proportion of starved piglets.

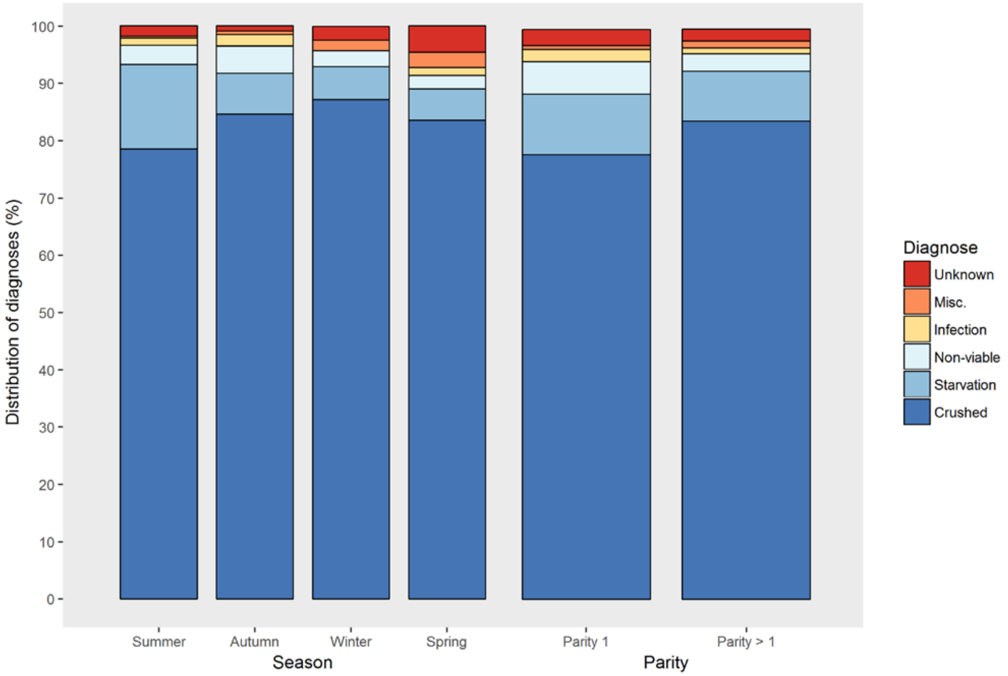


Figure 2. The distribution of piglets age zero to four days between all six diagnoses within seasons and parity groups.

The proportion of crushed and starved piglets (age zero to four days) ranged from 80 % to 95 % and from 2 % to 14 %, respectively. The distribution of all six diagnose categories within each herd together with herd live-born preweaning mortality is presented in Figure 3.

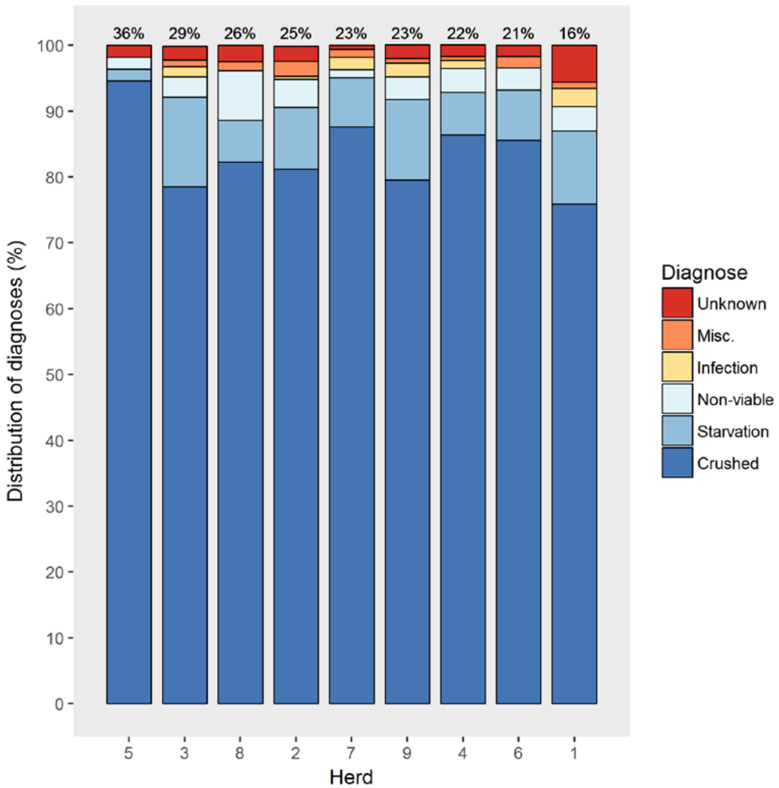


Figure 3. The distribution of piglets age zero to four days between all six diagnoses within each herd. Live-born mortality in each herd is specified above columns.

<u>Crushed piglets age zero to four days</u>

Forty-five percent of the crushed piglets (age zero to four days) had a body weight of less than 1 kg, 39 % between 1 kg and 1.5 kg and 16 % had a body weight above 1.5 kg. The proportion of males (entire and castrated) was 55 % which was significantly different to 0.5 (0.55, $X_1^2 = 8.90$, p-value = 0.003).

Nine hundred of the crushed piglets (age zero to four days) were intact with no missing organs or body parts and with no or a minor level of decay. Stomachs were empty in 33 %, half-full in 35 % and full in 32 % of these piglets. The median weights of piglets with an empty, half-full and full stomach were 820 g, 1040 g and 1290 g, respectively, and they were all significantly different (Kruskal-Wallis rank sum test, p-value < 0.001). The weight distribution of crushed piglets (age zero to four days) grouped according to quantity of milk in stomach at time of death is shown in Figure 4.

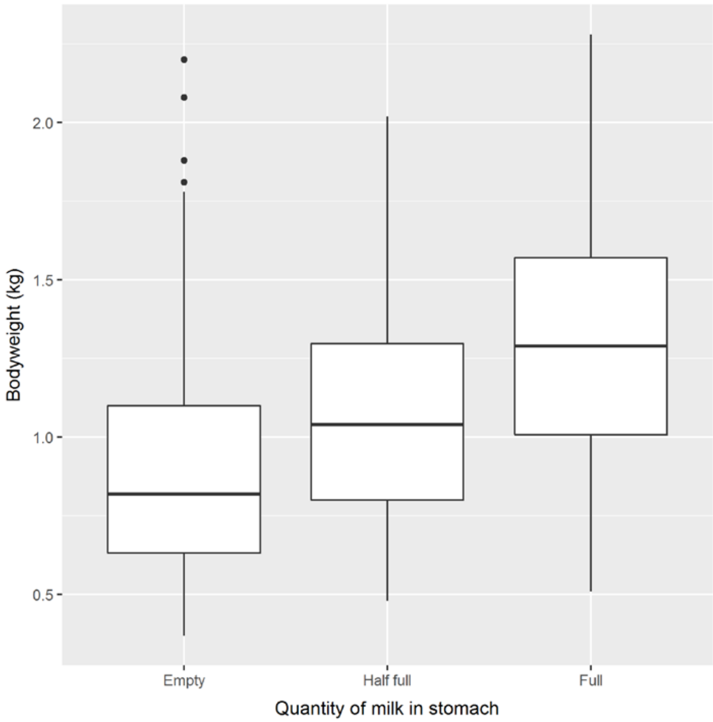


Figure 4. Boxplot showing the weight distribution of 900 crushed piglets (age zero to four days) grouped together according to quantity of milk in the stomach at time of death.

Miscellaneous

A total 27 piglets were diagnosed with miscellaneous causes of death. Nine piglets died of acute complications following castration with bleedings from the castration wound into the abdomen. Seven piglets died of congenital malformations, six from gastro-intestinal complications such as constipation, volvulus and necrotic anal prolapse, four piglets were severely anaemic and three piglets died with ascites and/or jaundice.

Euthanised piglets

The proportion of euthanised piglets was 8.3 % of which 86 %, 9 % and 5 % were euthanised within the three age groups, respectively. The proportion of euthanised piglets out of the total number of necropsied piglets ranged from 2 % to 12 % between herds. Detailed information about pathological findings together with gender and median BMI of euthanised piglets is presented in Table 8.

Table 8. Gender, weight and BMI of euthanised piglets stratified on cause of euthanasia.

Cause of euthanasia	Piglets		Gender[1] (%)			Weight (g)		BMI[2]		
	n	%	F	M	C	Mean	±SE	Median	1st qu.	3rd qu.
Non-viable	98	44	58	40	2	560	11	10.9	9.7	11.8
Starvation	47	21	57	32	11	870	49	12.0	10.7	13.0
Injured¤	19	8	42	37	16	1672	451	15.1	14.0	18.3
Infection	13	6	54	23	23	1307	120	14.8	13.0	18.3
Cong. malformation£	6	3	33	67	0	845	108	13.3	12.5	14.1
Unknown#	39	18	33	67	0	1284	132	14.4	12.8	17.1
Total	222	100	54	37	9	888	50	11.9	10.5	13.8

1: F = female, M = male, C = castrated male. 2: Body Mass Index = BMI [weight (kg)/CTR (m)^2].
¤: The injured piglets counted 15 piglets with bite wounds or other skin lacerations and four piglets with complications from castration. Piglets euthanised due to infection included five piglets with generalised exudative dermatitis, two with purulent arthritis in multiple joints, one with hepatitis and five were diagnosed with enteritis. £: Congenital malformation. #: No pathological findings and a body weight larger than 700 g.

Discussion

The total preweaning mortality in organic sow herds found in this study was on average 29.5 % (21.4-39.9 %) which is lower than the 33 % total preweaning mortality reported within Danish organic pig producing herds a decade ago (reported in Sorensen and Pedersen, 2013). In 2015, the mean total preweaning mortality in Danish conventional (indoor) herds was 21.5 % and the average number of total born piglets per litter 17.6 (Jessen, 2016). Thus, in general the average number of total born piglets per litter was 2.1 piglets lower (15.5) and total preweaning mortality 8.4 % higher (29.5 %) in the present study compared to that of conventional herds. The reason for the lower litter size in the organic herds may be explained by the origin of the sows used. As the organic producers may only purchase 20 % of their replacement gilts from conventional breeding herds (and because no organic breeding herds exists), the majority of the replacement gilts are bred within the herd. This could lead to a slower genetic progress that may be causing the lower litter sizes seen in the organic herds. The decline in mortality since 2007/2008 and the low mortality seen for herd 1 (21.4 %) suggest that Danish organic production conditions are not necessarily synonymous with a high piglet mortality. The variation in mortality between herds suggests that herd level risk factors such as management routines could account for some of the variation. Herd 1 was the largest participating herd with 910 productive sows per year, and recent work by Rosvold et al. (2017) showed a positive correlation between preweaning mortality and the size of the farrowing batch with a lower mortality for large farrowing batches. This effect is believed to be caused by a higher professionalism and systematic routines around farrowing in these herds (Rosvold et al., 2017). In addition, large herds with large farrowing batches have better opportunities to

implement management routines to improve survival by e.g. using nurse sows to handle surplus new-born piglets, thus potentially decreasing preweaning mortality. In herd 1 to 4, nurse sows (Baxter et al., 2013) were routinely used to handle surplus piglets.
The age distribution of necropsied piglets where 81 % died within four days *pp* is in accordance with previous findings in indoor loose-housed sows (Marchant et al., 2000, Rootwelt et al., 2013). This suggests that the necropsied piglets in the present study compose a representative sample of all dead piglets with regard to age distribution.

Males vs. females

The proportion of male piglets in the group of necropsied piglets dead *pp* was significantly larger (differed significantly to 0.5) than that of females. This is in accordance with Baxter et al. (2012) who suggest a male-biased piglet mortality causing more males than females to die during the preweaning period. Male piglets in the latter study were at greater risk of being crushed or dying due to other causes. A contributing factor to the higher proportion of dead males could be the surgical castration of male piglets with no use of anaesthesia. The pain and discomfort following this procedure together with potential complications such as abdominal bleedings, local infections and septicaemia could pose as disadvantageous compared to their female littermates. In accordance with Baxter et al. (2012), no significant effect of gender on the risk of stillbirth was found.

Stillborn piglets

The current results, showing a distribution of type I and type II stillborn piglets with type I piglets accounting for 12 % and type II for 88 % of the stillborn, are in accordance with Leenhouwers et al. (1999). They found that piglets classified as stillborn type I accounted for 10 % and type II for 90 % (Leenhouwers et al., 1999). In addition, Marchant et al. (2000) found that type I and II accounted for 22 % and 78 % of stillbirths, respectively. Type I stillbirths occur before the end of gestation and is most commonly attributed to infectious causes or placental insufficiency. Type II stillbirths occur during parturition and are often associated with non-infectious causes such as dystocia and intra uterine asphyxia. In the current study, the proportion of type I stillbirths was larger and the proportion of type II piglets smaller in autumn compared to the remaining part of the year and in multiparous compared to first parity sows. Rangstrup-Christensen et al. (2017b) did not find an increased risk of stillbirths in autumn on the same study population as the one used in the present study. Therefore, the proportion of type I vs type II stillbirths cannot be explained as merely an effect of type II stillbirth being lower and therefore type I being greater. The sows farrowing in autumn were serviced during summer where sows are at greater risk of suffering from heat stress. Heat stress has been found to affect mammal reproduction both with regard to the development of the oocyte, the foetus and the placenta (reviewed by Hansen, 2009). High ambient temperatures during early gestation could be a contributing factor to the greater proportions of type I deaths seen during autumn. However, no recordings of temperature were performed, and therefore, this causality is somewhat speculative. The effect of parity may be explained by the positive correlation between increasing parity and increasing litter size. In large litters, the risk of placental insufficiency is greater (Knight et al., 1977, Borges et al., 2005, Rootwelt et al., 2013), potentially leading to an increased risk of type I stillbirth.

The mean body weight of the stillborn piglets and the proportion of stillborn males in the current study are in agreement with results from a study on conventional Danish loose-housed sows. However, the mean BMI of 18.3 in Hales et al. (2013) is higher than the median BMI of 13.6 in the current study which is explained by the difference in CTR of 24.3 cm in the study by Hales et al. (2013) and 26.7 cm in the present study. Thus, piglets in the current study were both thinner and longer compared to piglets in the study by Hales et al. (2013). As the sows in the two studies were of the same genetic background, reasons for the differences could be different management routines. For example, feed composition is different in organic production compared to conventional production where e.g. artificial amino acids are not allowed in organic feed. Additionally, due to the housing conditions, farrowing supervision is scarce and farrowing assistance is practically absent within organic herds. In the study by Hales et al. (2013), farrowing assistance was performed which potentially altered which piglets were eventually stillborn. In 26 stillborn piglets from an outdoor production system in the UK, the mean BMI was comparable to what was seen in the present study, but stillborn piglets were both heavier and longer (Baxter et al., 2009). This difference could be explained by the larger total born litter size in the present study, resulting in an increased number of small piglets (Wientjes et al., 2012). However, in a recent study on indoor crated sows by Pandolfi *et al.* (2017), the mean weight of type I and II stillborn piglets was 200 g larger for both categories compared to the current study. As the study by Pandolfi et al. (2017) was conducted in French herds, differences in genetics may be part of the explanation for the weight differences between the two studies. Additionally, as explained above, management routines in organic production differ from those used in conventional herds, e.g. with respect to feeding and opportunity for conducting farrowing supervision and assistance.

In the present study, type II piglets had a significantly larger BMI compared to type I piglets. In utero piglets experience a rapid weight gain during the last week of gestation. Therefore, disproportional long and thin piglets resulting in a low BMI at birth could be indicative of an insufficient supply of nourishments during the last week of gestation.

Piglets dead pp

In the present study, 77 % of necropsied piglets dead *pp* were crushed. This is in accordance with previous studies on outdoor-housed sows where 74 % (KilBride et al., 2012) and 72 % (Edwards et al., 1994) of piglets dead *pp* were crushed. Of piglets dying within the first four days pp, 83 % died of crushing and 9 % died of starvation. These two causes of death together with the cause ‘non-viable piglets’ accounted for 96 % of necropsied piglets. This is in accordance with previous findings in both indoor loose-housed (Marchant et al., 2000), outdoor (Edwards et al., 1994) and Danish crated sows (Frandsen and Haugegaard, 2017). Small and hungry piglets with a poorer growth have been found to spend more time near a standing and sitting sow and thereby increasing the risk of crushing (Weary et al., 1996). Emaciated piglets that are not crushed by the sow while attempting to feed are likely to die later in lactation due to starvation. Hence, though crushing is the ultimate cause of death, low viability in combination with starvation may be the primary cause. This is supported by the result from the study by Frandsen and Haugegaard (2017) who also found the main causes of mortality to be crushing (47 %), starvation (18 %) and low viability (18 %).

Piglets age zero to four days

The group of piglets diagnosed as non-viable in the current study was comprised of both piglets with a body weight below 700 g and piglets heavier than 1 kg. Thus, the non-viable piglets were not a homogeneous group, suggesting that the causes of non-viability may differ between piglets. Small piglets are sensitive to hypoxia during parturition and have difficulties recovering from hypothermia *pp* (Herpin et al., 1996). Non-viability in large piglets is most often due to factors such as prolonged parturition and dystocia which increases the risk of *pp* hypoxia.

In a study by Quiniou et al. (2002), piglets with a birth weight of less than 1 kg were found to possess little chance of survival. In the current study, 49 % of the zero to four days old piglets had a body weight of less than 1 kg. If assuming that none of these piglets were heavier at birth, this could indicate that low birth weight was a contributing factor to mortality.

Sixty-seven percent of the zero to four days old crushed piglets had suckled prior to dying which is in accordance with what has previously been reported in both outdoor-housed and indoor loose-housed sows (Edwards et al., 1994, Marchant et al., 2000). However, the proportion of 67 % found in this study is larger than the 52 % (Hales et al., 2013) and 38 % (Damm et al., 2005) reported for Danish loose-housed sows. Thus, a larger proportion of crushed piglets in the present study was able to obtain milk compared to the crushed piglets in the two latter studies. A possible explanation for this difference could be that the straw bedding provided in the current study offered an insulating and warm microclimate that aided the piglets in maintaining their body temperature *pp* and thus facilitating suckling (Pedersen et al., 2016). This is especially advantageous in small neonatal piglets, since they experience a greater drop in temperature *pp* due to their greater surface to body mass ratio compared to heavier piglets (reviewed by Herpin et al., 2002). Furthermore, the deep straw bedding within the farrowing hut may allow piglets a better access to teats, particularly in the lower row, compared to the loose-housed sows in the previously mentioned studies by Damm et al. (2005) and *Hales et al.* (2013) where sows were kept on concrete floor.

Thirty-one percent of crushed piglets (age zero to four days) died with a full stomach. These piglets were heavier than both the crushed piglets with half-filled and empty stomachs. Piglets with empty stomachs had the lowest body weight (Figure 4). These results are most likely confounded with age. However, piglets with full stomachs (independent of age) were assumed to be viable, and the reason for the crushing of these piglets could not be explained by *pm* findings. Contrary, piglets with a half full stomach, unless just born (and thus not having had the time to fill their stomach before being crushed), were likely to be opportunistic drinkers, e.g. they could be piglets having difficulties reaching the udder, and thus having a poor chance of survival. The crushed piglets in the current study were not a heterogeneous group with regard to body weight and stomach filling which suggest that risk factors for crushing may be different for small under-weight piglets compared to viable well-fed piglets. Thus, preventive measures to lower mortalities due to crushing should be adapted accordingly. Further studies on sow and piglet behaviour preceding crushing of viable and well-fed piglets are needed.

A lower proportion of piglets were crushed during summer compared to the remaining part of the year in the current study. Moreover, the proportion of starved piglets was significantly higher during summer. Sows suffering from heat stress are at risk of impaired milk production (Quiniou and Noblet, 1999) which potentially increase the risk of piglets dying from starvation. Furthermore, during periods with high ambient temperatures, outdoor-housed sows will have to leave the hut and piglets to wallow. This could potentially lead to a lower frequency of nursing and thereby increase the risk of starvation. In addition, wallowing sows spend more time outside the hut which lowers the risk of crushing. As discussed previously, starvation is a contributing factor to crushing which suggests that the difference in the proportion of crushed and starved piglets seen during summer in the current study could be evidence of a shift where starvation is no longer a contributing factor to crushing but becomes the ultimate cause of death. Parity also affected the proportion of crushed piglets, and more crushed piglets came from multi-parous sows than first parity sows. This is in accordance with Weary et al. (1998), who found a high incidence of crushing with increasing parity, and in accordance with published results from a study done in the same study herds and study period as in the current study (Rangstrup-Christensen et al., 2017b). In the study by Rangstrup-Christensen et al. (2017b), the risk of mortality from parturition until castration increased with increasing parity. Therefore, it is assumed that the lower proportion of crushed piglets in first parity sows compared to multiparous sows seen in the current study is not the result of an increased number of piglets dying from other causes (because mortality was in fact higher in multiparous sows), but because less piglets die from crushing. In contrast, Pandolfi et al. (2017) showed that piglets from conventional crated sows were less likely to die from crushing than from other causes in connection with sows with a parity above two compared to first and second parity sows. The difference between the current results and those found by Pandolfi et al. (2017) could be related to the different housing systems and study design.

Piglets age five days to weaning

The distribution of diagnoses assigned to dead piglets above four days of age in the present study did not correspond to the results from Frandsen and Haugegaard (2017). In the latter, 39 % of necropsied piglets died of an infection. In the present study, infections only accounted for 20 % of the deaths. Conventional piglets are tail docked and teeth clipped which serve as a port of entrance for bacteria. In addition to this, 64 % of all piglets in the Frandsen and Haugegaard (2017) study had abrasions on the carpal joint and 35 % had lesions in the coronary band, both predisposing to septicaemia (which accounted for 79 % of the infections in their study). In the current study, neither abrasions on the carpal joint nor lesions in the coronary band were seen which may explain the lower proportion of piglets dying from infection and septicaemia. The study by Frandsen and Haugegaard (2017) was performed in herds participating in a project aiming at lowering piglet mortality which could also account for some of the differences between the two studies.

Euthanied piglets

The three major categories of euthanised piglets were non-viable, starvation and unknown. In smaller herds, the options to handle surplus piglets are limited, and if the number of piglets in a farrowing batch surpasses the number of functional teats, stock personnel may euthanise piglets considered less fit to survive. In the present study, it is believed that the differences seen between herds in number of euthanised piglets are possibly due to different strategies on handling surplus piglets.

Conclusion

This study is the first large scale study to determine causes of preweaning mortality in Danish organic outdoor-housed piglets. It was found that type II stillbirths accounted for 88 % of stillborn piglets, and that these piglets had a significantly higher BMI than type I piglets. The majority of live-born necropsied piglets died within the first four days *pp*, and crushing together with starvation accounted for 82 % of deaths within this period. The results suggest that low body weight was a contributing factor to crushing of piglets, and that some crushed piglets had a full stomach and a normal body weight. The heterogeneity of crushed piglets should be taken into account when implementing preventive measures to lower piglet mortality in the future. The total preweaning mortality varied substantially between the participating herds. This, in combination with a preweaning mortality at level with what is seen within the Danish conventional production system in one of the herds suggest that the production of Danish organic piglets is not necessarily synonymous to a high preweaning mortality.

Acknowledgement

The authors would like to thank all the participating producers and their employees for their hard work and dedication throughout the one-year study period. A special thanks to technicians Pia Haun Poulsen, Pernille Aagaard Madsen and John Misa Obidah for assistance during necropsies. Furthermore, the authors would like to thank Hanne Kongsted for competent guidance throughout the writing process. This work was funded as part of the VIPiglets project under the Organic RDD 2 program which is coordinated by International Centre for Research in Organic Food Systems (ICROFS). It has received grants, J.nr. 34009-13-0679, from the Green Growth and Development programme (GUDP) under the Danish Ministry of Food, Agriculture and Fisheries.

References

Andersen IL, Berg S and Boe KE 2005. Crushing of piglets by the mother sow (Sus scrofa) – purely accidental or a poor mother? Applied Animal Behaviour Science 93, 229-243.

Baxter EM, Jarvis S, Palarea-Albaladejo J and Edwards SA 2012. The Weaker Sex? The Propensity for Male-Biased Piglet Mortality. Plos One 7, 9.

Baxter EM, Jarvis S, D'Eath RB, Ross DW, Robson SK, Farish M, Nevison IM, Lawrence AB and Edwards SA 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69, 773-783.

Baxter EM, Jarvis S, Sherwood L, Robson SK, Ormandy E, Farish M, Smurthwaite KM, Roehe R, Lawrence AB and Edwards SA 2009. Indicators of piglet survival in an outdoor farrowing system. Livestock Science 124, 266-276.

Baxter EM, Rutherford KMD, D'Eath RB, Arnott G, Turner SP, Sandoe P, Moustsen VA, Thorup F, Edwards SA and Lawrence AB 2013. The welfare implications of large litter size in the domestic pig II: management factors. Animal Welfare 22, 219-238.

Borges VF, Bernardi ML, Bortolozzo FP and Wentz I 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine 70, 165-176.

Damm BI, Pedersen LJ, Heiskanen T and Nielsen NP 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Applied Animal Behaviour Science 92, 45-60.

Edwards SA, Smith WJ, Fordyce C and Macmenemy F 1994. An analysis of the causes of piglet mortality in a breeding herd kept outdoors. Veterinary Record 135, 324-327.

Frandsen DP and Haugegaard S 2017. Knowledge about causes of piglet mortality improved the survival rate. (In Danish). Viden om dødårsager forbedrede pattegriseoverlevelsen. Availible on: http://svineproduktion.dk/publikationer/kilder/lu_erfa/2017/1703.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. Journal of Animal Science 91, 4991-5003.

Hansen PJ 2009. Effects of heat stress on mammalian reproduction. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 3341-3350.

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

Herpin P, LeDividich J, Hulin JC, Fillaut M, DeMarco F and Bertin R 1996. Effect of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067-2075.

Jessen O 2016. National average for productivity in the pig production 2015. (In Danish). Landsgennemsnit for produktivitet i svineproduktionen 2015. Available online at: http://svineproduktion.dk/publikationer/kilder/notater/2016/1611.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 104, 281-291.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Marchant-Forde JN, Booth H and Green LE 2014. Risks associated with preweaning mortality in 855 litters on 39 commercial outdoor pig farms in England. Prev Vet Med 117, 189-199.

Knight JW, Bazer FW, Thatcher WW, Franke DE and Wallace HD 1977. Conceptus development in intact and unilaterally hysterectomized-ovariectomized gilts: interrelations among hormonal status, placental development, fetal fluids and fetal growth. Journal of Animal Science 44, 620-637.

Leenhouwers JI, van der Lende T and Knol EF 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243-253.

Marchant JN, Rudd AR, Mendl MT, Broom DM, Meredith MJ, Corning S and Simmins PH 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Veterinary Record 147, 209-214.

Pandolfi F, Edwards SA, Robert F and Kyriazakis I 2017. Risk factors associated with the different categories of piglet perinatal mortality in French farms. Preventive Veterinary Medicine 137, Part A, 1-12.

Pedersen LJ, Larsen ML and Malmkvist J 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets. Journal of Animal Science 94, 2151-2159.

Quiniou N and Noblet J 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. Journal of Animal Science 77, 2124-2134.

Quiniou N, Dagorn J and Gaudre D 2002. Variation of piglets birth weight and consequences on subsequent performance. Livestock Production Science 78, 63-70.

Rangstrup-Christensen L, Krogh MA, Pedersen LJ and Sorensen JT 2017a. Sow-level risk factors for stillbirth of piglets in organic sow herds. Animal 11, 1078-1083.

Rangstrup-Christensen L, Krogh MA, Pedersen LJ and Sorensen JT 2017b. Sow level risk factors for early piglet mortality and crushing in organic outdoor production. Animal 1-9. doi:10.1017/S1751731117002178.

Rootwelt V, Reksen O, Farstad W and Framstad T 2013. Postpartum deaths: Piglet, placental, and umbilical characteristics. Journal of Animal Science 91, 2647-2656.

Rosvold EM, Kielland C, Ocepek M, Framstad T, Fredriksen B, Andersen-Ranberg I, Naess G and Andersen IL 2017. Management routines influencing piglet survival in loose-housed sow herds. Livestock Science 196, 1-6.

Sorensen JT and Pedersen LJ 2013. Status, causes and challenges in regard to improving piglet mortality in Danish organic pig production. (In Danish). Status, årsager og udfordringer i forhold til løsning af forhøjet dødelighed hos økologiske pattegrise DCA rapport 021. Aarhus University. Tjele, Denmark.

Wallenbeck A, Gustafson G and Rydhmer L 2009. Sow performance and maternal behaviour in organic and conventional herds. Acta Agriculturae Scandinavica: Section A, Animal Science 59, 181-191.

Weary DM, Pajor EA, Thompson BK and Fraser D 1996. Risky behaviour by piglets: A trade off between feeding and risk of mortality by maternal crushing? Animal Behaviour 51, 619-624.

Weber R, Keil NM, Fehr M and Horat R 2007. Piglet mortality on farms using farrowing systems with or without crates. Animal Welfare 16, 277-279.

Westin R, Holmgren N, Hultgren J, Ortman K, Linder A and Algers B 2015. Post-mortem findings and piglet mortality in relation to strategic use of straw at farrowing. Preventive Veterinary Medicine 119, 141-152.

Wientjes JGM, Soede NM, van der Peet-Schwering CMC, van den Brand H and Kemp B 2012. Piglet uniformity and mortality in large organic litters: Effects of parity and pre-mating diet composition. Livestock Science 144, 218-229.

10 General discussion

The preweaning mortality in Danish organic pig production is higher than in Danish conventional pig production (Jessen, 2016) and in outdoor production systems in other European countries. Lowering piglet mortality in Danish organic pig production is a priority in order to increase the welfare of the piglets and to meet the principles of organic farming set by Organics International (Anonymous, 2017a). Moreover, a reduction in piglet mortality will benefit herd economy and help meet the expectations of a high level of animal welfare by the consumers of organic pork (Zander and Hamm, 2010).

The overall aim of this thesis was to identify causes and risk factors for total preweaning mortality within the Danish organic production setting. It is the intention that the knowledge generated within this thesis can aid in future work to discover preventative measures to lower preweaning mortality.

The general discussion is composed of three parts. In the first section, the hypotheses and results presented in the three research papers will be discussed briefly. This is followed by a discussion of the main methodological decisions made throughout the project. Lastly, an overall discussion including conclusions will relate the main results to the Danish organic production system.

10.1 Discussion of hypotheses

10.1.1 Hypothesis I – Risk factors for stillbirth

In my first study risk factors for stillbirth within the commercial Danish organic sow herds was investigated. It was hypothesised that summer season, increased litter size, high parity and body condition of the sow are risk factors for stillbirth in Danish organic sow herds. Based on the results presented in paper I the hypothesis was accepted.

A non-linear relationship between total born litter size and an increased probability of stillbirth was confirmed. This was in accordance with a previous study by Canario *et al.* (2006). The association between litter size and stillbirth is well-known and has been confirmed in previous studies in both crated and loose-housed sows (Fraser et al., 1997; Hales et al., 2014; Vanderhaeghe et al., 2010a). The association between total born litter size and stillbirth is believed to be due to prolonged parturition resulting in a higher risk of hypoxia and thereby a higher risk of stillbirth (Herpin et al., 1996).

Increasing sow parity and sow body condition were identified as risk factors for stillbirth. Increasing parity has previously been identified as a risk factor for stillbirth in organic indoor loose-housed sows (Wientjes et al., 2012) and indoor-crated sows (Leenhouwers et al., 1999). Moreover, an interaction between parity and body condition was found in the present study. Thus, thin sows with parity above four had a substantially increased probability of stillbirth compared to normal and fat sows with parity above four. On the contrary, in first parity sows the probability of stillbirth increased in fat sows compared to thin sows. The former is in accordance with the results from a study by Vanderhaeghe et al. (2010a) who found an increased risk of stillbirth in thin sows. The latter coincides with common knowledge of farmers to avoid fat gilts. The increased risk of stillbirth in fat gilts might be due to excessive amounts of adipose tissue surrounding the birth canal providing a physical obstruction in the pelvic region at parturition, potentially causing a prolonged farrowing which is a well-known risk factor for stillbirth (Oliviero et al., 2010). Furthermore, a low body condition in old sows could indicate a predisposing problem such as production exhaustion or disease increasing the risk of stillbirth.

Finally, it was confirmed that the risk of stillbirth increased during the summer months of May – August compared to the remaining part of the year. The thermal comfort zone of sows has been estimated to be below 20°C (Black et al., 1993) and, above these temperatures, sows are at risk of suffering from heat stress. All sows from the current study were housed outdoors with limited possibilities to control ambient temperature. Previous studies on crated indoor-housed sows has shown an association between ambient temperatures (22°C - 28°C) and an increased risk of stillbirth (Odehnalova et al., 2008; Vanderhaeghe et al., 2010b). The average temperature during the summer months (June to August) of 2014 was reported by the Danish Meteorological Institute to have been higher than the normal average for those months (Cappelen, 2014). Considering this, it could be reasonable to assume that the increased probability of stillbirth seen during the summer months might be explained by high ambient temperatures during farrowing. Results from paper III show that the ratio between type I and type II stillbirths was not altered during summer and thus, the increased probability of stillbirth in summer demonstrated in the present study is assumed to affect both types of stillbirths.

10.1.2 Hypothesis II – Risk factors for early piglet mortality and crushing

In my second study, risk factors for mortality and risk factors for crushing in litters with mortality from parturition until castration (3 - 5 days *pp*) were investigated. It was hypothesised that season, increased litter size, high parity, body condition of the sow and stillborn littermates are risk factors for 1) piglet mortality from parturition until castration (3 - 5 days *pp*) and 2) crushing of live-born piglets in litters with mortality from parturition until castration (3 - 5 days *pp*). Based on the results presented in paper II the hypothesis was partly accepted.

In the following section "piglet mortality" refers to mortality from parturition until castration.

It was confirmed that the risk of mortality from parturition until castration increases with the increasing parity of the sow. This is in accordance with Wientjes et al. (2012) who found that highly prolific organic sows with parity above four had a significantly higher early mortality compared to sows with lower parities. Total litter size was not directly included in the analysis as a predictive variable but was accounted for by the offset LTR (days from parturition until castration multiplied by live-born piglets) together with the dichotomous variable describing the presence of stillborn littermates within the litter. Therefore, live-born litter size can in itself not be confirmed as a risk factor. However, LTR and stillborn littermates were both confirmed as risk factors for mortality from parturition until castration. A positive (but undesirable) relationship between increasing parity and increasing litter size has previously been demonstrated (Weber et al., 2009, Wientjes et al., 2012, Hales et al., 2014). Therefore, an increase in litter size with increasing parity could explain some of the effect of parity seen in the present study. Litter size is a well-known risk factor for piglet mortality. The within-litter weight variation of piglets is greater in large litters, consequently increasing the proportion of LBW piglets (Quesnel et al., 2008). LBW piglets are less adapted to the extra uterine life and are at greater risk of dying compared to lager littermates (Baxter et al., 2008, Hales et al., 2013).

Body condition score of the sow was confirmed as a risk factor for piglet mortality with an increased risk of mortality in fat sows being in accordance with a previous study performed on both indoor and outdoor loose-housed sows (Wulbers-Mindermann et al., 2002). A high body condition score is associated with prolonged farrowing (Oliviero et al., 2010), with an increased risk of piglets late in the birth order suffering from hypoxia at birth, with an increased risk of dying later in lactation (Herpin et al., 2001). It was shown that season affects piglet mortality, with the lowest mortality rate during spring and highest during summer. This effect might be explained by a higher ambient temperature during the summer months. Previous studies has found that sows are at risk of suffering from heat stress during high ambient temperatures (Black et al., 1993). Temperatures above 25°C have been found negatively to affect milk production (Quiniou and Noblet, 1999), potentially leading to starvation in piglets and thus increased mortality. Moreover, sows spend more time inside the hut in the first days *pp* and wallow less during this period compared to later in gestation (Schild et al., 2016), potentially increasing the risk of heat stress.

Parity and live-born litter size were confirmed as risk factors for crushing of at least one piglet in litters with mortality. In a study on French outdoor-housed sows, first parity sows were found to be more responsive to squeals from piglets trapped underneath the sow. Moreover, the same study found a relationship between crushed piglets and increasing litter size, also in accordance with the present study (Vieuille et al., 2003).

10.1.3 Hypothesis III – Causes of preweaning mortality

In my third study, the causes of mortality were identified by *pm* examinations.
It was hypothesised that season and parity of the sow affect the proportion of identified causes of mortality based on *pm* examinations during a one-year period. Based on the results presented in paper III the hypothesis was partly accepted.
With regard to stillborn piglets, the study confirmed that the proportion of type I piglets was larger and therefore the proportion of type II piglets was smaller in autumn compared to the rest of the year. The results from paper I did not show an increased risk of stillbirth during autumn. Therefore, it is believed that the change in the proportion between type I and type II stillbirths is in fact due to an increase in number of type I stillbirths. Sows farrowing in autumn are serviced in summer and high ambient temperatures in early gestation might contribute to a greater proportions of type I deaths seen during autumn. In addition, it was confirmed that the proportion of type I piglets was larger in sows with parity above one, compared to first parity sows. As discussed previously, there is a positive correlation between increasing parity and increasing litter size, potentially accounting for some of the effect of parity. There is a greater risk of placental insufficiency in large litters (Knight et al., 1977, Borges et al., 2005, Rootwelt et al., 2013), which could lead to an increased risk of type I stillbirth.
In piglets of zero to four days of age, it was confirmed that the proportion of crushed piglets was significantly lower in summer compared to the remaining part of the year. Furthermore, it was confirmed that the proportion of starved piglets was significantly higher during summer compared to the remaining part of the year. In paper II, it was found that the risk of mortality from parturition until castration was highest during summer. Thus, it is reasonable to assume that the difference in proportion of crushed and starved piglets seen in summer is not due to an increased number of piglets surviving but because an increased number of piglets die of starvation instead of crushing. Starvation is a known risk factor for crushing (Pedersen et al., 2011a) and the two causes of death are highly linked. One explanation could be in increased risk of heat stress in sows during high

ambient temperatures (Black et al., 1993) with a subsequent impaired milk yield (Quiniou and Noblet, 1999).

It was confirmed that the proportion of crushed piglets was significantly higher in multiparous sows compared to first parity sows. This is accordance with results from paper II where the risk of mortality from parturition until castration was higher in older sows compared to younger sows. Therefore, it is assumed that the lower proportion of crushed piglets in first parity sows compared to multiparous sows is not the result of an increased number of piglets dying from other causes, but because fewer piglets die from crushing. This interpretation is supported by the results presented in paper II where the probability of crushing in litters with mortality increased with increasing parity. The results are in accordance with a study by Weary et al. (1998) who found that a high incidence of crushing was associated with increasing parity. As discussed in the previous section, the decreased risk of crushing in first parity sows could among others, be due to younger sows being more attentive to squeals from trapped piglets compared to older sows (Vieuille et al., 2003).

The results from paper III showed a ratio between type I and type II stillborn piglets of 12 % and 88 %, respectively. This distribution is in accordance with Leenhouwers et al. (1999) who found that type I accounted for 10 % and type II for 90 % of stillborn piglets. In addition, stillborn piglets were found to be both thinner and longer compared to piglets in the study by Hales et al. (2013) performed on conventional non-crated sows. The study by Hales et al. (2013) was conducted three years prior to the present study and it is possible that a continuous genetic progress towards larger litters could potentially result in piglets being both lighter and longer. This could perhaps account for some of the differences seen between the two studies. When looking at the live-born piglets, it was demonstrated that the majority of the necropsied piglets died of crushing (77 %) and starvation (10 %). This is in agreement with previous studies. Edwards et al. (1994) found that 72 % and 16 % of live-born mortality was due to crushing and starvation, respectively. Marchant et al. (2000) found that crushed and starved piglets accounted for 75 % and 19 % of live-born mortality up to 7 days *pp*, respectively. The former study was performed in outdoor-housed sows and the latter in indoor loose-housed sows. Eighty-one percent of necropsied piglets in the current study died within the first four days *pp* which is in accordance with previous findings in indoor loose-housed sows (Marchant et al., 2000, Rootwelt et al., 2013). Moreover, it was found that half of these piglets had a body weight of less than 1 kg at time of death, suggesting that low body weight was a contributing factor to the cause of death. It was confirmed that, of the crushed piglets which died within four days *pp*, 67 % had

suckled prior to death. These crushed piglets were a heterogeneous group consisting of both small and hungry piglets and heavier well-nourished piglets. Thus, risk factors for crushing in Danish organic herds differ between piglets. This should be taken into account when implementing preventive measures to lower mortalities due to crushing.
It was found that the average total preweaning mortality was 29.5 % (ranging from 21.4 % to 39.9 % between herds), within the study population. This is higher than what was reported from the Danish conventional herds in 2015 (Jessen, 2016), but lower than the 33 % total preweaning mortality in Danish organic sow herds reported by Sorensen and Pedersen (2017) a decade ago. Moreover, one herd (herd 1) differed markedly from the remaining herds by having a total preweaning mortality of 21.4 %. This indicates that the commercial production of Danish organic piglets is not necessarily synonymous with a high preweaning mortality.

10.2 Discussion of applied methods

In this section, the importance of selected methods applied in the three studies will be discussed.

10.2.1 Observational study

The study was performed as an observational study over a one-year period in Danish commercial sow herds. The intention of observational studies is to observe the study population without making any interventions. Emphasis therefore has to be put on the fact that the recordings are not intervening with variables under investigation (Dohoo et al., 2003). The observations in the present set-up were based on the recordings made by the stock personnel. To exemplify this, a hypothetical case could be that counting of piglets would startle and disturb a sow to an extent where she would trample the piglets resulting in increased mortality. Moreover, this hypothetical startle/disturb effect could potentially be more pronounced in gilts compared to older sows which would influence both the predictive and outcome variables. It is not believed that performing the recordings influenced the predictive variables, nor the outcome studied. In the current project, identified risk factors significantly affected piglet mortality, meaning that the planned size of the study population and the assumed variation in both outcome and predictive variables were sufficient to overrule the noise from the uncontrolled management routines.

10.2.2 Selection of study herds

The aim of the study was to investigate risk factors for, and causes of, piglet mortality within commercial Danish sow herds. Thus, small backyard productions were excluded as it was believed that these herds present different risk factors compared to commercial herds. The nine study herds, constituting the study population were selected to represent the target population. To minimise selection bias, herds were included in the study population disregarding previous knowledge of the piglet mortality within the herd. In addition, the study population was composed to include both large and small herds to reflect the target population. Half of all productive organic sows in Denmark at the time of the study were included in the study population. One third of organic commercial sow herds (> 50 sows) at the time of study were included. It is therefore reasonable to assume that the results generated within the study population can be generalised to the whole target population.

10.2.3 Recordings from the farrowing field

As highlighted in section 8.3, motivation and communication with all participants within the herds were highly prioritised throughout the entire project period. The validity of the outcome of the project was dependent on the reliability and quality of the collected material. Precisely what has been gained by this approach is difficult to evaluate objectively. However, feedback from stock personnel and herd owners during the project point towards the fact that the communication strategy had a positive effect and has helped keep the motivation throughout the study period.

Both the design of the booklet/recording sheet and the decision to perform the recordings at sow level proved feasible. After a short adjustment period in the beginning of the study period, the recordings fitted well with the working routines in the farrowing field and proved to be a useful tool for stock personnel to keep track of activities in the farrowing field, especially in large herds with numerous people working in the farrowing field. Several herds adapted the booklet/recording sheet into their working routines after the end of the study. In spite of the communication strategy and the participant's involvement in the design of the booklet/recording sheet, some recordings proved difficult for the stock personnel to complete. As can be seen from Table 2 in section 8.5 some recordings were included in the initial set-up but were left out of the analyses presented in paper I and II. These were 1) gait score of the sow when moved into the farrowing field 2) number of functional teats on gilts 3) number of small live-born piglets (≤ 21 cm) at the first check-up *pp* and 4) information about sick sows (date, treatment and cause). All four variables were intended to be investigated as risk factors for piglet mortality. Unfortunately, these recordings were not performed with satisfactory accuracy, with too many missing values, and thus could not be included in the statistical analyses.

The overall assessment of the communication strategy is that it was worthwhile despite the minor difficulties explained above and that it helped assuring the quality and reliability of the collected data.

10.2.4 Necropsy of piglets

Dead piglets were frozen at the farm and thawed prior to *pm* examinations. This approached proved efficient to obtain the volume and quality of material expected prior to the onset of the study period. The selection of sows from whom to collect dead piglets was intended to cover the range of parities within the herds. This was successfully accomplished and the piglets collected for necropsy originated from sows with a wide range of parities. However, a limited number of sows with parity above four were present in herd 3 leading to a limited number of piglets being collected from sows of parity above four. Consequently, when performing the regression analyses to test the effect of parity on difference in proportions of mortality causes (paper III), parity had to be grouped as a dichotomous variable in order to avoid 0 and 1 parametrisation.

10.2.5 Cross fostering and statistical analyses

Mortality in surplus piglets moved to nurse sows was not included in the analysis for risks factors for mortality from parturition until castration (paper II). However, all live-born piglets were included in calculation of LTR by the birth sow. Thus, some piglets were included in the LTR (and therefore part of the population at risk of dying) and were subsequently moved out of the study population before their mortality could be accounted for. A potential consequence of this could be that the impact and magnitude of the risk factors for mortality from parturition until castration presented in paper II are either under- or overestimated, depending on the number of piglets moved and what “quality” (low vs. high viability) of piglets were moved. If piglets with a high viability were removed, the remaining population at risk would be in a combined greater risk of dying and the impact and magnitude of the risk factors would be over-estimated. On the contrary, if low-viability piglets were removed from the population at risk, an under-estimation of the risk factors would occur.

When examining the farrowings included in the risk factor analysis in paper II, 1 % of live-born piglets were removed from the study population between first check-up *pp* and castration. This percentage being rather low, it is thought reasonable to assume that the results presented in paper II are only slightly affected by the alteration of the study population.

Another aspect to keep in mind when interpreting the results from the negative binomial regression analysis presented in paper II is the construction of the offset variable LTR. As explained in Methodological considerations section 8.5.1 cross-fostering of piglets in and out of litters could not be included in the LTR variable. This means that all live-born piglets were recorded as being at risk of dying by the birth sow. If a piglet was moved to a new sow afterwards, any mortality in this piglet would be linked to the new sow and not to birth sow.

It is likely that this will influence the outcome of the analysis on some way but it is difficult to assess exactly how and to what extent. As discussed in State of the Art section 5.4.3 cross-fostering of piglets is a potential risk factor for mortality. If piglets are moved too early *pp* they are in risk of ingestion of insufficient amounts of colostrum, moreover if they are moved too late, fights to re-establish teat order will increase. Cross-fostering later than 24h *pp* have been confirmed as a risk factor for mortality in outdoor house sows (Kilbride et al.,2014). It could also be expected that the violation of the internal biosecurity when moving piglets between litters will influence the mortality. The impact of these risk factors could be dissimilar depending on whether it is low or high viability piglets that are being moved between litters. The management underlying the decisions on how cross-fostering was conducted and which piglets were cross fostered within each herd is not included in the present study. Therefore, it is not possible to account for exactly how these decisions have affected the obtained results.

10.3 Overall discussion and conclusions

The association between total preweaning mortality and being born into a larger litter within the Danish organic pig production demonstrated in this thesis emphasises previous results from several studies across production systems (KilBride et al., 2012, Wientjes et al., 2012, Hales et al., 2015a). When interpreting the effect of increasing litter size on the total preweaning mortality, it is important to think not only of litter size as merely a measure of how many piglets are being born into a litter but also consider that the survivability of piglets within these larger litters might be compromised. If the number of live-born piglets exceeds the number of functional teats, the surplus piglets are at risk of suffering from both starvation due to lack of nourishment, and are also more prone to crushing as demonstrated by Weary et al. (1996). The challenge of assuring an adequate milk intake in larger litters may to some extent be coped with by different management strategies such as cross-fostering (equalisation, standardisation and nurse sows) and by euthanising surplus piglets deemed to possess the lowest chance of survival. Such management strategies, like cross-fostering by litter equalisation and standardisation, is commonly used within the Danish organic pig production and nurse sows are being used in larger herds. However, many of the challenges facing piglets born into larger litters are affecting the piglets prior to the first check-up *pp*. Additionally, these challenges will potentially keep negatively affecting the piglets' chance of survival even after cross-fostering takes place. Large litters are associated with intra-uterine crowding, potentially increasing the within-litter weight variation, the proportion of piglets with a low birth weight (LBW piglets) and piglets being immature at birth (IUGR piglets) (Foxcroft et al., 2006, Quesnel et al., 2008). LBW piglets are at greater risk of suffering from hypoxia during parturition compared to heavier littermates and are more prone to suffer from hypothermia due to a poor thermoregulatory ability (Herpin et al., 2001). Thus, LBW piglets are poorly adapted to the extra uterine life and have a greater risk of dying before weaning compared to heavier littermates (Herpin et al., 1996). The variation in both body weight and BMI of stillborn piglets and piglets that died within four days *pp* presented in paper III suggests that within-litter weight variation and LBW piglets may explain some of the effect of increasing litter size on total preweaning mortality demonstrated in this thesis. The impact and importance of the risk factors associated with LBW mentioned above might be different in a less intensive outdoor production system and should therefore be investigated within this system. This is supported by results obtained by Baxter et al. (2009) who demonstrated that indicators for survivability known from indoor-crated sows were not equally influential in the outdoor farrowing system. Considering the challenges faced by piglets born into large litters (LBW and IUGR) it is reasonable to assume that assuring each piglet access to a functional teat is not enough to reduce the negative effect of litter size on preweaning mortality. Special care and attention that could increase the survival of LBW piglets are of limited practical use within the outdoor production system. Thus, it appears challenging to lower the effect of large litters on preweaning mortality within the current conditions in Danish organic sow herds. Numerous other studies has shown a negative relationship between litter size and survival rate (KilBride et al., 2012, Wientjes et al., 2012). This indicates that lowering the litter size through e.g. genetic selection for less but larger piglets would be a potential tool to improve survival rate in the outdoor organic production.

In this thesis, it was established that the majority of live-born piglets died from crushing and thus, a substantial overlap between risk factors for mortality and risk factors for crushing is therefore plausible. High parity was found to be a risk factor for mortality within the first four days *pp* and for the probability of crushing in litters with mortality, this being in accordance with (Weary et al., 1998). It has been suggested that the association between increasing parity and an increasing litter size (Weary et al., 1998) could explain some of the effect of increasing parity on mortality and crushing. However, litter uniformity is also partly affected by parity as such, independent of the effect of litter size (Wientjes et al., 2012). Thus, heterogeneous litters (with increased within-litter weight variation and LBW piglets) could possibly account for some of the effect of increasing parity on both the probability of stillbirth and the risk of early mortality. With increasing parity, alterations in the sows' physical abilities and appearances could expected. Sows of high parity are believed to have less uterine muscle tone resulting in an increased risk of stillbirths and older sows are perhaps less agile and thus slower at responding to squeals by trapped piglets. Vasdal and Andersen (2012) found that sub-functional udder morphology, making it difficult for piglets to reach and suckle a functional teat within 24 h *pp*, was more pronounced in sows of parity three to five compared to first and second parity sows. As discussed previously, it is crucial for survival that piglets obtain an adequate amount of colostrum. It is possible that the effect of increasing parity on mortality in Danish organic sow herds demonstrated in the current thesis can be explained by a combination of the above mentioned risk factors associated with high parity. However, since no recordings of these factors are included in the study, associations mentioned are somewhat speculative and will need to be investigated further. Nevertheless, there is an increased risk associated with high parity sows which should be taken into account while working in the farrowing field. Additionally, the interaction between high parity and low body condition score of the sow demonstrated in the current study, suggest that the probability of stillbirth can be lowered if emphasis is put into avoiding thin and old sows. A targeted supervision of high parity sows, especially thin sows, and their litters together with a culling strategy where sows are carefully evaluated with regard to the above mentioned risk factors before being serviced, would be beneficial in decreasing preweaning mortality.

A seasonal effect on preweaning mortality within the Danish organic pig production was confirmed with an increased risk of total preweaning mortality during summer. The average temperature of the summer months of 2014 were higher compared to the normal average temperatures for those months (Cappelen, 2014) and it is therefore reasonable to assume that the recorded high mortality rate could be an effect of high ambient temperatures. Piglets and sows have distinctively different comfort temperatures. New-born piglets thrive at temperatures around 30°C and lactating sows have a thermal comfort zone below 20°C (Black et al., 1993). A potential negative effect of high temperatures are therefore likely to be related to heat stress in the sow rather than a direct effect on the piglets. From previous studies, it is well known that the productivity of sows is affected by high ambient temperatures (Quiniou and Noblet, 1999, Odehnalova et al., 2008, Vanderhaeghe et al., 2010a). Therefore, temperatures between 18 to 23°C are commonly recommended in farrowing units. However, options to control the ambient temperatures within the farrowing field are practically non-existing. Nevertheless, potential measures to lower heat stress in sows, such as providing a suitable wallow, ensuring a shaded area within the paddock and creating a through draft within the hut should be applied in warm conditions. The two latter steps have been incorporated into the industry agreement, with effect from 1 January 2018 and prioritising these measures could prove a useful tool in lowering preweaning mortality.

In conclusion, this thesis presents new knowledge about risk factors and causes of preweaning mortality in Danish organic sow herds. Crushing and starvation were identified as the major causes of death in piglets born alive. Large litters and increasing parity were found to be associated with an increased risk of stillbirth, early mortality and crushing. Additionally, both stillborn and live-born dead piglets showed variation in body weight and BMI, which, as previously discussed, is unfavourably associated with large litter sizes. A seasonal effect on the preweaning mortality was confirmed. This caused an increased risk of stillbirth and early mortality during the summer months. Moreover, the proportion of type I stillbirths in sows serviced during the summer was larger compared to the remaining part of the year. Finally, it was demonstrated that the total preweaning mortality varied substantially between the participating herds. This, in combination with a preweaning mortality at a level which is commonly seen within the Danish conventional production system in one of the herds suggests that the production of Danish organic piglets is not necessarily synonymous with a high preweaning mortality.

11 Perspectives

The research presented in this thesis has identified causes of, and risk factors for, piglet mortality in Danish organic sow herds. At herd level, the results may help the herd veterinarians and stock personnel to identify sows, or groups of sows, in need of extra attention and care due to an increased risk of piglet mortality.

The results from the current study raise several relevant questions when working towards a lower piglet mortality. An increased piglet mortality was seen during the summer months and it was hypothesised that this was an effect of high ambient temperatures resulting in heat stress in the sows. In order to determine if this causality is actually present, future studies implementing recordings of temperature and humidity in combination with the behaviour of the sow and piglets are needed. Additionally, if the above causality between mortality and high ambient temperatures was established, the possibilities to introduce sow lines with a greater tolerance to high ambient temperatures could be beneficial to investigate further. Moreover, studies in which traits associated with high parity that are responsible for the increased risk of piglet mortality are needed. Such knowledge would be highly useful to stock personnel when evaluating if high parity sows are fit to continue in the production or should be culled.

The results showed a great variation of the total preweaning mortality between the participating herds. Investigating the different management routines and strategies within the herds could provide valuable knowledge to be used in a ‘best management practice’ to lower preweaning mortality.

When looking at the results in a broader perspective it could be questioned whether the current genetics used in Danish organic sow herds is suitable. The less intensive production system, with limited possibilities to supervise and assist during farrowing, and the challenges associated with handling of surplus piglets, could point towards the fact that the sows and the housing system are not completely compatible. Working towards implementing sow lines that produce litters with fewer, more uniform piglets and piglets with a higher birth weight would be beneficial in order to lower the preweaning mortality.

Finally, the level of mortality in one herd was comparable to what is seen in the Danish conventional system and in the organic production systems in other European countries. This proves that Danish organic pig production is not synonymous with a higher level of piglet mortality than what is seen within the conventional pig production. Furthermore, it demonstrates that within the Danish organic pig production there is a potential to significantly lower the preweaning mortality resulting in better welfare for the piglets while simultaneously securing a better herd economy.

12 References

Andersen IL, Naevdal E and Boe KE 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (Sus scrofa). Behavioral Ecology and Sociobiology 65, 1159-1167.

Anonymous, 2008: Industry agreement on production of organic pigs reared in Denmark (effective til 31 December 2017). (In Danish). Brancheaftale vedrørende supplerende regler for produktion af økologiske svin, der opdrættes i Danmark. Availible on: https://www.friland.dk/media/1654/brancheaftale-svin.pdf

Anonymous, 2017a: The Orginc Principles 2005. Webpage of Organics International Available online: https://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture

Anonymous, 2017b: Statistics on organic agriculture 2016. (In Danish). Statestik over økologiske jordbrugsbedrifter 2016. Miljø- og Fødevareministeriet. Landbrugs- og Fiskeristyrrelsen. Available online: http://mfvm.dk/fileadmin/user_upload/MFVM/Nyheder/Statistik_oekologiske_jordbrugsbedrifter_2016.pdf

Anonymous, 2017c: Industry agreement on production of organic pigs reared in Denmark (effective by 1 January 2018). (In Danish). Brancheaftale vedrørende supplerende regler for produktion af økologiske svin, der opdrættes i Danmark. Availible online: https://www.lf.dk/~/media/lf/aktuelt/nyheder/2017/maj/brancheaftale-oekologiske-svin.pdf?la=da

Anonymous, 2017d: Guidance on organic production 2017. (In Danish). Vejledning om økologisk jordbrugsproduktion 2017. Miljø- og Fødevareministeriet. Landbrugs- og Fiskeristyrrelsen. Available online: http://lfst.dk/fileadmin/user_upload/NaturErhverv/Filer/Indsatsomraader/Oekologi/Jordbrugsbedrifter/Vejledning_til_oekologisk_jordbrugsproduktion/Okologivejledning_April_2017.pdf

Bauer R, Walter B, Hoppe A, Gaser E, Lampe V, Kauf E and Zwiener U 1998. Body weight distribution and organ size in newborn swine (sus scrofa domestica) -- a study describing an animal model for asymmetrical intrauterine growth retardation. Experimental and Toxicologic Pathology 50, 59-65.

Baxter EM, Adeleye OO, Jack MC, Farish M, Ison SH and Edwards SA 2015. Achieving optimum performance in a loose-housed farrowing system for sows: The effects of space and temperature. Applied Animal Behaviour Science 169, 9-16.

Baxter EM, Jarvis S, D'Eath RB, Ross DW, Robson SK, Farish M, Nevison IM, Lawrence AB and Edwards SA 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69, 773-783.

Baxter EM, Jarvis S, Sherwood L, Robson SK, Ormandy E, Farish M, Smurthwaite KM, Roehe R, Lawrence AB and Edwards SA 2009. Indicators of piglet survival in an outdoor farrowing system. Livestock Science 124, 266-276.

Baxter EM, Rutherford KMD, D'Eath RB, Arnott G, Turner SP, Sandoe P, Moustsen VA, Thorup F, Edwards SA and Lawrence AB 2013. The welfare implications of large litter size in the domestic pig II: management factors. Animal Welfare 22, 219-238.

Berger F, Dagorn J, LeDenmat M, Quillien JP, Vaudelet JC and Signoret JP 1997. Perinatal losses in outdoor pig breeding. A survey of factors influencing piglet mortality. Annales De Zootechnie 46, 321-329.

Black JL, Mullan BP, Lorschy ML and Giles LR 1993. Lactation in the sow during heat-stress. Livestock Production Science 35, 153-170.

Bloemhof S, Mathur PK, Knol EF and van der Waaij EH 2013. Effect of daily environmental temperature on farrowing rate and total born in dam line sows. Journal of Animal Science 91, 2667-2679.

Borges VF, Bernardi ML, Bortolozzo FP and Wentz I 2005. Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine 70, 165-176.

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

Cappelen J 2014. Vejret i Danmark - sommer 2014. Retrieved on 16 June 2016 from http://www.dmi.dk/vejr/arkiver/maanedsaesonaar/201402/vejret-i-danmark-sommeren-2014/

Damgaard LH, Rydhmer L, Løvendahl P and Grandinson K 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling1. Journal of Animal Science 81.

Damm BI, Pedersen LJ, Heiskanen T and Nielsen NP 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Applied Animal Behaviour Science 92, 45-60.

Devillers N, Le Dividich J and Prunier A 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5, 1605-1612.

Dohoo I, Martin W and Stryhn H 2003. Veterinary Epidemiologic Research. Chapter 7 pp. 139-149.

Edwards SA, Smith WJ, Fordyce C and Macmenemy F 1994. An analysis of the causes of piglet mortality in a breeding herd kept outdoors. Veterinary Record 135, 324-327.

Edwards SA, Riddoch I and Fordyce C 1995. Effect of outdoor farrowing hut insulation on piglet mortality and growth. Farm Building Progress 117, 33-35.

Ersbøll AK and Toft N 2004. In Introduction to veterinary epidemiology, pp. 47-60. Biofolia, Denmark.

Foxcroft GR, Dixon WT, Novak S, Putman CT, Town SC and Vinsky MDA 2006. The biological basis for prenatal programming of postnatal performance in pigs12. Journal of Animal Science 84, E105-E112.

Fraser D, Phillips PA and Thompson BK 1997. Farrowing behaviour and stillbirth in two environments: an evaluation of the restraint-stillbirth hypothesis. Applied Animal Behaviour Science 55, 51-66.

Früh B, Bochicchio D, Edwards S, Hegelund L, Leeb C, Sundrum A, Werne S, Wiberg S and Prunier A 2014. Description of organic pig production in Europe. Organic Agriculture 4, 83-92.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. Journal of Animal Science 91, 4991-5003.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal 8, 113-120.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2015a. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality 1. Journal of Animal Science 93, 4079-4088.

Hales J, Moustsen VA, Devreese AM, Nielsen MBF and Hansen CF 2015b. Comparable farrowing progress in confined and loose housed hyper-prolific sows. Livestock Science 171, 64-72.

Harper GC and Makatouni A 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal 104, 287-299.

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

Herpin P, LeDividich J, Hulin JC, Fillaut M, DeMarco F and Bertin R 1996. Effect of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067-2075.

Holinger M, Edwards S, Illmann G, Leeb C, Milsova M, prunier A, Rudolph G and Früh B 2015. Fertility. Improving health and welfare of pigs – A handbook for organic farmers pp. 7 - 26. Research Institute of Organic Agriculture, Frick, Switzerland.

Jessen O 2016. National average for productivity in the pig production 2015. (In Danish). Landsgennemsnit for produktivitet i svineproduktionen 2015. Available online at: http://svineproduktion.dk/publikationer/kilder/notater/2016/1611.

Johnson AK and McGlone JJ 2003. Fender design and insulation of farrowing huts: effects on performance of outdoor sows and piglets. Journal of Animal Science 81, 955-964.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 104, 281-291.

KilBride AL, Mendl M, Statham P, Held S, Harris M, Marchant-Forde JN, Booth H and Green LE 2014. Risks associated with preweaning mortality in 855 litters on 39 commercial outdoor pig farms in England. Prev Vet Med 117, 189-199.

Knage-Rasmussen KM, Houe H, Rousing T and Sorensen JT 2014. Herd- and sow-related risk factors for lameness in organic and conventional sow herds. Animal 8, 121-127.

Knight JW, Bazer FW, Thatcher WW, Franke DE and Wallace HD 1977. Conceptus development in intact and unilaterally hysterectomized-ovariectomized gilts: interrelations among hormonal status, placental development, fetal fluids and fetal growth. Journal of Animal Science 44, 620-637.

Knol EF, Leenhouwers JI and van der Lende T 2002. Genetic aspects of piglet survival. Livestock Production Science 78, 47-55.

Koketsu Y, Takahashi H and Akachi K 1999. Longevity, lifetime pig production and productivity, and age at first conception in a cohort of gilts observed over six years on commercial farms. Journal of Veterinary Medical Science 61, 1001-1005.

Lawrence AB, McLean KA, Jarvis S, Gilbert CL and Petherick JC 1997. Stress and parturition in the pig. Reproduction in Domestic Animals 32, 231-236.

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

Leenhouwers JI, van der Lende T and Knol EF 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243-253.

Leenhouwers JI, Wissink P, van der Lende T, Paridaans H and Knolt EF 2003. Stillbirth in the pig in relation to genetic merit for farrowing survival. Journal of Animal Science 81, 2419-2424.

Lucia T, Correa MN, Deschamps JC, Bianchi I, Donin MA, Machado AC, Meincke W and Matheus JEM 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. Preventive Veterinary Medicine 53, 285-292.

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

Mainau E and Manteca X 2011. Pain and discomfort caused by parturition in cows and sows. Applied Animal Behaviour Science 135, 241-251.

Marchant JN, Rudd AR, Mendl MT, Broom DM, Meredith MJ, Corning S and Simmins PH 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Veterinary Record 147, 209-214.

Milligan BN, Fraser D and Kramer DL 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science 76, 181-191.

Muns R, Nuntapaitoon M and Tummaruk P 2016. Non-infectious causes of pre-weaning mortality in piglets. Livestock Science 184, 46-57.

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

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

Oliviero C, Heinonen A, Valros A, Halli O and Peltoniemi OAT 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Animal Reproduction Science 105, 365-377.

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

Pandolfi F, Edwards SA, Robert F and Kyriazakis I 2017. Risk factors associated with the different categories of piglet perinatal mortality in French farms. Preventive Veterinary Medicine 137, Part A, 1-12.

Panzardi A, Bernardi ML, Mellagi AP, Bierhals T, Bortolozzo FP and Wentz I 2013. Newborn piglet traits associated with survival and growth performance until weaning. Preventive Veterinary Medicine 110, 206-213.

Pedersen LJ, Larsen ML and Malmkvist J 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets. Journal of Animal Science 94, 2151-2159.

Pedersen LJ, Jorgensen E, Heiskanen T and Damm BI 2006. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. Applied Animal Behaviour Science 96, 215-232.

Pedersen LJ, Berg P, Jorgensen G and Andersen IL 2011a. Neonatal piglet traits of importance for survival in crates and indoor pens. Journal of Animal Science 89, 1207-1218.

Pedersen ML, Moustsen VA, Nielsen MBF and Kristensen AR 2011b. Improved udder access prolongs duration of milk letdown and increases piglet weight gain. Livestock Science 140, 253-261.

Quesnel H, Brossard L, Valancogne A and Quiniou N 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal 2, 1842-1849.

Quiniou N and Noblet J 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. Journal of Animal Science 77, 2124-2134.

Quiniou N, Dagorn J and Gaudre D 2002. Variation of piglets birth weight and consequences on subsequent performance. Livestock Production Science 78, 63-70.

Roca A, Johnson AK, Karriker LA, Timms LL, Abell CE and Stalder KJ 2016. How do sow postures change when lameness is induced using a chemical synovitis model? Livestock Science 192, 55-59.

Rootwelt V, Reksen O, Farstad W and Framstad T 2012. Associations between intrapartum death and piglet, placental, and umbilical characteristics. Journal of Animal Science 90, 4289-4296.

Rootwelt V, Reksen O, Farstad W and Framstad T 2013. Postpartum deaths: Piglet, placental, and umbilical characteristics. Journal of Animal Science 91, 2647-2656.

Rosvold EM, Kielland C, Ocepek M, Framstad T, Fredriksen B, Andersen-Ranberg I, Naess G and Andersen IL 2017. Management routines influencing piglet survival in loose-housed sow herds. Livestock Science 196, 1-6.

Rutherford KMD, Baxter EM, D'Eath RB, Turner SP, Arnott G, Roehe R, Ask B, Sandoe P, Moustsen VA, Thorup F, Edwards SA, Berg P and Lawrence AB 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Animal Welfare 22, 199-218.

Salomonsen CM, 2017. Personal communication by e-mail 12-07-2017.

Schild S-LA., Rangstrup-Christensen L, and Pedersen LJ 2016. Food futures: ethics, science and culture, pp 98-104

Sorensen AIV, Lundsby K, Larsen LS, Wingstrand A 2011. Characteristics of Danish pig herds 23007-2008. (In Danish). Karakteristik af danske svinebesætninger 2007-2008. Report from DTU Food, National Food Institute.

Sorensen JT and Pedersen LJ 2013. Status, causes and challenges in regard to improving piglet mortality in Danish organic pig production. (In Danish). Status, årsager og udfordringer i forhold til løsning af forhøjet dødelighed hos økologiske pattegrise DCA rapport 021. Aarhus University. Tjele, Denmark.

Sorensen JT and Pedersen LJ 2015. The extent of the use of nurse sows and possible measures to improve their welfare. (In Danish). Omfanget af brugen af ammesøer og mulige tiltag til forbedring af deres velfærd. Available online at: http://pure.au.dk/portal/files/90756027/Notat_ammes__er_velf_rd060315.pdf

Spicer EM, Driesen SJ, Fahy VA, Horton BJ, Sims LD, Jones RT, Cutler RS and Prime RW 1986. Causes of preweaning mortality on a large intensive piggery. Australian Veterinary Journal 63, 71-75.

Sprecher DJ, Leman AD, Dziuk PD, Cropper M and Dedecker M 1974. Causes and control of swine stillbirths. Journal of the American Veterinary Medical Association 165, 698-701.

Su G, Lund MS and Sorensen D 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. Journal of Animal Science 85, 1385-1392.

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

Thorsen CK, Schild S-LA, Rangstrup-Christensen L, Bilde T, and Pedersen LJ 2017. The effect of farrowing duration on maternal behavior of outdoor kept sows. Livestock Science 204, 92-97.

Thorup F 2017. Stillborn piglets. (In Danish). Dødfødte grise. Available online at:http://svineproduktion.dk/Viden/I-stalden/Management/Faring/Doedfoedte-grise

Tuchscherer M, Puppe B, Tuchscherer A and Tiemann U 2000. Early identification of neonates at risk: Traits of newborn piglets with respect to survival. Theriogenology 54, 371-388.

Vaillancourt J and Martineau GP 1988. Freezing a monitoring tool of preweaning mortality in swine medicine. Medecin Veterinaire du Quebec 18, 139-145.

van Dijk AJ, van Rens B, van der Lende T and Taverne MAM 2005. Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. Theriogenology 64, 1573-1590.

Vanderhaeghe C, Dewulf J, de Kruif A and Maes D 2013. Non-infectious factors associated with stillbirth in pigs: A review. Animal Reproduction Science 139, 76-88.

Vanderhaeghe C, Dewulf J, Ribbens S, de Kruif A and Maes D 2010a. A cross-sectional study to collect risk factors associated with stillbirths in pig herds. Animal Reproduction Science 118, 62-68.

Vanderhaeghe C, Dewulf J, De Vliegher S, Papadopoulos GA, de Kruif A and Maes D 2010b. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Animal Reproduction Science 120, 78-83.

Vasdal G and Andersen IL 2012. A note on teat accessibility and sow parity - consequences for newborn piglets. Livestock Science 146, 91-94.

Vasdal G, Ostensen I, Melisova M, Bozdechova B, Illmann G and Andersen IL 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science 136, 225-231.

Vieuille C, Berger F, Le Pape G and Bellanger D 2003. Sow behaviour involved in the crushing of piglets in outdoor farrowing huts - a brief report. Applied Animal Behaviour Science 80, 109-115.

Weary DM, Pajor EA, Thompson BK and Fraser D 1996. Risky behaviour by piglets: A trade off between feeding and risk of mortality by maternal crushing? Animal Behaviour 51, 619-624.

Weary DM, Phillips PA, Pajor EA, Fraser D and Thompson BK 1998. Crushing of piglets by sows: effects of litter features, pen features and sow behaviour. Applied Animal Behaviour Science 61, 103-111.

Weber R, Keil NM, Fehr M and Horat R 2009. Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livestock Science 124, 216-222.

Wegner K, Lambertz C, Das G, Reiner G and Gauly M 2014. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. Animal 8, 1526-1533.

Westin R, Holmgren N, Hultgren J, Ortman K, Linder A and Algers B 2015. Post-mortem findings and piglet mortality in relation to strategic use of straw at farrowing. Preventive Veterinary Medicine 119, 141-152.

Wientjes JGM, Soede NM, van der Peet-Schwering CMC, van den Brand H and Kemp B 2012. Piglet uniformity and mortality in large organic litters: Effects of parity and pre-mating diet composition. Livestock Science 144, 218-229.

Woodward, M 2005. Epidemiology Study Design and Data Analysis, 2nd Edition. Chapter 10 pp 515-550.

Wulbers-Mindermann M, Algers B, Berg C, Lundeheim N and Sigvardsson J 2002. Primiparous and multiparous maternal ability in sows in relation to indoor and outdoor farrowing systems. Livestock Production Science 73, 285-297.

Young MG, Tokach MD, Goodband R, Nelssen JL and Dritz SS 2001. The relationship between body condition score and backfat in gestating sows. Kansas State University, Kansas,.

Yun J, Swan KM, Vienola K, Farmer C, Oliviero C, Peltoniemi O and Valros A 2013. Nest-building in sows: Effects of farrowing housing on hormonal modulation of maternal characteristics. Applied Animal Behaviour Science 148, 77-84.

Zaleski HM and Hacker RR 1993. Variables related to the progress of parturition and probability of stillbirth in swine. Canadian Veterinary Journal-Revue Veterinaire Canadienne 34, 109-113.

Zander K and Hamm U 2010. Consumer preferences for additional ethical attributes of organic food. Food Quality and Preference 21, 495-503.

13 Appendix

13.1 Appendix I

Herd characteristics, management information and method of mortality recording stratified on herd.

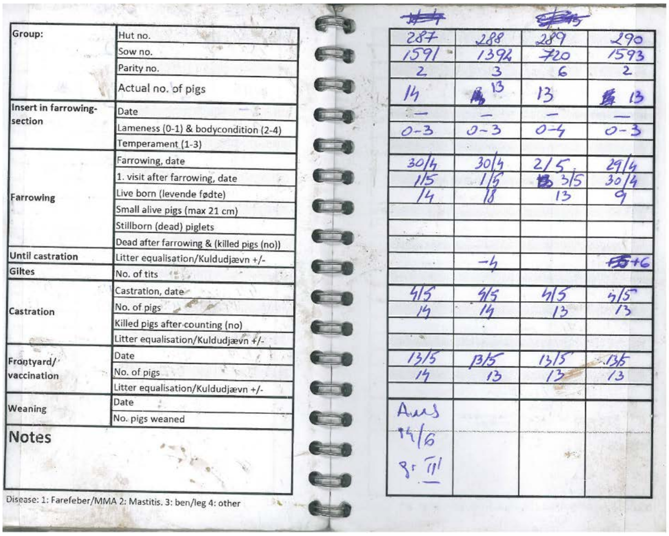
Table 1. Herd characteristics, management information and method of mortality recording stratified on herd.

Herd	Size¤	Farrowing batches, Interval	Sows, n	Nurse sows$	Weaning age	Removal of fender (days *pp*)	Method of recording
1	910	3 weeks	100	Yes	6-8 weeks	14	Booklet
2	360	3 weeks	45	Yes	6-8 weeks	21	Info sheet
3	550	3 weeks	65	Yes	6-8 weeks	14	Booklet*
4	345	2 weeks	30	Yes	6-8 weeks	14-18	Booklet*
5#	200	-	-	No	10 weeks	10-12	Info sheet
6	275	4 weeks	50	No	6-8 weeks	12-14	Booklet
7	270	2 weeks	25	No	6-8 weeks	10	Booklet
8	85	3 weeks	8	No	6-8 weeks	10-21	Booklet*
9	110	3 weeks	15	No	6-8 weeks	5-10	Booklet

¤: Productive sows per year.
$: Routinely use of two-step nurse sows.
*: Herds gathered information in the manner they did prior to start of the study period and registrations were transferred into the booklets subsequently.
#: Herd 5 did not organise gestating sows into farrowing batches. Sows were continuously inseminated and moved to the farrowing field accordingly. Piglets for necropsy were collected continuously until reaching 25 sows.

13.2 Appendix II

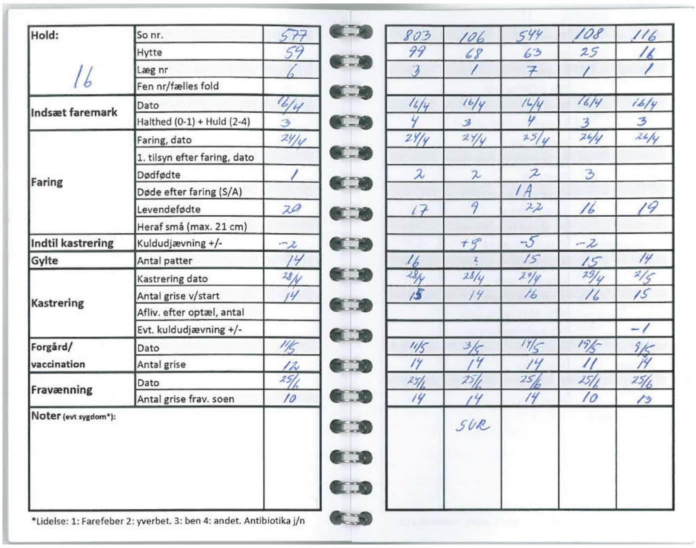
Booklets and recording sheets showing methods of recording.



Group:	Hut no.	287	288	289	290
	Sow no.	1591	1394	720	1593
	Parity no.	2	3	6	2
	Actual no. of pigs	14	13	13	13
Insert in farrowing-section	Date	–	–	–	–
	Lameness (0-1) & bodycondition (2-4)	0-3	0-3	0-4	0-3
	Temperament (1-3)				
Farrowing	Farrowing, date	30/4	30/4	2/5	29/4
	1. visit after farrowing, date	1/5	1/5	3/5	30/4
	Live born (levende fødte)	14	18	13	9
	Small alive pigs (max 21 cm)				
	Stillborn (dead) piglets				
	Dead after farrowing & (killed pigs (no))				
Until castration	Litter equalisation/Kuldudjævn +/-		-4		+6
Giltes	No. of tits				
Castration	Castration, date	4/5	4/5	4/5	4/5
	No. of pigs	14	14	13	13
	Killed pigs after counting (no)				
	Litter equalisation/Kuldudjævn +/-				
Frontyard/ vaccination	Date	13/5	13/5	13/5	13/5
	No. of pigs	14	13	13	13
	Litter equalisation/Kuldudjævn +/-				
Weaning	Date				
	No. pigs weaned				
Notes					

Disease: 1: Farefeber/MMA 2: Mastitis. 3: ben/leg 4: other

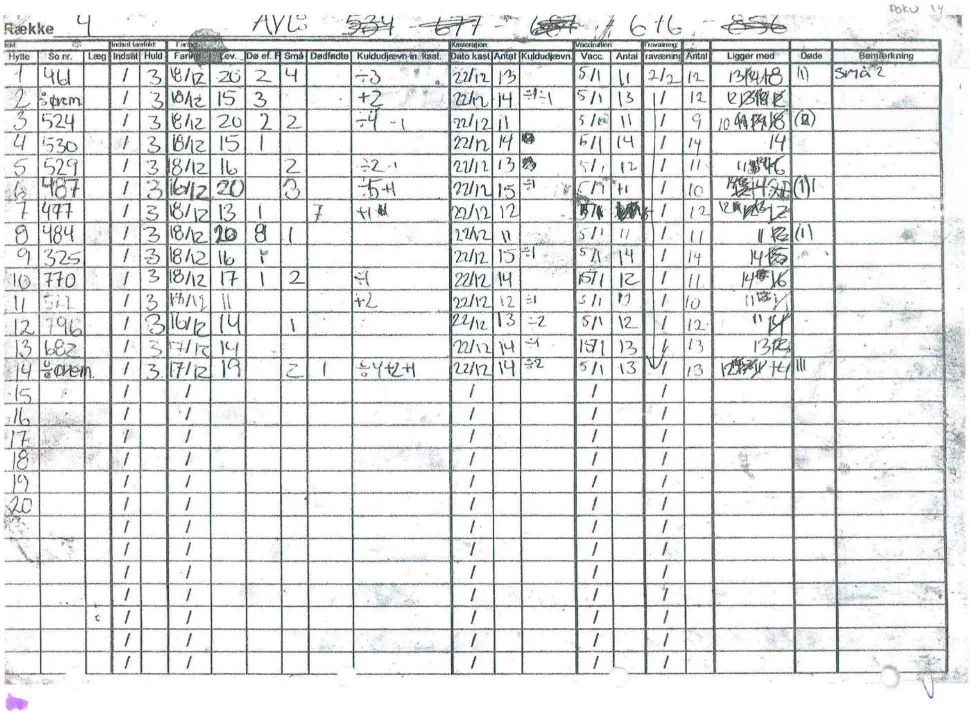
Figure 1. English booklet.
The recordings were written directly into the booklet in the farrowing field.



Hold: 16	So nr.	577	803	106	544	108	116
	Hytte	59	99	68	63	25	16
	Læg nr	6	3	1	7	1	1
	Fen nr/fælles fold						
Indsæt faremark	Dato	16/4	16/4	16/4	16/4	16/4	16/4
	Halthed (0-1) + Huld (2-4)	3	4	3	4	3	3
Faring	Faring, dato	24/4	24/4	24/4	25/4	26/4	26/4
	1. tilsyn efter faring, dato						
	Dødfødte	1	2	2	2	3	
	Døde efter faring (S/A)				1A		
	Levendefødte	20	17	9	22	16	19
	Heraf små (max. 21 cm)						
Indtil kastrering	Kuldudjævning +/-	-2		+9	-5	-2	
Gylte	Antal patter	14	16	[illegible]	15	15	14
Kastrering	Kastrering dato	28/4	28/4	28/4	29/4	29/4	2/5
	Antal grise v/start	14	15	14	16	16	15
	Afliv. efter optæl, antal						
	Evt. kuldudjævning +/-						-1
Forgård/ vaccination	Dato	11/5	11/5	3/5	11/5	11/5	9/5
	Antal grise	12	17	14	14	11	14
Fravænning	Dato	25/6	25/6	25/6	25/6	25/6	25/6
	Antal grise frav. soen	10	14	14	14	10	13
Noter (evt sygdom*):				SUR			

*Lidelse: 1: Farefeber 2: yverbet. 3: ben 4: andet. Antibiotika j/n

Figure 2. Danish booklet.
Recordings were from the farrowing field were copied into the booklet after weaning of the farrowing batch.



POKU 14

Række 4 AVL: ~~534~~ – ~~677~~ – ~~687~~ / 616 – ~~856~~

fold:			Indsat farefold:		Faring:						Kasteration:			Vaccination:		Fravænning:				
Hytte	So nr.	Læg	Indsat	Huld	Faring	Lev.	Dø ef. F	Små	Dødfødte	Kuldudjævn in. kast.	Dato kast	Antal	Kuldudjævn.	Vacc.	Antal	Fravænning	Antal	Ligger med	Døde	Bemærkning
1	461		/	3	18/12	20	2	4		÷3	22/12	13		5/1	11	2/2	12	13 [illegible] 18	(1)	Små 2
2	♀ prem.		/	3	18/12	15	3			+2	22/12	14	÷1 ÷1	5/1	13	/	12	12 13 [illegible]		
3	524		/	3	18/12	20	2	2		÷4 -1	22/12	11		5/1	11	/	9	10 [illegible] 18	(2)	
4	530		/	3	18/12	15	1				22/12	14	[illegible]	5/1	14	/	14	14		
5	529		/	3	18/12	16		2		÷2 -1	22/12	13	[illegible]	5/1	12	/	11	11 [illegible] 16		
6	487		/	3	16/12	20		3		÷5 +1	22/12	15	÷1	5/1	11	/	10	[illegible]	(1) 1	
7	477		/	3	18/12	13	1		7	+1 [illegible]	22/12	12		[illegible]	[illegible]	/	12	12 [illegible] 12		
8	484		/	3	18/12	20	8	1			22/12	11		5/1	11	/	11	11 12	(1)	
9	325		/	3	18/12	16	1				22/12	15	÷1	5/1	14	/	14	14 15		
10	770		/	3	18/12	17	1	2		÷1	22/12	14		15/1	12	/	11	14 [illegible] 16		
11	[illegible]		/	3	18/12	11				+2	22/12	12	÷1	5/1	11	/	10	11 [illegible]		
12	796		/	3	16/12	14		1			22/12	13	÷2	5/1	12	/	12	11 14		
13	682		/	3	17/12	14					22/12	14	÷1	15/1	13	/	13	13 12		
14	♀ prem.		/	3	17/12	19		2	1	÷4 +2 +1	22/12	14	÷2	5/1	13	/	13	12 [illegible] 14	III	
15			/		/						/			/		/				
16			/		/						/			/		/				
17			/		/						/			/		/				
18			/		/						/			/		/				
19			/		/						/			/		/				
20			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				
			/		/						/			/		/				

Figure 3. Recording sheet.
The recordings were performed directly onto the recording sheet in the farrowing field.

13.3 Appendix III

Description of the criteria and definitions of the recorded variables by the stock personnel in the farrowing field.

Prior to the start of the data collection, all participants were carefully instructed in how to perform the recordings and how to distinguish between live-born and stillborn piglets. Guidance and practical instructions were done in the farrowing field to test and adjust the observers' ability to perform the recordings correctly.

Visual scoring of sow body condition (BCS)

The body condition score scale was modified from the scale available at ProPig (Holinger et al., 2015), and the categories were defined as follows:

2) Thin – Ribs, backbone and hipbones are obvious or easily detected with pressure.

3) Moderate – Ribs, backbone and hipbones are barely visible or are barely felt with firm pressure.

4) Fat – Ribs, backbone and hipbones cannot be seen or felt when firm pressure is applied, or fat deposits are clearly visible.

Pictures to emphasise the visible differences between the groups supplemented the description (Figure 4).

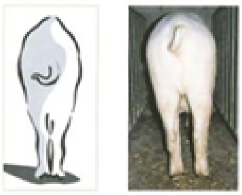
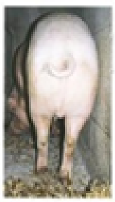
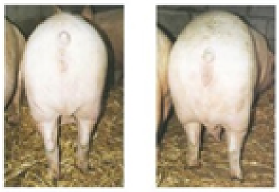
BCS 2 – Thin	BCS 3 – Normal	BCS 4 – Fat
		

Figure 4. Body condition score of sows.

Scoring of lameness (gait scoring)

Score 0: The sow walk normal or shows only weak signs of lameness or uneven gait

Score 1: The sow show obvious signs of lameness, reduced weight bearing on minimum one leg and/or the sow cannot stand up.

Identification of stillborn piglets at first check-up pp

Observers in all nine herds were instructed in distinguishing stillborn from live-born piglets prior to the start of the recordings. A wide and uncontracted umbilical cord, in combination with the presence of intact cartilaginous tips on hoofs with no sign of wear or intact or partial intact foetal membrane covering the piglet, was defined as sufficient evidence of the piglet being stillborn. Pictures illustrating the three criteria are shown in Figure 5.

Figure 5. Physical appearance of stillborn piglets.
1: A wide and uncontracted umbilical cord.
2: Intact cartilaginous tips on hoofs.
3: Partial intact foetal membrane covering the piglet.

13.4 Appendix IV

Protocol used during *post-mortem* examinations.

Table 2. Protocol used during *post mortem* (*pm*) examinations.

Variable	***Category***
Weight	Measured in grams
Length	CTR measured in cm
State of decomposition	0: Non to mild 1: Moderate 2: Heavy 3: To decomposed for *pm*
Gender	0: Female 1: Male 2: Castrate
IUGR (Figure 6)	0: Normal (0 of 3 criteria) 1: Mild (1-2 of 3 criteria) 2: Complete (3 of 3 criteria) ***Criteria*** • Steep, dolphin-like forehead • Bulging eyes • Wrinkles perpendicular to the mouth
Umbilical cord (Figure 7)	0: Moist 1: Dried 2: Not present or cannot be assessed
Cartilaginous tips on hoofs (Figure 8)	0: Intact 1: Lightly worn 2: Not present
Air filling lungs	0: Floats 1: Sinks 2: Cannot be assessed
Stomach content	0: Milk 1: Amnion fluid 2: Meconium .: No content

Variable	***Category***
Milk quantity in stomach	0: Empty (if "." in stomach content) 1: Half full 2: Full .: (if "1" or "2" in stomach content)
Nutritional state	0: < 700 g OR emaciated 1: Well below average – prominent spine and ribs with little or no abdominal or subcutaneous fat 2: Below average – initial sharpness of the back line with loss of muscle and fat 3: Normal
Stillborn – Type (Figure 9)	0: *Pre-partum* (type I) 1: *Intra-partum* (type II) .: Cannot be assessed

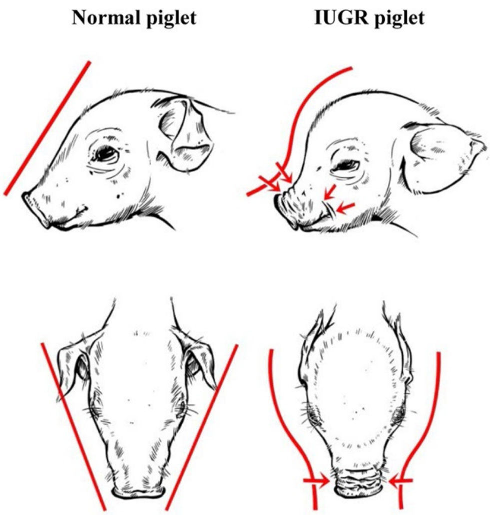


Figure 6. Illustrations of a normal (left) and a growth-restricted piglet (right). Criteria for growth restriction were 1) steep, dolphin-like forehead, 2) bulging eyes, and 3) wrinkles perpendicular to the mouth. IUGR = intrauterine growth restriction (cited from Hales et al., 2013).

Figure 7. Umbilical cord.
1: Dried (contracted)
2: Moist (not contracted)

Figure 8. Cartilaginous tips on hoofs.
0: Intact
1: lightly worn
2: Not present

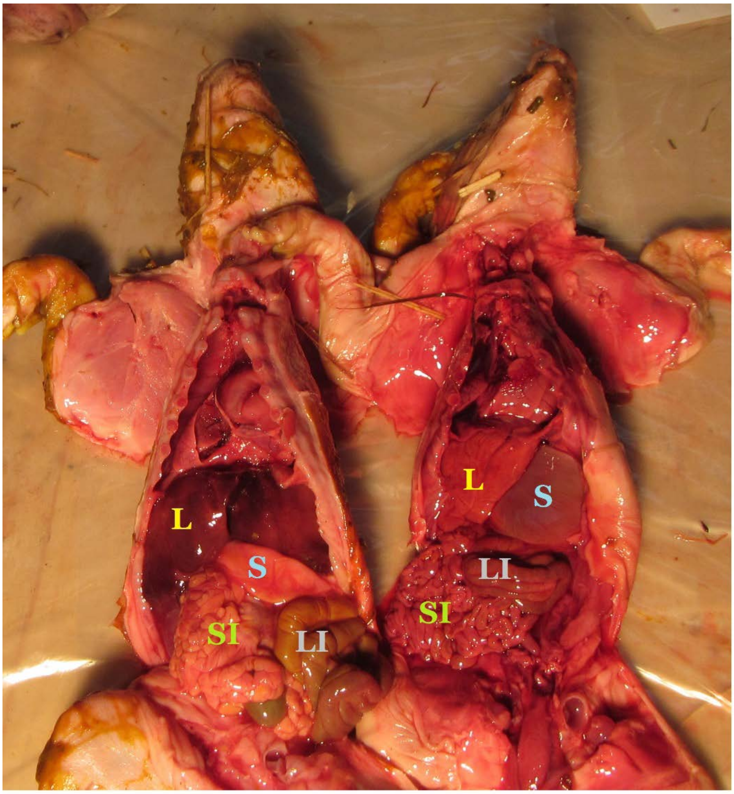


Figure 9. Stillborn piglets – *Intra-partum* or type II (left) and *pre-partum* or type I (right).
L: Liver, S: Stomach, SI: Small intestines, LI: Large intestines.

Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. Journal of Animal Science 91, 4991-5003.

Holinger M, Edwards S, Illmann G, Leeb C, Milsova M, prunier A, Rudolph G and Früh B 2015. Fertility. Improving health and welfare of pigs – A handbook for organic farmers pp. 7 - 26. Research Institute of Organic Agriculture, Frick, Switzerland.

High piglet mortality is a considerable problem in Danish organic sow herds. The aim of this study was to determine causes of preweaning mortality and to identify risk factors for piglet mortality within the Danish organic pig production. A large-scale study was performed in nine commercial Danish organic sow herds during a one-year period. Data included recordings on piglet mortality in 6000 litters. Moreover, 3000 piglets were necropsied in order to determine the cause of death. The results indicates that it is possible to achieve a lower piglet mortality in the future and that the Danish organic pig production and a high piglet mortality is not inevitably synonymous.