Impact of litter size on sow health and welfare

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Cover: Moderate litter size

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Abstract

Genetic improvement of litter size has been the main breeding goal in piglet production during the last decades, resulting in a steady increase in total number of born piglets in each litter both in Sweden and in other European countries. It has been suggested that large litters pose a major welfare problem for sows and piglets. However, there is a lack of recent studies investigating the impact of litter size on the health and welfare of sows. Therefore the objective of this thesis was to investigate the association between litter sizes and sow health and welfare. The two studies included in this thesis were performed as observational studies and investigated by retrospective analysis of available pig production data. The first study investigated the association between litter sizes and sow stayability, and the second study the association between litter size and medical treatment of sows during farrowing and lactation. The final dataset used in the first study included a study population of 38 878 sows in 24 herds and the final dataset in the second study included observations from 1 947 litters from 655 sows.

Associations between litter size and sow health and welfare was found. There was an association between litter size and stayability of the sow, as well as association between litter size and medical treatment of the sow. The results from both studies imply that sows with medium sized litters have a better lifetime production than sows with very small or large litters. Piglet producers should therefore pay even more attention to prophylactic management of sows during gestation and lactation. In planning of breeding strategies and annual removal of sows, piglet producers should also aim for keeping sows giving birth to a medium-sized litter, with approximately 12 to 14 piglets born in total in their breeding program, as this seems to improve sows' stayability and decreasing the risk of unplanned removal which would favour health and welfare of both sow and piglets.

Keywords: stayability, removal reason, piglet production, oxytocin, antibiotics

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Kullstorlekens påverkan på suggans hälsa och välfärd

Sammanfattning

Att avla fram stora kullar har varit ett av de främsta avelsmålen inom smågrisproduktionen under de senaste decennierna. Detta har resulterat i en stadig ökning av det totala antalet smågrisar som föds i varje kull, både i Sverige och i andra Europeiska länder. Tidigare forskning tyder på att stora griskullar påverkar både suggors och smågrisars välfärd negativt. Det saknas emellertid nyare studier som undersöker hur kullstorleken påverkar suggans hälsa och välfärd. Syftet med avhandlingen var därför att undersöka eventuella samband mellan kullstorlek och suggans hälsa och välfärd. De två studierna som ingår i avhandlingen utfördes som två olika epidemiologiska observationsstudier där tillgängliga produktionsdata i två oberoende databaser från smågrisbesättningar undersöktes och analyserades retrospektivt. I den första studien utgjordes studiepopulationen av 38 878 suggor från 24 olika besättningar och i den andra studien utgjordes studiepopulationen av 1 947 kullar från 655 suggor.

Resultaten visar att det finns ett samband mellan kullstorlek och suggans hälsa och välfärd. Dels påvisades ett samband mellan kullstorlek och suggans hållbarhet, dels ett samband mellan kullstorlek och medicinsk behandling av suggan under dräktighet och laktation. Resultaten av studierna antyder att medelstora kullar är bättre att satsa på jämfört med väldigt små och stora kullar. Smågrisproducenter bör därför satsa mer på förebyggande hälsovård av suggor under dräktighet och laktation. I avelsplaneringen och den årliga utslagningen av suggor, bör smågrisproducenterna sträva efter att behålla de suggor som föder medelstora kullar om ungefär 12 till 14 smågrisar födda totalt i kullen. Denna typ av avelsplanering kan förbättra suggans hållbarhet och minska risken för oplanerad utslagning samt förbättra välfärden för både smågris och sugga.

Nyckelord: hållbarhet, utslagningsorsak, smågrisproduktion, oxytocin, antibiotika

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Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Andersson, E.*, Frössling, J., Engblom, L., Algers, B. and Gunnarsson, S. (2016). Impact of litter size on sow stayability in Swedish commercial piglet producing herds. *Acta vet scand,* 58, 31. doi:10.1186/s13028-016-0213-8.

II Andersson, E.*, Frössling, J., Westin, R., Algers, B. and Gunnarsson, S. Relationship between litter size and medical treatments of Swedish Yorkshire sows during farrowing and lactation. Manuscript.

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The contribution of Emma Andersson to the papers included in this thesis was as follows:

I Design of study, data retrieval, statistical analyses and drafting of manuscript

II Design of study, data retrieval, statistical analyses and drafting of manuscript

Abbreviations

S1S2	Small first litter and small second litter
S1M2	Small first litter and medium second litter
S1L2	Small first litter and large second litter
M1S1	Medium first litter and small second litter
M1M2	Medium first litter and medium second litter
M1L2	Medium first litter and large second litter
L1S2	Large first litter and small second litter
L1M2	Large first litter and medium second litter
L1L2	Large first litter and large second litter
NSAID	Non-steroid anti-inflammatory drug

Introduction

Health and welfare in piglet production

There are several definitions of animal welfare. Webster (2011) describes animal welfare in farm animals as 'the state of body and mind of a sentient animal as it attempts to cope with its environment'. Furthermore, he argues that the definition of animal welfare includes the full spectrum from healthy to sick and pain to pleasure. Broom & Fraser (2015), also states that health and feelings are important parts of the term animals' welfare. Butterworth (2009), claims that animal welfare is a characteristic of an individual animal.

The scientific assessment of animal welfare has developed rapidly during recent years. It is important to assess animal welfare in an objective way when evaluating and comparing animal welfare in different or specific situations (Broom & Fraser, 2015). The European Food and Safety Authority (EFSA) Animal Health and Welfare panel was requested to develop several scientific opinions concerning animal-based measures to assess the welfare of livestock animals. In 2011, EFSA presented a technical report about animal based measures for assessing the welfare of pigs (Spoolder *et al.*, 2011). With focus on animal health and welfare, one conclusion was that large litters pose a major welfare problem, recommending that genetic selection for litter size should not aim at exceeding having an average of 12 piglets alive born in a litter. Furthermore, Andersen *et al.*, (2011) concludes in their study that 10 to 11 piglets could be close to the upper limit the domestic sow is capable of taking care of.

Sows´ strategy with low investment in in each piglet during gestation and high volume of offspring in each litter has been beneficial for modern piglet production. The genetic improvement of litter size have been the main breeding goal in piglet production during the last decades, resulting in a steady increase in total number of born piglets in each litter, in Sweden

(Andersson *et al.*, 2016) and in other European countries (Baumgartner, 2011).

There is a trade-off between number and quality of young born piglets in a litter, e.g. resulting in, piglets born small and having high mortality rates in the litter (Drake *et al.*, 2008). During the same period of time that litter sizes have increased in piglet production, problems with piglet mortality also have increased (Baumgartner, 2011; Andersson *et al.*, 2016). This development has caused welfare problems for piglets born in large litters, causally related both to gestation and lactation (Rutherford *et al.*, 2013). Furthermore, there has been an increase in the proportion of stillborn piglets, a decrease in the proportion of weaned piglets and a larger variation in quality of piglets (Lund *et al.*, 2002; Milligan *et al.*, 2002; Weber *et al.*, 2007; Rutherford *et al.*, 2013).

Resource allocation can be explained as the result of trade-offs among reproduction, growth, survival and other life-history traits (Glazier, 2009). There is a parent-offspring conflict, between sow and piglets, over resource allocation as neonatal mortality may improve a sows overall fitness by enabling her to invest more resources in her remaining piglets while maintaining her own body condition (Drake *et al.*, 2008). Sows reach their mature size around their seventh parity, meaning that young sows are supposed to simultaneously grow and successfully reproduce (Knap & Rauw, 2009). The robustness of the sow may be reduced in highly productive pig genotypes. Intense piglet production demand many resources from the sow and functions, such as immune response, and coping with other stressors can become resource-limited (Knap & Rauw, 2009).

Impact of litter size on health and welfare of sows

It is important to consider sow health and welfare when aiming for a successful piglet production (Jaaskelainen *et al.*, 2014). During lactation the sow invests a substantial part of her resources into the piglets. Therefore, it is challenging for the sow to maintain body condition while nursing a large litter size, and a risk of substantial weight loss of the sow during lactation (Drake *et al.*, 2008). This may in turn be associated with an increased risk of clinical disease during lactation (Sterning *et al.*, 1997).

There is a high annual removal rate of gilts and sows in Sweden (Engblom *et al.*, 2007). Removal rates seem to have increased during the same period that litter sizes have increased. Health problems, such as reproductive disorders and udder problems, are associated with unplanned removal of sows in early parities (Engblom *et al.*, 2007). Removal of these sows is an

economical problem for the producers as sows need to stay in production at least three parities to be profitable (Stalder *et al.*, 2003).

Still, impact of litter size on sow health and welfare is uncertain. A large litter size may cause an impaired health and welfare of the sow (Rutherford *et al.*, 2013). A Swedish study from 1978, found a significant positive association between large litter size and agalactia (Hermansson *et al.*, 1978). The authors also found that sows affected with agalactia postpartum were more likely to be culled compared to sows that did not have agalactia. However, there is a lack of recent studies investigating the impact of litter size on the health and welfare of sows. Therefore, the objective of this thesis was to investigate the association between litter sizes and sow health and welfare. The two studies included in the thesis were performed as observational studies and investigated by retrospective analysis of available pig production data.

Aims

The overall aim of this thesis was to investigate if there are associations between litter size and sow health and welfare. The specific aims of the two studies were:

- To investigate the association between litter sizes and sow stayability.
- To describe and evaluate the impact of first and second parity litter size on sow stayability and removal reasons.
- To investigate the association between litter size and medical treatment of sows during farrowing and lactation.
- To describe and evaluate medical treatment of sows during farrowing and lactation.

Materials and methods

Both studies were performed as observational studies, investigated by retrospective analysis of available pig production data. The first study was designed to investigate the association between litter sizes and sow stayability. Furthermore, it was used to describe and evaluate the impact of first and second parity litter size on sow stayability and removal reasons. The second study was designed to investigate the association between litter size and medical treatment of sows during farrowing and lactation. Furthermore, it was used to describe and evaluate medical treatment of sows during farrowing and lactation.

Study populations

Sow stayability and removal reasons (Paper I)

This study used data from a sow database established at the Swedish University of Agricultural Sciences (SLU). The database included production data from sows in Swedish commercial piglet producing herds. Data from the database were extracted in January 2014. The source population consisted of 63 844 registered sows from 28 herds. To be included in the study population sows had to be born between January 1, 1997 and December 31, 2009. This was done to analyse sows that potentially could produce at least four litters before the end of the study period. Sows had to be crossbred and to produce at least one litter with the minimum of one piglet born in total. To be included in the dataset, individual herds had to contribute with $\geq$ 1% of the observations. The final dataset included a study population of 38 878 sows in 24 herds. There were no data available of herd location, housing system or management.

Medical treatment (Paper II)

In this study data from the research farm owned by the Swedish University of Agricultural Sciences was available. Production data and records of medical treatments of sows during farrowing and lactation for every litter born in the time period from January 1st 2001 to December 31st 2010 were extracted. Only purebred Yorkshire sows were included in the study. The final dataset included observations from 1 947 litters from 655 sows. Included sows were born between 1997 and 2009.

Data records

Litter size (total number of piglets born) was chosen as the exposure variable in both studies.

Sow stayability and removal reasons (Paper I)

In the first study, litter size in first and second parity litter was chosen as exposures of interest in the analyses. First parity litter size was categorised into ten groups, in order to describe and evaluate the impact of first parity litter size on sow stayability. For analysis of the combined effect of the litter size in first and second parities, the litter size born in total was categorised into small (S; $\leq$ 11 piglets), medium (M; 12-14 piglets) or large (L; $\geq$ 15 piglets). Based on these three categories, the litter size in first and second parity was combined into nine categories: small-small (S1S2), small-medium (S1M2), small-large (S1L2), medium-small (M1S2), medium-medium (M1M2), medium-large (M1L2), large-small (L1S2), large-medium (L1M2) and large-large (L1L2).

Stayability was analysed as sows' probability of producing a total number of litters in her lifetime, higher or equal to the population median. A sows' probability of having a second litter (considering her first parity litter size) or a third litter (considering the combined litter size based on first and second parity) was shown descriptively.

Sow removal was firstly described regarding to whether the sow was euthanized or not. Secondly, removal reasons were described using nine categories of removal reason which previously has been analysed by Engblom *et al.*, 2007.

Medical treatment (Paper II)

In the second study, the medical treatment of sows during farrowing and lactation was chosen as outcome. The production data records consisted of sow identities, sow birth year, parity number, farrowing date, total number of piglets born per litter, number of piglets born alive per litter, number of piglets weaned per litter and weaning date. Season of farrowing was extracted from farrowing date.

Records of medical treatment of individual sow included: date of medical treatment, type of drug or treatment, dosage and reason for medical treatment. The day of farrowing was defined as day 0 and any medical treatment given to the sow the day before farrowing (to include onset of farrowing) until the day of weaning was included in the analyses. Medical drugs and treatments given during the study period were categorised into four categories: oxytocin, antibiotics, anti-inflammatory drugs (NSAIDs and cortisone) and miscellaneous treatments (e.g. selenium and vitamins). Furthermore, reasons for medical treatment were grouped into four categories: leg and claw disorders, udder and reproductive tract disorders, lethargy (fever and loss of appetite) and miscellaneous disorders.

Statistical analyses

The statistical software Stata (release 12, StataCorp LP, College Station, TX) was used for data editing and statistical analyses.

Sow stayability and removal reasons (Paper I)

Potential association between litter size and the probability of producing four or more litters in a lifetime was analysed using mixed-effects logistic regression. The unit of interest was sow and litter size was the exposure of interest. Herd was included as a random variable in the models. Other variables, considered of interest to control for in the primary models, were birth year of the sow, age of first farrowing and season at first farrowing. Potential association, between the outcome variable and these covariates, were first assessed using univariable regression and then further investigated using multivariable regression. The final models were built using backward stepwise elimination. Variables with non-significant results ($p>0.05$) were not included in the final models. Interaction between litter size and birth year of the sow was tested for in all the primary models but was not significant and therefore not included in any of the final models.

Medical treatment (Paper II)

To investigate the association between litter size and medical treatment of sows during farrowing and lactation multivariable multilevel logistic regression model was used. Each observation represented one litter, and each sow could thus contribute to several observations in the data. For the outcome variable in the statistical analysis, observations where the sow received at least one medical treatment during farrowing or lactation were registered as "yes" (1), and observations where the sow did not receive any medical treatment were registered as "no" (0). In addition to litter size, i.e. total number of piglets born, parity of the sow and season for when the litter was born were included as covariates in the model. The year when the litter was born and sow identity of the litter, was included as random variables (multilevel effects).

Initially empty models were tested to estimate the random effects of year and sow identity, as single level random effects and as multilevel random effects with sow identity nested within year. Litter size, parity and season were first tested for their association with the outcome by univariable multilevel logistic regression analysis. Litter size was analysed as a continuous variable in the model and showed a significant ($p<0.001$) association with the outcome. The association with season and parity and the outcome were not significant. Even so, parity was selected for further analysis and entered to the multivariable model as fixed effect.

As part of building the regression model, different formats of the litter size variable were tried. In addition to the original continuous form, this included categorisation using 11 categories, best fit first or second-degree fractional polynomials and linear splines. The final multivariable multilevel logistic regression model was then constructed using manual backward stepwise elimination. The different models with categorised litter size and the model with litter size as a continuous variable were compared by comparing their Bayesian information criterion (BIC).

Results

These sections summarize the main results from the two studies. More detailed information can be found in the individual papers.

Sow stayability (Paper I)

Among sows giving birth to 9-16 piglets born in total in their first parity, a higher proportion had a second litter, and a higher proportion was able to stay four litters or more, compared to sows giving birth to ≤ 8 or ≥ 17 piglets. The regression model of this outcome variable (i.e. sow stayability) showed significant negative associations between first parity litter sizes of ≤ 8, 15 and ≥ 17 piglets compared to sows giving birth to 13 piglets.

Group S1M2 and M1M2 had a higher proportion of sows having a third litter and a higher proportion of sows that was able to produce ≥ 4 litters than the other groups. Except for sows in group S1M2, all groups were significantly associated with an impaired ability to produce ≥ 4 litters compared to sows in the M1M2 group.

Removal reasons (Paper I)

With an increasing first parity litter size, there was an increasing trend in proportion of sows being euthanized. Sows having ≤ 8 piglets was the largest group removed due to low productivity whereas sows having ≥ 14 piglets had the largest proportions of sows removed due to udder problems. Problems with lameness and/or foot lesions increased in proportion with increasing litter size. It was found that 12.0% of sows giving birth to ≥ 17 piglets were removed due to old age compared to 20.6% of sows giving birth to nine piglets in their first parity litter.

The proportion of sows being euthanized was higher in the groups having a large first or second parity litter than in the other groups (6.0%-6.9% and 4.1%-5.7%, respectively). Sows having a large litter in first or second parity also had the lowest proportion of sows being removed due to old age. The proportion of sows being removed due to lameness and/or foot lesions increased with an increasing second litter size.

Medical treatment (Paper II)

During the ten-year period studied, 19.9% of the litters had a sow that was given at least one medical treatment during farrowing and lactation. This percentage increased with parity, and differed between litter size, years and season. Out of these sows, 36.4% received more than one medical treatment. Oxytocin was the most common given medical drug and was given alone or in combination with antibiotics and/or NSAID or cortisone to 81.4% of the treated sows. The first given medical treatment was given during the first days of lactation (median 1 day, range -1 to 36 days).

The main reason for giving medical drug or treatment to sows during farrowing and lactation was udder and reproductive tract disorders. Of the first medical treatments, 45.5% were given due to problem with milk let-down. The second most common reason was weak contractions during farrowing (11.0%) and fever was the third most common reason (10.0%). Furthermore, fever was the most common reason for giving medical drugs or treatments more than once to a sow.

Results from the final multivariable multilevel logistic regression showed, with a 95% Confidence Interval (CI), that the odds of medical treatment decreased for every additional piglet born in total up to five piglets (OR: 0.50, p=0.002, CI: 0.32-0.78). For litter sizes $\geq$ 5 piglets born in total the odds of medical treatment increased for each additional piglet being born (OR: 1.11, p< 0.001, CI: 1.06-1.15). The random effect of year when the litter was born explained 2.3% of the variance between observations whereas sow identity nested within year explained 13.5% of the variance of observations.

General discussion

The overall aim of this thesis was to investigate if there are associations between litter size and sow health and welfare. The specific aims of the two studies included to investigate the association between litter sizes and sow stayability, and the association between litter size and medical treatment of sows during farrowing and lactation.

An association between litter size and sow health and welfare was found, i.e. an association between litter size and stayability of the sow as well as an association between litter size and medical treatment of the sow. Results from both studies imply that very small and large litters are not necessarily better than medium sized litters. Overall, the results indicate that piglet producers should pay more attention to prophylactic management of sows during gestation and lactation. Furthermore, they should, in the planning of breeding strategies and annual removal of sows, aim for keeping sows giving birth to a medium-sized litter, with approximately 12 to 14 piglets born in total, as this seems to improve sows' stayability and decreasing the risk of unplanned removal. That would favour health and welfare of both sow and piglets.

Impact of litter size on sow health and welfare

It is important to consider animal welfare of sows in modern intensive piglet production. Sows´ strategy with low investment in in each piglet during gestation, and high volume of offspring in each litter has been beneficial for modern piglet production; but success may also come with failure, and there are always economic choices to be made regarding to investments in animal welfare and any incurring gains.

The impact of litter size on sow health and welfare have previously been unclear. Rutherford *et al.* (2013), concludes in a review article that a large

litter size may cause an impaired health and welfare of the sow. Webster (2011) argue that we must consider the full spectrum from healthy to sick, from pain to pleasure, when assessing welfare in farm animals. Concluding the results from the two epidemiological studies included in this thesis, I claim that litter size has an impact on sow health and welfare.

In the first study, sows having small or large litters in their first parities had a negative effect on their stayability (i.e sows' probability of producing a total number of litters in their lifetime, higher or equal to the population median). These sows were therefore forced to be removed early in their productive life. The population median of total number of litters produced in a sows lifetime found in our study corresponds well to the average parity number at removal found in the study of Engblom *et al.* (2007). Knap & Rauw (2009) claims that the robustness of the sow may be reduced in highly productive pig genotypes as functions, such as immune response and coping with other stressors can become resource-limited. This may be an explanation of why sows giving birth to large litters were forced to be removed early in their productive life.

Sows giving birth to a small litter, were more commonly removed from the herd because of low productivity and/or old age (i.e. planned removal). Unplanned removal (i.e. euthanizing the sow due to health problems such as udder problems and lameness and/or foot lesions) was more common amongst sows with large first and second litter sizes. This indicate that large litters have a negative effect on the general health of the sow. These findings are also supported by research of Engblom *et al.* (2007) and concludes that planned removals are less likely to be linked to impaired health and welfare compared to unplanned reasons.

Results from the second study also support the idea that litter size has an impact on sow health and welfare. In the second study, we found an association between litter size and medical treatment of sows during farrowing and lactation. The odds of medical treatment decreased for every additional piglet born in total up to five piglets. In larger litters (≥5 piglets) the odds of medical treatment increased for each additional piglet being born. Disease of the sow during gestation can result in a small number of piglets born per litter (Friendship and O'Sullivan, 2015), which can explain why we found a negative association between medical treatment of sow and a very small litter size. In this case, it is logical to consider that the health and welfare of the sow reasonably have had an impact on litter size and not the other way around.

During gestation and lactation, the sow invests a lot of her resources into the piglets. Therefore, nursing a large litter while maintaining her own body

condition is a challenge for the sow, risking substantial weight loss of the sow during lactation (Drake *et al.*, 2008). This may in turn be associated with an increased risk of clinical disease during lactation (Sterning *et al.*, 1997). Taking this into account, and in contrast to the small litters, it is reasonable to conclude that large litters have a great impact on sow health and welfare Already 40 years ago, a Swedish study found a significant positive association between large litter size and disease in terms of agalactia (Hermansson *et al.*, 1978). Hermansson *et al.* (1978), also found that sows with agalactia during farrowing were at larger risk of getting the same disorder in their next parity. Later several studies have shown positive associations between large litters and sow disease occurrence (Bäckström *et al.*, 1984; Gerjets *et al.*, 2011). Prolonged farrowing duration (Oliviero *et al.*, 2010; Tummaruk & Sang-Gassanee, 2013) and birth interventions (Gerjets *et al.*, 2011), have been suggested as factors that may explain why larger litter sizes have a negative effect on disease occurrence.

Sows in the second study were mainly treated on the day of farrowing or the first two days after farrowing. The time and main reason for medical treatment of sows in the second study indicate that most of the treated sows were affected by the mastitis-metritis-agalactia (MMA) complex or weak contractions. Agalactic sows fails to meet the nutritional needs of the piglets. Since time during farrowing and those first days in lactation are very important for the newborn piglets (Edwards & Baxter, 2015), an impaired health status of the sow most likely also will have a negative effect on piglet health and welfare. Hermansson *et al.* (1978) found that sows affected with agalactia postpartum more likely weaned fewer piglets and were exposed to greater risk to be culled, compared to sows that did not have agalactia. Engblom *et al.* (2007) found that sows with udder problems and reproductive disorders was associated with unplanned removal. The odds of medical treatment increased for each additional piglet being born in a large litter. All together the results from the second study indicates that a negative health status of the sow will have an obvious negative effect on the economics of the producer.

Main breeding goals, when improving the production efficiency in modern piglet production has so far been increasing the number of piglets born in every litter (Rutherford *et al.*, 2013). Results from the first study indicates that sows giving birth to large litters in early parities have a negative effect on sow stayability and productive lifetime, indicating that those sows may not be profitable. Sows that stay in the herd for a longer period have a prolonged productive lifetime and are more profitable than sows with a shorter productive lifetime (Lucia *et al.*, 2000; Stalder *et al.*,

2003). The loss of piglets and sows early in their productive life, due to unplanned removal, in conjunction with the costs for medical treatment causes economic losses for the producer. Keeping sows giving birth to large litters is not always economically worthwhile.

Methodological considerations

In both studies, we used secondary data which had not been collected for the specific research questions. Data was retrieved from two different databases and a lot of efforts have been made to validating these data to reduce bias and increase precision. Using already established databases has advantages, such as being readily available and saving time and money. However, there are also disadvantages needed to be considered. One is the process of recording of data being beyond our control.

Recordings in the first study was made at different farms by different observers. The robustness of data is therefore assessed to be moderate and we selected the indicators of interest, based on their relevance, completeness and consistency. At the same time the main strength in the first study was the large amount of data in the database; 15 years of data and records from 28 commercial piglet producing herds in Sweden.

In the second study, data from commercial piglet producing herds could not be used as there are no central database comprising records of medical treatments of individual sows in those herds. Therefore, data from a research farm was used. Specific data of interest for the second study was selected based on its relevance, completeness and consistency. To achieve a large study sample, ten years of data was chosen. The robustness of data could be expected to be moderate since over time, recording was made by different persons (mainly research technicians), although all transcription of data from manual records into digital records was made by the same person. Compared to the database used in the first study, the strength of the database used in the second study was that it consisted of data from a research farm. The location, housing system and management were the same for all sows, which decreased the sources of bias.

Litter size was chosen to be the exposure variable in the analyses. It is important to consider both the number of piglets born alive as well as stillborn piglets when assessing the effects of litter size on sow welfare (Baxter *et al.*, 2013; Rutherford *et al.*, 2013), because it wears the sow carrying and giving birth to the large litter. Litter size in both studies were therefore defined as the total number of piglets born.

In general, unplanned removals of sows are performed before the sows have produced their third litter (Engblom *et al.*, 2007). Therefore, the first and the second litters were considered the most interesting to be studied from a welfare and health perspective, and chosen to be the exposure in the analyses of the first study. A choice also supported by other studies showing that sow performance based on the first litter provide insight into the rest of the sow's productive life (Hoge & Bates, 2011), and that sows with large first parities litter size have been shown to continue having large litter sizes during their lifetime (Hoving *et al.*, 2011).

The classification of small, medium and large litter size in the first study was based on other studies and natural biological considerations. The Animal Health and Welfare panel of the European Food and Safety Authority, EFSA, reviewed the scientific literature of the topic, concluding that large litters pose a major welfare problem both for the piglets and sows. EFSA panel recommendation, for genetic selection, is that a litter should not exceed 12 piglets born alive on average. This correspond to approximately 13 piglets born in total counting with less than 10% piglets being born dead (Spoolder *et al.*, 2011). Furthermore, Andersen *et al.* (2011) suggest that 10 to 11 piglets is the maximum of what a domestic sow may be capable of taking care of during the lactation period. Rutherford *et al.* (2013) and Baxter *et al.* (2013) classified seven to 13 piglets to be a small/medium sized litter and 14 piglets or more as large or very large litter sizes. These authors also argue that the average number of 14 functional teats seen in current sows should be the upper limit of a litter size, a statement also supported by Chalkias *et al.* (2014).

In the first study the sows were crossbred in various combinations. About 25% of the observations in the source population had missing information about breed and was mainly associated with specific herds. However, purebred Yorkshire or Landrace were excluded from analysis as these breeding herds often have different removal strategies, as their production aims are different from herds producing piglets for slaughter. The herd in the second study mainly consisted of purebred Yorkshire, and to avoid any effects of breed on the outcome all crossbred and other purebred sows in the data base were excluded from analyses. Sows in the second study were housed on a research farm and the production goals may differ from those in commercial herds. However, the total number of piglets born in each litter corresponded well to the number that could be expected in commercial piglet producing herds in Sweden and elsewhere during this time period (Tummaruk *et al.*, 2000; Cutshaw *et al.*, 2014). The results of associations found in the two studies may be applicable on most pig breeds, but the

categorisation of a small, intermediate and large litter size probably applies mainly on crossbreed Yorkshire and Landrace sows kept under similar production systems as Swedish commercial piglet production.

Reflection and ideas for further studies

"Enough is as good as a feast" seems to be applicable in modern piglet production. Finding the golden middle ground between sow health and welfare and a profitable piglet production, the producers should aim for breeding sows having medium litter sizes (12 to 14 piglets). Biology adapts slowly to new environmental and physiological challenges. Even if there has been a breeding success in number of piglets being born in each litter in commercial piglet production, the body and mind of the sow remain as a constraining factor. The reproductive system of the sow is not biological developed to carry or nurse more piglets than the size of the uterus and the number of functional teats. One could ask, what is the point in aiming to have more than 14 piglets in each litter? Many piglets in large litters (>14 piglets) are born dead or with physiological problems that exposes the piglets for an increased risk of dying the first few days of life. Different management interventions are needed for sows with larger litter than they can nurse. Those systems are not needed to the same extent if the sow is giving birth to a litter size she is capable to take care of on her own. It is important to consider the resource allocation theory in piglet production to have a sustainable and profitable sow in future modern piglet production.

Sow health and welfare play a fundamental role in successful piglet production. Producers should pay special attention to sows giving birth to large litters, during and just after farrowing, and especially consider the risk for these sows having health problems. That would favour welfare in both sow and piglets. The performance of the individual sow should also be considered in the planning of breeding strategies and annual removal. In the long run, it is more profitable keeping sows giving birth to moderate litter sizes. It will reduce the unplanned removals, which in turn makes it easier to get well-planned production and to keep intact groups. Intact groups provide better health status when stalls can be emptied and washed as planned. Furthermore, a decreased proportion of unplanned removals lower the cost of recruitment animals as sows must produce at least three litters before providing a positive income for the producer (Stalder *et al.*, 2003).

The association between litter size and sow health and welfare needs to be further investigated. Particularly the need of medical treatment, with oxytocin early in lactation and at higher parities, needs to be further

investigated. Furthermore, my ideas for future studies are continuing study production data, aiming to study if the same association as we have found in the two studies exists in today's piglet production and in other breeds. The economics of breeding for moderate litter sizes also needs to be further investigated, and this should especially include financial gains of breeding for sustainable sows held under high animal health and welfare standards.

Conclusion

Association between litter size and sow health and welfare was found in the two studies.

- Associations between litter sizes in low parities and sow stayability were found in the first study.
- There were differences in removal reason between sows having small, medium or large first parities litter sizes.
- Association between litter size and medical treatment of sows during farrowing and lactation were found in the second study.
- Oxytocin was the most commonly given medical drug and the proportion of sows treated increased with an increasing parity.

Results imply that very small and large litters are not necessarily better than medium sized litters. Piglet producers should pay even more attention to prophylactic management of sows during gestation and lactation, and, in the planning of breeding strategies and annual removal of sows, should aim for keeping sows giving birth to a medium-sized litter with approximately 12 to 14 piglets born in total, as this seems to improve sows' stayability and decreasing the risk of unplanned removal. That would favour health and welfare of both sow and piglets.

References

Andersen, I. L., Naevdal, E. & Boe, K. E. (2011). Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (Sus scrofa). *Behavioral Ecology and Sociobiology*, 65(6), pp 1159–1167.

Andersson, E., Frössling, J., Engblom, L., Algers, B. & Gunnarsson, S. (2016). Impact of litter size on sow stayability in Swedish commercial piglet producing herds. *Acta Veterinaria Scandinavica*, 58(1).

Bäckström, L., Morkoç, A. C., Connor, J., Larson, R. & Price, W. (1984). Clinical study of mastitis-metritis-agalactia in sows in Illinois. *Journal of the American Veterinary Medical Association*, 185(1), pp 70–73.

Baumgartner, J. (2011). Pig industry in CH, CZ, DE, DK, NL, NO, SE, UK, AT and EU. In: Baumgartner, J. (Ed), Vienna, Austria, 2011. pp 3–7.

Baxter, E. M., Rutherford, K. M. D., D'Eath, R. B., Arnott, G., Turner, S. P., Sandøe, P., Moustsen, V. A., Thorup, F., Edwards, S. A. & Lawrence, A. B. (2013). The welfare implications of large litter size in the domestic pig II: management factors. *Animal Welfare*, 22(2), pp 219–238.

Broom, D. M. & Fraser, A. F. (2015). The welfare of pigs. In: Broom, D. M. & Fraser, A. F., (Eds) *Domestic animal behaviour and welfare*. Wallingford, UK: CABI, pp 297-307.

Butterworth, A. (2009). Animal welfare indicators and their use in society. In: Smulders, F. J. M. & Algers, B. (Eds) *Food safety assurance and veterinary public health; Welfare of production animals: assessment and management of risks*. The Netherlands: Wageningen Academic Publishers, pp 371–389.

Chalkias, H., Ekman, E., Lundeheim, N., Rydhmer, L. & Jacobson, M. (2014). Inverted teats (Mammillae invertitae) in gilts - Effect on piglet survival and growth rate. *Journal of Animal Science*, 92(6), pp 2587–2594.

Cutshaw, R. L., Schinckel, A. P., Schultz, M. M., Fix, J., Brubaker, M. & Einstein, M. (2014). Relationships among sow productivity traits within purebred and crossbred litters. *Livestock Science*, 170, pp 193–202

Drake, A., Fraser, D. & Weary, D. M. (2008). Parent-offspring resource allocation in domestic pigs. *Behavioral Ecology and Sociobiology*, 62(3), pp 309–319.

Edwards, S. A. & Baxter, E. M. (2015). Piglet mortality: causes and prevention. In: Farmer, C. (Ed) *The gestating and lactating sow*. Wageningen: Wageningen Academic Publishers, pp 253–278.
Engblom, L., Lundeheim, N., Dalin, A.-M. & Andersson, K. (2007). Sow removal in Swedish commercial herds. *Livestock Science*, 106(1), pp 76–86.
Friendship, R. M. & O'Sullivan, T. L. (2015). Sow health. In: Farmer, C. (Ed) *The gestating and lactating sow*. Wageningen: Wageningen Academic Publishers, pp 409–422.
Gerjets, I., Traulsen, I., Reiners, K. & Kemper, N. (2011). Assessing individual sow risk factors for coliform mastitis: A case–control study. *Preventive Veterinary Medicine*, 100(3–4), pp 248–251.
Glazier, D. S. (2009). Resource Allocation Patterns. In: Rauw, W. M. (Ed) *Resource Allocation Theory Applied to Farm Animal Production*. USA: CABI, pp 22–36.
Hermansson, I., Einarsson, S., Larsson, K. & Bäckström, L. (1978). On the agalactia post partum in the sow. A clinical study. *Nordisk veterinaermedicin*, 30(11), pp 465–473.
Hoge, M. D. & Bates, R. O. (2011). Developmental factors that influence sow longevity. *Journal of Animal Science*, 89(4), pp 1238–1245.
Hoving, L. L., Soede, N. M., Graat, E. A. M., Feitsma, H. & Kemp, B. (2011). Reproductive performance of second parity sows: Relations with subsequent reproduction. *Livestock Science*, 140(1–3), pp 124–130.
Jaaskelainen, T., Kauppinen, T., Vesala, K. M. & Valros, A. (2014). Relationships between pig welfare, productivity and farmer disposition. *Animal Welfare*, 23(4), pp 435–443.
Knap, P. W. & Rauw, W. M. (2009). Selection for High Production in Pigs. In: Rauw, W. M. (Ed) *Resource Allocation Theory Applied to Farm Animal Production*. USA: CABI, pp 210–229.
Lucia, T., Dial, G. D. & Marsh, W. E. (2000). Lifetime reproductive and financial performance of female swine. *Journal of the American Veterinary Medical Association*, 216(11), pp 1802–1809.
Lund, M. S., Puonti, M., Rydhmer, L. & Jensen, J. (2002). Relationship between litter size and perinatal and pre-weaning survival in pigs. *Animal Science*, 74, pp 217–222.
Milligan, B. N., Fraser, D. & Kramer, D. L. (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(1–2), pp 181–191.
Oliviero, C., Heinonen, M., Valros, A. & Peltoniemi, O. (2010). Environmental and sow-related factors affecting the duration of farrowing. *Animal Reproduction Science*, 119(1–2), pp 85–91.
Rutherford, K. M. D., Baxter, E. M., D'Eath, R. B., Turner, S. P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V. A., Thorup, F., Edwards, S. A., Berg, P. & Lawrence, A. B. (2013). The welfare implications of large litter size in the domestic pig I: biological factors. *Animal Welfare*, 22(2), pp 199–

218.
Spoolder, H., Bracke, M., Mueller-Graf, C., Edwards, S. & Authority, E. F. S. (2011). *Prepatory work for the future development of animal based measures for assessing the welfare of sow, boar and piglet including aspects related to pig castration*. Parma: European Food Safety Authority.
Stalder, K. J., Lacy, R. C., Cross, T. L. & Conatser, G. E. (2003). Financial impact of average parity of culled females in a breed-to-wean swine operation using replacement gilt net present value analysis. *Journal of Swine Health and Production*, 11(2), pp 69–74.
Sterning, M., Hulten, F., Holst, H., Einarsson, S. & Andersson, K. (1997). Relationships between health and weight loss during lactation and between health and ability to return to oestrus after weaning in primiparous sows. *Journal of Veterinary Medicine Series A-Physiology Pathology Clinical Medicine*, 44(5), pp 301–311.
Tummaruk, P., Lundeheim, N., Einarsson, S. & Dalin, A. M. (2000). Reproductive performance of purebred swedish landrace and swedish yorkshire sows: I. Seasonal variation and parity influence. *Acta Agriculturae Scandinavica A: Animal Sciences*, 50(3), pp 205–216.
Tummaruk, P. & Sang-Gassanee, K. (2013). Effect of farrowing duration, parity number and the type of anti-inflammatory drug on postparturient disorders in sows: a clinical study. *Tropical Animal Health and Production*, 45(4), pp 1071–1077.
Weber, R., Keil, N. M., Fehr, M. & Horat, R. (2007). Piglet mortality on farms using farrowing systems with or without crates. *Animal Welfare*, 16(2), pp 277–279.
Webster, J. (2011). Husbandry and Animal Welfare. In: Webster, J. (Ed) *Management and Welfare of Farm Animals: The UFAW Farm Handbook*. 5th. ed. Chichester: Wiley-Blackwell, pp 1–30.

Popular science summary

Sow health and welfare plays a fundamental part in successful piglet production. The main breeding goal in piglet production has, so far, been to increase the number of piglets born in each litter to improve the production efficiency. This strive has been successful as there has been a steady increase in litter size during the last decades. However, this development has also caused negative side-effects. Problems include an increase in the proportion of stillborn piglets, a decrease in the proportion of weaned piglets and a larger variation in quality of piglets. Effects of large litters on sows are more uncertain but may include impaired health and welfare of the sow.

Swedish commercial piglet producing herds have (like other countries with high production levels) high piglet mortality and high annual removal rate of gilts and sows. These problems seem to have increased during the same period that litter sizes have increased. The first study in my thesis therefore aimed to investigate whether there is an association between litter sizes and sow stayability.

Nursing a large litter size while maintaining her own body condition is a challenge for the sow, and there is a risk of substantial weight loss of the sow during lactation. This may in turn be associated with an increased risk of clinical disease during lactation. However, there is a lack of studies investigating the effect of litter size on the health and need of medical treatment of sows. Therefore, the objective of the second study in my thesis was to investigate the association between litter size and medical treatment of sows during farrowing and lactation.

The first study was performed as a retrospective study using data from a sow database established at the Swedish University of Agricultural Sciences, SLU. The database included production data from sows in Swedish commercial piglet producing herds. The second study, investigated the

potential association between medical treatment of sows and litter size by retrospective analysis of available pig production data from a research farm owned by the SLU.

Associations between litter sizes in low parities and sow stayability were found in the first study. There were differences in removal reason between sows having small, medium or large first parities litter sizes. Results indicating that aiming for keeping sows giving birth to a medium-sized litter, with approximately 12 to 14 piglets born in total, may improve sows stayability and decreasing the risk of unplanned removal.

Results from the second study showed an association between litter size and medical treatment of sows during farrowing and lactation. The odds for a sow needing medical treatment during farrowing and/or lactation decreased for every additional piglet born in total up to five piglets. From five piglets born in total, the odds of receiving medical treatment during farrowing and/or lactation increased for each additional piglet being born. Oxytocin was the most commonly given medical drug and the proportion of sows treated increased with an increasing parity.

All together results imply that litter size has an impact on sow health and welfare. Larger litters are not necessarily better than medium sized litters. The results from these two studies suggest that Swedish pig producers would benefit from aiming keeping sows giving birth to a medium-sized litter, with approximately 12 to 14 piglets born in total, as this seems to improve their stayability, decreasing the risk of unplanned removal and also is better from a health perspective. This should be considered in the planning of breeding strategies and annual removal of sows.

The association between litter size and sow health and welfare needs to be further investigated. Particularly the need of medical treatment, with oxytocin early in lactation and at higher parities, needs to be further investigated. Furthermore, associations between litter size and sow's health and lifetime production should be investigated from an economical perspective.

Populärvetenskaplig sammanfattning

Suggans hälsa och välfärd spelar en grundläggande roll i framgångsrik smågrisproduktion. För att öka lönsamheten så har ett av de huvudsakliga avelsmålen under senare tid varit att öka antalet smågrisar födda i varje kull. Strävan har varit framgångsrik och det har skett en stadig ökning av kullstorleken under de senaste årtiondena. Utvecklingen har emellertid medfört negativa bieffekter, bland annat i form av ökad andel dödfödda grisar, en minskad andel avvanda smågrisar och större variation i kvaliteten på smågrisarna. Effekten av stora kullar på suggor är osäker, men kan innebära en nedsatt hälsa och välfärd hos suggan.

Svenska smågrisproducerande besättningar har, liksom andra länder med höga produktionsnivåer, hög smågrisdödlighet och hög årlig utslagning av gyltor och suggor. Dessa problem verkar ha ökat under samma tidsperiod som kullstorlekarna har ökat. Den första studien i min avhandling syftar därför till att undersöka om det finns en koppling mellan kullstorlekar och suggans hållbarhet.

Att ta hand om en stor kull smågrisar samtidigt som suggan själv ska behålla en egen god kroppskondition är en utmaning. Det finns risk för en betydande viktminskning av suggan under digivningen, som i sin tur ökar risken för sjukdom under digivningen. Det är emellertid brist på studier som undersöker effekten av kullstorlek på hälsan och behovet av medicinsk behandling av suggor. Därför var syftet med den andra studien i min avhandling att undersöka sambandet mellan kullstorlek och medicinsk behandling av suggor vid grisning och amning.

Den första studien utfördes som en retrospektiv epidemiologisk studie med data från en suggdatabas etablerad vid Sveriges lantbruksuniversitet (SLU). I databasen ingår produktionsdata från suggor i svenska kommersiella smågrisproducerande besättningar.

I den andra studien undersöktes det potentiella sambandet mellan medicinsk behandling av suggor och kullstorlek genom retrospektiv

epidemiologisk analys av tillgänglig produktionsdata från SLUs tidigare försöksgård.

Samband mellan kullstorlekar i låga kullnummer och suggans hållbarhet hittades i den första studien. Det fanns skillnader i utslagningsorsak mellan suggor som i sina första kullar hade små, medelstora eller stora kullstorlekar. Om smågrisproducenterna i sin avelsplanering och planering av utslagning av suggor behåller de suggor som i sina första kullar ger en medelstor kull, med cirka 12 till 14 smågrisar födda totalt, så bör suggornas hållbarhet i besättningen på sikt öka och risken för oplanerad utslagning av suggor i besättningen minska.

Resultat från den andra studien visade en koppling mellan kullstorlek och medicinsk behandling av suggor vid grisning och laktation. Oddsen för att en sugga behövde medicinsk behandling under grisning och/eller laktation minskade för varje ytterligare smågris född totalt upp till fem grisar. Från fem grisar födda totalt ökade oddsen för medicinsk behandling av suggan under grisning och/eller laktation. Oxytocin var det vanligaste läkemedlet som gavs till suggan under dräktighet och/eller laktation. Andelen behandlade suggor ökade med ökande kullnummer.

Sammanfattningsvis så tyder resultaten från de två studierna att kullstorlek påverkar suggans hälsa och välfärd. Större kullar är inte nödvändigtvis bättre än medelstora kullar. Svenska smågrisproducenter skulle dra nytta av att suggor föder medelstora kullar, med ungefär 12 till 14 grisar födda totalt, eftersom detta tycks förbättra suggans hållbarhet, minskar risken för oplanerad utslagning samt är bättre ur ett hälsoperspektiv. Detta bör beaktas vid avelsplaneringen och planeringen av utslagning av suggor i besättningen.

Sambandet mellan kullstorlek och suggans hälsa och välfärd behöver undersökas ytterligare. Detta gäller särskilt behovet av medicinsk behandling av suggan med oxytocin tidigt under laktation samt av vid högre kullnummer. Vidare bör samband mellan kullstorlek och suggans hälsa och livstidsproduktion undersökas närmre ur ett ekonomiskt perspektiv.

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