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Warm versus cold - piglets' usage of the creep area and mortality due to crushing

Master thesis

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Affidavit

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

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Date & Signature

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3 Abstract

In organic pig production, free farrowing systems are legally required in the EU. Well-functioning free farrowing systems are of great importance and it is necessary to evaluate how to reduce piglet losses in such systems. Piglet mortality is especially high during the first days after birth. It is generally assumed that the risk to be crushed by the sow is reduced by an increased usage of the creep area. An important factor is the thermal environment. The aim of the present study was to investigate the effect of temperature difference between creep area and sow area on creep area usage and the influence of creep area usage on the crushing losses of suckling piglets. Data of 41 litters from three farms were included in the analysis. The piglets' behaviour was assessed continuously for 72 hours post natum from video recordings. Furthermore, all crushing losses were registered. The creep area and sow area temperature were recorded using temperature loggers. The higher the temperature difference and the temperature quotient (temperature difference divided by temperature in the sow area), the more litters were likely to reach the "75 % criterion" (= 75 % of the piglets were observed in the creep area at the same time). For litters, which reached this criterion, temperature difference and temperature quotient did not affect the latency of reaching this criterion. The piglets' creep area usage increased from day 1 to day 3, and with increasing age of the piglets, an increasing temperature difference / quotient resulted in an increased creep area usage. Creep area usage had no effect on the proportion of crushed piglets. A heated creep area should be available for the piglets especially at cold temperatures in the sow area. Since a higher creep area usage did not result in less crushing losses, other factors such as litter size or birth weight may have a greater impact on this category of losses.

4 Zusammenfassung

In der ökologischen Schweinehaltung sind freie Abferkelsysteme gesetzlich vorgeschrieben. Gut funktionierende freie Abferkelsysteme mit möglichst geringen Ferkelverlusten spielen eine wichtige Rolle; die Ferkelsterblichkeit ist in den ersten Lebenstagen besonders hoch. Es wird angenommen, dass eine erhöhte Ferkelnestnutzung in den ersten Lebenstagen das Risiko minimiert, von der Sau erdrückt zu werden. Ein wichtiger Faktor für die Ferkelnestnutzung ist die thermische Umgebung. Ziel der vorliegenden Arbeit war es, den Einfluss der Temperaturdifferenz zwischen Ferkelnest und Sauenbereich auf die Ferkelnestnutzung und den Einfluss der Ferkelnestnutzung auf die Erdrückungsverluste zu untersuchen. Die Studie berücksichtigte 41 Würfe von drei Betrieben. Die Ferkelnestnutzung wurde 72 Stunden post natum kontinuierlich anhand von Videomaterial erfasst und alle Erdrückungsverluste notiert. Die Ferkelnest- und Sauenbereichstemperatur wurden mit Temperaturloggern aufgezeichnet. Eine steigende Temperaturdifferenz bzw. ein steigender Temperaturquotient (Temperaturdifferenz dividiert durch die Temperatur im Sauenbereich) erhöhten die Wahrscheinlichkeit, mind. 75 % der Ferkel eines Wurfes gleichzeitig im Nest zu beobachten. Bei Würfen, die dieses 75%-Kriterium erreichten, hatten jedoch sowohl Temperaturdifferenz als auch -quotient keinen Einfluss auf die entsprechende Latenzzeit. Die

Ferkelnestnutzung nahm von Tag 1 bis Tag 3 stetig zu, und mit zunehmendem Alter der Ferkel führte ein(e) zunehmende(r) Temperaturdifferenz/-quotient zu einer erhöhten Ferkelnestnutzung. Die Ferkelnestnutzung hatte aber keinen Einfluss auf den Anteil erdrückter Ferkel. Insbesondere bei kalten Temperaturen im Sauenbereich sollte für die Ferkel ein warmes Ferkelnest zur Verfügung stehen. Da eine verstärkte Nutzung nicht mit geringeren Erdrückungsverlusten einherging, scheinen andere Faktoren wie Wurfgröße oder Geburtsgewicht einen größeren Einfluss auf diese Verluste zu haben.

5 Introduction and research questions

In organic pig production, free farrowing systems are legally required, and by the year 2033, in Austria sows in conventional pig production systems must not be crated for longer than the critical life phase of the suckling piglets. Well-functioning free farrowing systems therefore (will) play a major role in organic as well in conventional husbandry systems.

Free farrowing systems play an essential role for a better well-being of the sow, compared to sows kept in crates at farrowing and early lactation. To meet the physiological as well as the behavioural needs of sows around farrowing and lactation, it is indispensable to keep the sows in free farrowing systems. Sows kept in farrowing crates are prevented from turning and moving around at farrowing, though it is known, that sows prefer spaces which allow turning around (Phillips et al., 1992). A few days before farrowing sows are more active and start building a nest from several materials. Free ranging sows normally walk many kilometres the day prior to farrowing (Jensen, 1986). Free farrowing systems enable more piglet and sow interactive behaviour, such as sniffing and touching (Cronin et al., 1996).

In addition, piglet survival plays a major role when assessing farrowing systems. In free farrowing systems, newborn piglets face many challenges and risks due to the loose sow and housing in often uninsulated barns. For the survival of the piglets, a constantly high body temperature and regular milk intake right after birth are of utmost importance (Herpin et al., 2002). Piglet mortality is especially high during the first days after birth, with starvation and crushing being responsible for 50 - 80 % of the losses (Marchant et al., 2001). It is generally assumed that the risk to be crushed by the sow is reduced by an increased usage of the creep area in the first few days after birth, thus reducing pain and suffering going along with crushing events (Vasdal et al., 2009). Consequently, it is desirable to design the creep area as attractive as possible for the piglets. An important factor, which influences the usage of the creep area, is the thermal environment. The reported effects of the temperature in the creep area on its usage are controversial. Some authors report that piglets prefer to stay close to the sow instead of spending the first few days after birth in the creep area, even if unfavourable thermal conditions prevail in the sow area (Hrupka et al., 1998; Vasdal et al., 2009; Vasdal et al., 2010; Andersen et al., 2007; Moustsen & Pedersen, 2007). Others, however, report that the time the piglets spend in the creep area is significantly influenced by the temperature in the sow area or the temperature difference between creep area and sow area (Burri et al., 2009; Schormann, 2007). Previous studies have mostly been carried out under controlled conditions with regard to the ambient temperature in the sow area and have focused on the absolute creep area temperature (e.g. comparison of two different temperature settings), or on the absolute temperature in the sow area. The effect of temperature difference and temperature quotient on creep area usage and mortality rate has not been intensively studied so far.

Aim of the study:

The overall aim of this project was to identify favourable thermal conditions for the piglets in order to increase the regular usage of the creep area. More specifically, we aimed to evaluate the effect of the temperature difference between sow area and creep area and temperature quotient (temperature difference divided by temperature in the sow area) on creep area usage and the crushing losses of organic suckling piglets.

Research questions:

With our study, we aimed to answer the following research questions:

- How does temperature difference / temperature quotient affect the latency (time since end of farrowing) to observe 75 % of the piglets of the litter in the creep area for the first time?
- How does temperature difference / temperature quotient affect the piglets' usage of the creep area (usage during the first three days of life)?
- How does the piglets' usage of the creep area affect crushing losses (proportion of crushed piglets per day)?

Hypotheses:

We hypothesised that the thermal environment in the creep area, specifically the temperature difference between creep area and sow area and the temperature quotient, influences piglets' usage of the creep area. We predicted that an increase in temperature difference leads to an increased creep area usage and that an increased creep area usage results in reduced piglet crushing.

6 Overview of the literature

6.1 Thermoregulation and lying behaviour of suckling piglets during their first days of life

Under natural conditions the sow builds a nest for the piglets, which ensures a thermal microclimate for the piglets providing them with an appropriate environment to protect them from hypothermia (Stangel & Jensen, 1991). At birth the ability to conserve heat is very limited: piglets are almost hairless, devoid of subcutaneous fat and wet. Newborn piglets are poorly insulated and their homeothermic balance depends essentially on their ability to produce heat. Moreover, unlike most newborn mammals, piglets do not possess brown adipose tissue (Herpin et al., 2002). One effective strategy to reduce heat loss is by social thermoregulation. Young suckling piglets spend up to 70 % of the day lying in their group of littermates (Ziron & Hoy, 2003). Huddling of newborn piglets can reduce their lower critical temperature, which ranges between 30 °C to 34 °C (Close, 1992), and may thus reduce the risk of hypothermia. Moreover, staying close together may reduce the risk of getting lost or being detected by predators in natural conditions (Vasdal et al., 2009). The lying behaviour of piglets is an excellent indicator of their preference for the surface type and the temperature of this surface (Schormann & Hoy, 2006). Ideally, piglets are lying in a lateral position. The lower the ambient temperature, the closer the piglets lie together or even on top of each other. Suckling piglets are thus able to change their individual resting positions by changing the degree of huddling to adapt to their thermal environment (Vasdal, 2010). However, it needs to be considered that in the first week of their life, piglets are highly motivated to huddle together even if there is no obvious thermoregulatory need for this behaviour. Figure 1 shows the different lying positions of piglets depending on the thermal environment.

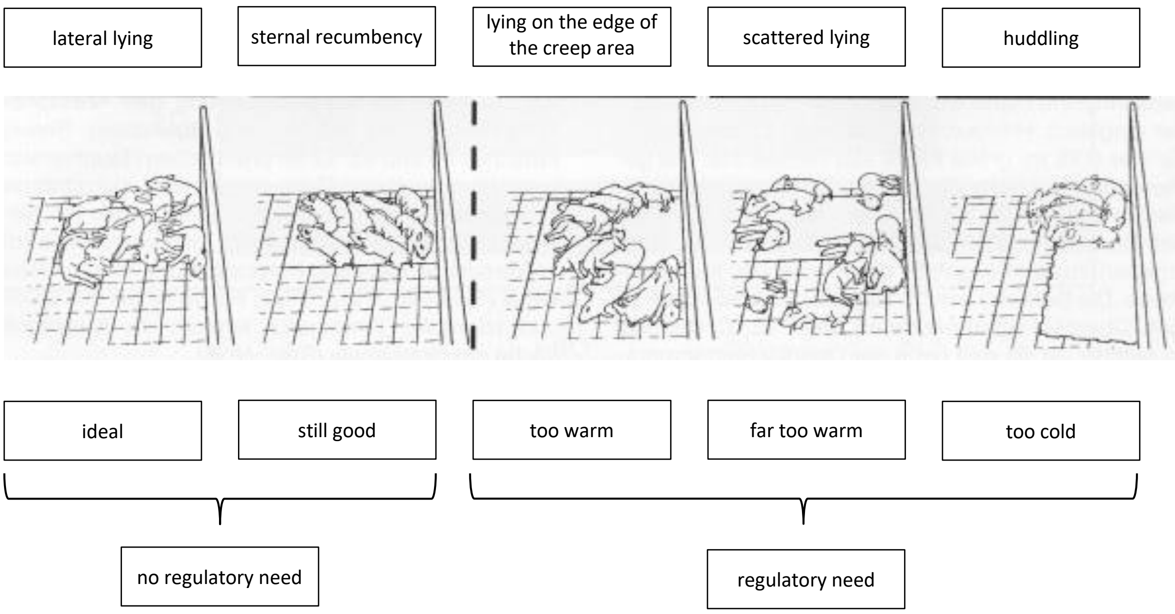

Figure 1. Lying positions of young piglets depending on the thermal environment (adapted from Jais and Kühberger, 2005).

6.2 Factors influencing pre-weaning piglet mortality and crushing losses

The evolutionary strategy adopted by pigs is to have a large litter and little time and energy is invested into each individual piglet – the survival of the strongest is promoted. A level of piglet mortality of 10 – 20 % can be considered as normal for the reproductive biology of the pig and has been selected as an optimal evolutionary strategy (Edwards, 2002). Pre-weaning piglet mortality rates vary greatly (Sultana et al., 2017) with stillbirths accounting for 30 – 40 % of the total mortality (Edwards, 2002). Piglet mortality is especially high during the first two days after birth (Herpin et al., 2002, Andersen et al., 2005, Dyck & Swierstra, 1986), with starvation and crushing being responsible for 50 – 80 % of the losses during this time (Marchant et al., 2001). High mortality rates of suckling piglets are not only an economic problem, but also represent an animal welfare and ethical aspect.

Piglet mortality is the outcome of complex interactions between the sow (e.g. maternal behaviour, colostrum, parity number, nutrition, maternal stress, litter size), the piglets (e.g. birth weight, vitality, sex) and the environment (e.g. housing system, management practices, season, temperature) (Andersen et al., 2009).

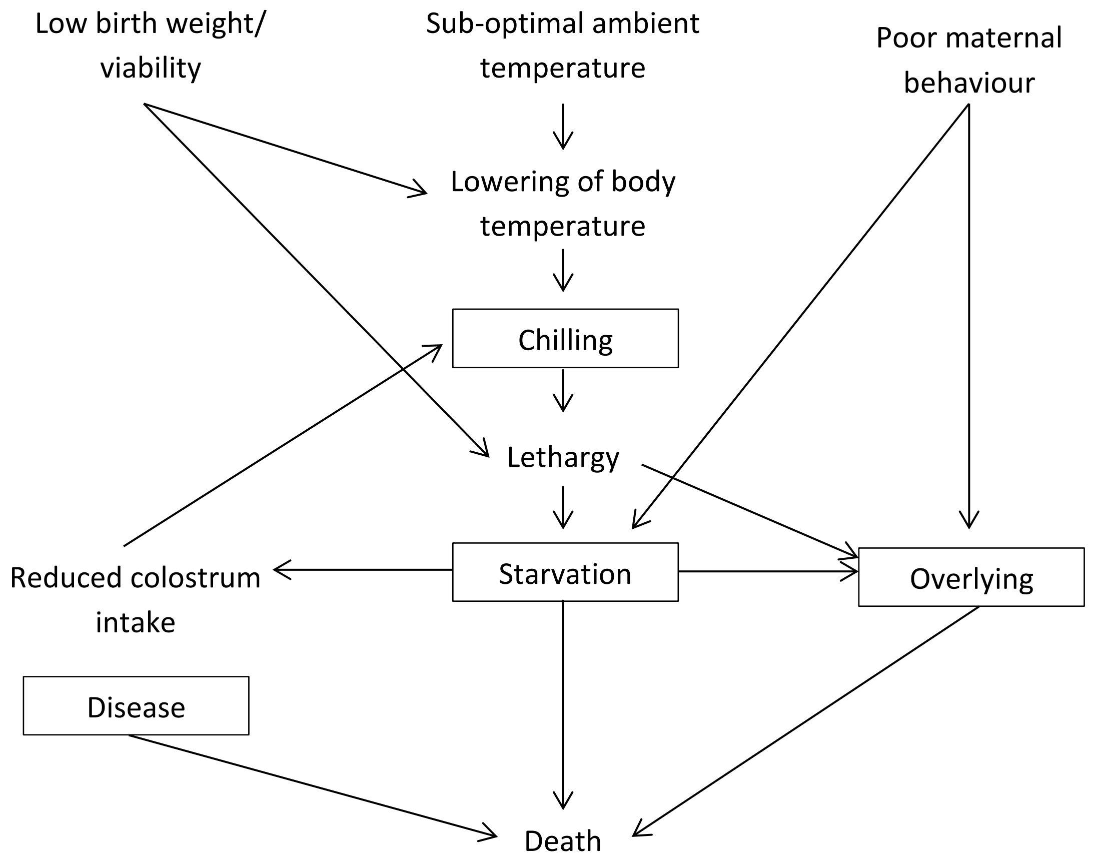

Figure 2. Interactive events occurring in the chilling-starvation-overlying-disease complex (Edwards, 2002).

Figure 2 describes the relationship of different influencing factors on piglet mortality. Pre-weaning mortality increases with litter size and piglets of low birth weight are at particular risk (Herpin et al., 2002). The birth weight of the piglets is the most important influencing factor, which directly influences their thermoregulatory capacity and growth (Muns et al., 2016). Small piglets are mainly at risk, because heat loss per unit of body weight is inversely related to body size (Herpin et al., 2002). The need for warmth decreases with increasing body weight and age (Ziron & Hoy, 2003).

Birth is an abrupt process where the piglet must overcome respiratory, immunological, digestive, nutritional and thermoregulatory challenges. Newborn piglets suddenly experience a decrease of 15 °C to 20 °C in ambient temperature. The lower critical temperature of a newborn piglet is 34 °C (e.g. English & Morrison, 1984), lower ambient temperatures will result in cold stress (Andersen et al., 2009). Cold stress at birth leads to a less aggressive nursing behaviour caused by diminished strength of the piglet. This again reduces the amount of colostral nutrients available for thermogenesis making the piglet more prone to be crushed by the sow. Furthermore, piglets that suffer from hunger and have a lower weight gain spend more time near the sow nuzzling the udder outside nursing times – this itself increases the risk of being crushed by the sow (Weary et al., 1996). Piglets with a poor ability to maintain their body temperature in the first two hours after birth are those that are most likely to starve or being crushed (Pedersen et al., 2006). For the survival of the piglets the maintenance of a homeothermic balance (= maintenance of a high and constant body temperature) and the establishment of regular nutrition right after birth is of utmost importance. One key factor here is the inherent vitality immediately after birth. This includes the ability to quickly stand and become active, to locate the udder, to compete with littermates for teat access and withdraw plentiful colostrum (Edwards, 2002). According to a study of Andersen et al. (2009), quickly drying and placing the newborn piglets under a heat lamp may increase the vitality of the piglet in a way that potentially reduces the risk of being crushed by the sow. However, piglets should not be confined in the creep area, as this would reduce the time for suckling (Andersen et al., 2009).

Records of piglet mortality indicate that most deaths of liveborn piglets are attributed to crushing and starvation, but these ultimate causes are often secondary to the effects of perinatal hypothermia. Many piglets are finally killed by crushing, but they are often predisposed by failure to achieve regular and adequate intake of milk. It should thus be differentiated between crushing of diseased and crushing of healthy piglets, even though it is difficult to differentiate the real cause of death (Edwards, 2002). In order to reduce piglet losses an improvement of the maternal characteristics of sows (Valros et al., 2003) and improved management of farrowing should be aimed at (Andersen et al., 2009, 2007; White et al., 1996).

6.3 Creep area - an important part of a farrowing pen

To meet both the thermal requirements of the sow and of the piglets, a two-climate strategy has been developed. Room temperature in the farrowing unit is usually kept around 20 °C, which corresponds to the thermal comfort zone of the sow (Svendsen & Svendsen, 1997). For the piglets, a microclimate of 30 °C to 34 °C should be created in the creep area to avoid hypothermia (Vasdal et al., 2010). Creep areas are thus an important part of a farrowing pen. There are many different design options and heat sources in the creep areas, but they should all be built and managed in a way that the piglets find the creep area as early as possible in order to be warm and to be protected against injuries from the mother respectively crushing losses. It is generally assumed that the risk to be crushed by the sow is reduced by an increased usage of the creep area in the first few days after birth, thus reducing pain and suffering going along with crushing events (Vasdal et al., 2009; Vasdal, Andersen & Pedersen, 2009).

Under natural conditions, piglets are in close contact with the mother sow and their littermates during the first two days of life. The piglets leave the nest, which the sow has built before farrowing, only to defecate (Stanged & Jensen, 1991). Lying close to the sow after birth is a highly adaptive behaviour as staying close to the udder increases the piglets' chances of survival and it can therefore be considered as a battle against biology to aim attracting piglets away from the sow (Vasdal et al., 2010).

6.4 Factors influencing creep area usage

There are many ways to create the creep area attractive to the piglets (Lay et al., 1999, Morrison et al., 1983, cited from Vasdal et al., 2009). The most important aspect is a warm, soft and dry lying area (Ziron & Hoy, 2003) without draught and with easy access (Zhang & Xin, 2001).

6.4.1 Light

The reported effects of light in the creep area are controversial. Some authors found that piglets prefer dim and dark areas over bright areas (Rohde Parfet & Gonyou, 1991). Preference of dark areas may be instinctive behaviour to avoid being noticed by predators (Larsen & Pedersen, 2015). Larsen and Pedersen (2015) discovered that light in the creep area does not attract piglets to use the creep area. Piglets prefer to sleep in the dark and therefore choose to stay next to the sow, if in the creep area light-emitting infrared heat lamps are present (Larsen & Pedersen, 2015).

However, other authors reported that piglets fear staying in darkness (Tanida et al., 1996). So the results of Ollmann (2019) showed that the duration piglets stayed in the creep area was not affected by light in the creep area, but light led to a sooner exploration of the creep area. In contrast, Morello et al. (2019) described a higher usage of bright creep areas compared to dark creep areas.

6.4.2 Temperature

Young piglets need ambient temperatures of at least 30 °C to 32 °C in the first 10 days of life (Schormann & Hoy, 2006). Numerous studies have shown that piglets prefer to stay near the sow and their littermates instead of being in the warm creep area for the first few days after birth, even if unfavourable thermal conditions prevail in the sow area (Hrupka, et al., 1998; Vasdal et al., 2009; Andersen et al., 2007; Moustsen & Pedersen, 2007). In the study by Vasdal et al. (2010), an improvement in thermal comfort and a softer surface in the creep area neither led to increased creep area usage, nor was there a relationship between creep area usage and mortality. It therefore seems difficult to lure the piglets away from the mother sow in the first days of life, potentially because sows provide heat, but also olfactory, tactile and auditory stimuli. Moreover, there is a generally high motivation for piglets to lie next to other members of the same species, not only the sow. For example, one study showed that piglets prefer to lie next to an anesthetised piglet in a cold area than to lie alone in a warm area (Hrupka et al., 2000). Physical contact seems thus to be more important than the ambient temperature and the presence of littermates in the creep area could be more important to attract piglets in the creep area than radiant heat intensity (Hrupka et al., 2000).

However, according to Burri et al. (2009), the time that piglets spend in the creep area is significantly influenced by the room temperature - the higher the room temperature, the longer it takes the piglets to use the creep area after birth and the less time they spend there. In addition, with higher temperatures in the sow area on the first day after farrowing, it takes longer until at least 75 % of the piglets stay for more than 15 minutes in the creep area the first time after birth. The results of the study by Schormann (2007) also show that the motivation of suckling piglets to go to a warm creep area is higher at a room temperature of 18 °C than at a room temperature of 26 °C. In line to other studies, results of the study of Morello et al. (2019) showed that an lower ambient temperature respectively an increasing temperature difference between creep area and sow area increases creep area usage.

Most of the previous studies have been carried out under temperature-controlled conditions with little variation in the ambient temperature in the sow area. The present study was carried out under organic farming conditions which differ from those in many other studies, as temperature in the sow area fluctuated over the course of the study since barns were not insulated. The aim of our study was to evaluate the effect of the temperature difference between sow area and creep area and the temperature quotient (i.e. temperature difference divided by temperature in the sow area) on creep area usage and the crushing losses of organic suckling piglets. Thus, the temperature difference between creep area and sow area did not only depend on creep area temperature and the temperature quotient was consequently taken into account. So far, the temperature quotient has not been considered in other studies.

7 Animals, material & methods

A total of 48 sows and their piglets were studied at two private organic pig farms and at the Institute of Organic Farming and Farm Animal Biodiversity in Wels from June 2017 to May 2018 (all Upper Austria). Due to missing data, e.g. lack of video material or temperature records or too small litter size (less than five piglets), seven litters were excluded from video evaluation. Therefore, data of in total 41 litters from the three farms were finally included in the analysis. This comprises data of 14 control litters from another study, which dealt with the effect of light in the creep area. However, the general conditions of the two studies were the same.

7.1 Experimental facilities

Table 1 provides an overview of the three farms, the animals included in this study and their performance data.

Table 1. Overview of the three farms, the animals and their performance data.

	Institute of Organic Farming and Farm Animal Biodiversity	Farm A	Farm B
Organic farm	Yes	Yes	In conversion
Number of breeding sows	51	16	17
Number of observed litters for the present study (finally included in the analysis)	29*	7*	5*
Number of observed liveborn piglets	437	98	71
Number of batches	12	4	3
Breeding sows	Large White, F1, F2	F1	F1
Breeding boar	Pietrain	Pietrain	Pietrain
Number of WelCon farrowing pens	5	10	13
Farrowing pattern	3 weeks rhythm	3 weeks rhythm	No rhythm
Average creep area temperature	24,2 °C	23,4 °C	23,4 °C
Average temperature in the sow area	17,9 °C	17,3 °C	17,3 °C
Average number of liveborn piglets per litter	M: 15.1 SD: 2.7	M: 14 SD: 4.8	M: 14.2 SD: 3.9
Average birth weight per liveborn piglet (kg)	M: 1.48 SD: 0.41	M: 1.40 SD: 0.41	M: 1.38 SD: 0.32
Average crushing losses per litter day 1-3 (n)	M: 2.9 SD: 2.5	M: 2.4 SD: 2.2	M: 2 SD: 1.6
Average parity number	M: 3.9 SD: 1.8	M: 4.3 SD: 3.5	M: 7 SD: 2.5

M = Mean, SD = Standard deviation

*Due to missing data, e.g. video material, temperature records or too small litter size (less than five piglets), seven litters were excluded from video evaluation.

7.2 Housing of the sows and their litters

All farms were equipped with WelCon open farrowing pens (built by the company Schauer). WelCon stands for **wel**fare for sow and piglets and **con**venience for farmers. A WelCon farrowing pen is divided into a creep area (~ 1 m^2), a lying area (~ 4.6 m^2), a feeding area (~ 1.5 m^2) and an outdoor run (~ 6.25 m^2) (Figure 3). The pen is designed as a one-way traffic system. In order to reach the feeding area the sow leaves the lying area into the outdoor run, where the drinker and a rack for hay or silage is placed, from there she enters the feeding area. Ideally, the sow urinates and defecates in the outdoor run, thus keeping the lying area inside clean. From the feeding area the sow gets through a second door into the lying area again. For medical interventions of the piglets, for example vaccinations, castration or iron supplementation, the sow can be confined in the feeding area. For this purpose the door leading to the lying area can be locked with a lever. Adjacent to the lying area of the sow is the creep area and the feeding area for the piglets. For medical treatments the piglets can be locked inside the creep area.

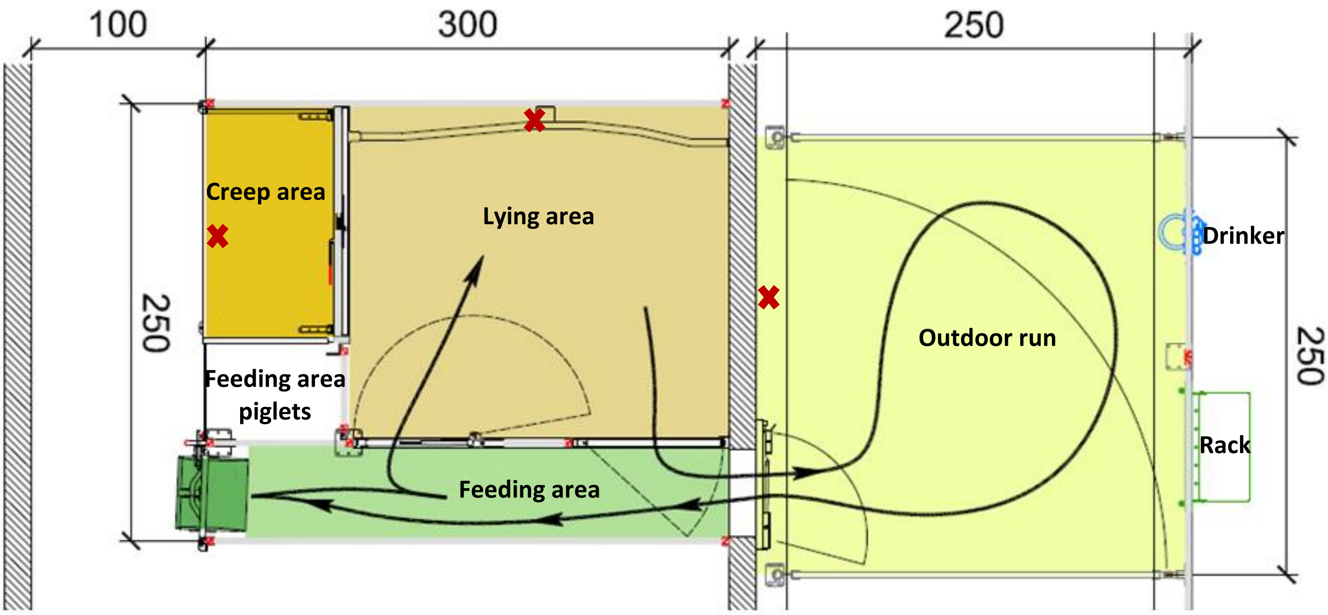

Figure 3. Floor plan of a WelCon farrowing pen and positions of the temperature loggers (adapted from Schauer Agrotronic GmbH, 2017)**.**

7.2.1 Creep area

The creep area is a closed box, which the piglets can access directly from the lying area (Figure 4). The total space allowance of the creep area is 1 m^2 with 75 cm width and 135 cm length and a height of 60 cm. The height of the aperture facing the lying area was 25 cm. In Wels and on Farm B, infrared cover heating plates "ATX®-IR-Tierheizelement 260W 390x1230" were installed, while on Farm A, an equivalent product of "WMT Thermosysteme GmbH" was used. The infrared heating plates can be controlled manually in steps of 0.5 °C. In all farms, the wooden floor was littered with straw (approximately 5 cm thick). There was no light installed in the creep area.

Figure 4. Opened creep area and infrared cover heating plate.

7.3 Experimental design

On each farm the multiparous sows were randomly assigned to the farrowing pens. It was paid attention, to assign the gilts in a counterbalanced way to the two treatments. All sows were housed in the farrowing pens at least a few days before the expected farrowing date.

The treatment consisted of two different temperature settings in the creep areas: 20 °C and 36 °C to create pronounced temperature differences between the creep area and the sow area. For each batch, the creep area temperature was set alternately at 20 °C and 36 °C. The creep area temperature and the temperature in the sow area were recorded with temperature loggers. In the final analysis, the two settings were not distinguished, but the absolute temperature was used.

7.3.1 Video recordings of the farrowing pen including the entrance of the creep area

One camera per pen was installed in a way that ensured a good view of the creep area's entrance and of the lying area of the sow (Figure 5). Recordings started a few days before the scheduled farrowing date and lasted until 72 hours post natum.

Figure 5. Camera setting above the farrowing pen. The entrance to the creep area is on the left side.

In Wels a Geovision NVR-SYS-i5 system, at Farm A and at Farm B NUUO systems were used. In Wels the videos were recorded in black and white, on the other two farms the videos were recorded in colour, only at night in black and white.

7.3.2 Video evaluation, behavioural observation and ethogram

The piglets' behaviour was evaluated continuously for 72 hours, starting at birth of the last piglet of the litter.

The video material was evaluated on the basis of an ethogram (Table 2) using Mangold Interact®. It was the aim to continuously record the time and number of piglets entering and leaving the creep area to get information on the latency for 75 % of the litter in the creep area and the average duration of the creep area usage per piglet. For this purpose several codes for different events were established in Interact. In addition to the events set in the ethogram, the event "dead piglet" was also recorded. The event "dead piglet" was set as the death of a piglet was clearly apparent - this determined the current number of live piglets of the litter. In addition, manual comments were continually added in order to be able to follow the progress of the evaluation.

Table 2. Ethogram - basis for video analysis in Interact® (created by Anna Ollmann).

Event	Start	End	Comment
Piglet enters/leaves creep area	More than half of the body is in the creep area	More than half of the body is outside of the creep area	When sow blocks view to entrance: piglets are logged in/out when last/first visible
Sow leaves/enters pen	More than half of the body outside the pen	More than half of the body inside the pen	Does not count as leaving when sow tries to go out but comes back because the door to the outdoor run is locked
Human influence	Door is opened or other human influence visible	Door is closed, no human influence visible	
Creep area closed	Entrance to the creep area is closed	Entrance is opened	Piglets cannot enter/leave the creep area when it is closed. This duration was therefore excluded from analysis
Farrowing ended	Birth of last piglet (dead or alive)	-	To determine the start of the 72h observation period

Before starting the video evaluation, inter- and intra-observer reliability was checked. As videos from another study were partly used, inter-observer reliability was first investigated. Videos, which had already been evaluated by the other author, were watched and the results compared. At least five onset times of the event “End of farrowing” and at least 150 onset times of the event “Piglet enters/leaves creep area” were compared between the two observers. The differences of the onset times were calculated by subtracting the onset time from Observation 1 from the onset time from Observation 2. Furthermore the correlation of the onset times of the observations was calculated. The results are presented also as diagrams (see chapter 8.1 Inter- and Intra-observer reliability).

The second step related to intra-observer reliability, to check if the results are consistent, when observing videos at different times. There were at least 24 hours between two observations of the same videos. After finishing the evaluation of the video material, a second intra-observer reliability testing was carried out. As for the inter-observer reliability, the differences between onset times (for the events “End of farrowing” and “Piglet enters/leaves creep area”) and correlations of the onset times of the observations were calculated and presented in diagrams.

Video recordings per litter were not analysed at once. Video data per litter was split up in four parts: video day 0 = from end of farrowing until midnight, video day 1 = midnight until midnight, video day 2 = midnight until midnight, video day 3 = midnight until the time, when farrowing ended on video day 0. For each “day” for all litters a random number was assigned in Excel. The order of video evaluation then followed this number.

The outcome of video analysis using Interact were Excel files, with information on the onset and offset time of the different events and the durations of the events “sow influence”, “human influence” and “creep area closed” (Figure 6). However, the data sheets, which were directly exported from interact did not provide the information on how many piglets have been in the creep area at a certain time respectively how high the proportion of piglets in the creep area is. Therefore a conversion of the files was necessary in the next step.

	B	C	D	E	F	G	H	I	J	K	L	M
1	Onset_Time	Offset_Time	Duration	Sau	Mensch	CreepAreaClosed	EndeGeburt	AlleImNest	AlleInBucht	Bucht_Ferkel	Nest_Ferkel	Tot_Ferkel
248	04:18:30	04:38:32	00:20:01	1								
249	04:18:52	04:18:52	00:00:00							1		
250	04:20:44	04:20:44	00:00:00							1		
251	04:20:44	04:20:44	00:00:00							1		
252	04:20:45	04:20:45	00:00:00							1		
253	04:20:52	04:20:52	00:00:00							1		
254	04:21:08	04:21:08	00:00:00								1	
255	04:21:37	04:21:37	00:00:00							1		
256	04:21:42	04:21:42	00:00:00							1		
257	04:22:05	04:22:05	00:00:00						1			
258	04:28:33	04:28:33	00:00:00								1	
259	04:29:32	04:29:32	00:00:00							1		
260	04:41:50	04:41:50	00:00:00								1	
261	04:42:29	04:42:29	00:00:00							1		
262	04:42:43	04:42:43	00:00:00								1	
263	04:42:54	04:42:54	00:00:00								1	
264	04:42:58	04:42:58	00:00:00								1	
265	04:42:58	04:42:58	00:00:00								1	
266	04:42:59	04:42:59	00:00:00								1	
267	04:42:59	04:42:59	00:00:00								1	
268	04:43:00	04:43:00	00:00:00								1	
269	04:43:32	04:43:32	00:00:00							1		
270	04:43:53	04:43:53	00:00:00								1	
271	04:44:03	04:44:03	00:00:00								1	
272	04:44:38	04:44:38	00:00:00							1		

Figure 6. Example of an exported data file of Interact. The offset/onset times and durations of the different events are listed.

Using a software (“piglet count”) created with Python, Excel sheets were generated on basis of the Interact® records. These spreadsheets contained for each time a piglet had been observed entering or leaving the creep area the total number of piglets in the creep area, as well as whether “human influence” or “sow influence” had occurred. Video data per litter was organized in three parts: day post natum 1 = 24 hours from time, when farrowing ended, day post natum 2 = end of day 1 plus 24 hours, day post natum 3 = end of day 2 plus 24 hours. These days are named “day 1”, “day 2“ and “day 3” in the presentation of the results. The number of piglets in the creep area and the proportion of piglets in the creep area were calculated. Each time a piglet entered or left the creep area a new line at the respective time with the new count is given. Figure 7 shows an example of such an excel file. In addition, to calculate the average number of piglets inside the creep area and the average creep area usage per piglet excel files with 10-min. scan intervals were created (Figure 8).

	A	B	C	D	E	F	G
1	Day	Time	Count	HumanInfluence	SowInfluence	Eff. Littersize	% im Nest
3479	3	16.04.2018 04:10	2	0	0	15	13%
3480	3	16.04.2018 04:10	1	0	0	15	7%
3481	3	16.04.2018 04:10	0	0	0	15	0%
3482	3	16.04.2018 04:11	1	0	0	15	7%
3483	3	16.04.2018 04:11	2	0	0	15	13%
3484	3	16.04.2018 04:11	3	0	0	15	20%
3485	3	16.04.2018 04:11	4	0	0	15	27%
3486	3	16.04.2018 04:11	5	0	0	15	33%
3487	3	16.04.2018 04:12	4	0	0	15	27%
3488	3	16.04.2018 04:12	3	0	0	15	20%
3489	3	16.04.2018 04:12	4	0	0	15	27%
3490	3	16.04.2018 04:12	5	0	0	15	33%
3491	3	16.04.2018 04:12	6	0	0	15	40%
3492	3	16.04.2018 04:12	7	0	0	15	47%

Figure 7. Example "piglet count": information regarding day, time, number of piglets in the creep area, human/sow influence, effective litter size and proportion of piglets in the creep area.

	A	B	C	D	E	F	G	H
1	Day	Date	Time	Count	HumanInfluence	SowInfluence	Eff. Littersize	% im Nest
322	3	16.04.2018	04:10:00	2	0	0	15	13%
323	3	16.04.2018	04:20:00	3	0	1	15	20%
324	3	16.04.2018	04:30:00	0	0	1	15	0%
325	3	16.04.2018	04:40:00	0	0	1	15	0%
326	3	16.04.2018	04:50:00	8	0	0	15	53%

Figure 8. Based on the "piglet count" files in Figure 7, new files were created simulating 10-min. scan intervals.

7.3.3 Temperature setting and temperature recording

According to the experimental design, it was initially planned to distinguish between the two temperature settings, but it was soon discovered that especially high temperatures (e.g. 36 °C) were often not achieved and that the temperatures achieved in the creep area often overlapped between treatments. Numerous preliminary tests followed to determine appropriate temperatures in the creep area. In order to get an idea how infrared rays act on the piglets, a dead piglet with a thermometer directly under the skin, was placed in a creep area (Figure 9). The temperature underneath the skin and the ambient air temperature in the creep area were evaluated at different set creep area temperatures. The temperature underneath the skin was a few degrees higher than the ambient air temperature. It was finally decided to set the thermostat of the creep area heating panels alternately at 20 °C and 36 °C. Although these temperatures were not achieved, such a marked difference was important to create a bigger range of temperature differences between creep area and lying area of the sow. However, the final evaluation did not distinguish between the two different temperature settings, but the absolute temperature data were taken into consideration.

Figure 9. Subcutaneous temperature measurements in a dead piglet and concurrent measurement of the ambient air temperature.

Moreover, the impact of the position of the loggers in the creep area on the measured temperature was investigated in advance. The loggers were installed in different areas of the creep areas at different set temperatures.

Using a thermal imaging camera (FLIR T420), surface temperature, heat emission and outward heat losses were investigated prior to data collection (Figure 10). There were no differences between the pens. In addition, a uniform heat emission of the heating plates was detected, which indicated comparable conditions in the study farms.

Figure 10. Thermal images of the creep area entrance, the outer surface of the creep area and the infrared heating plate.

In the creep area, in the sow area and in the outdoor run, temperature loggers (HOBO® Pendant® Temperature/Light Data Logger (UA-002-xx) Manual) (used on all farms) and Saveris H2D data loggers (used occasionally in Wels) were installed. In the creep area and in the lying area of the sow, the loggers were installed at piglet height, covered with a protective hood. One logger was installed in the outdoor run in approximately 1.5 m height. The position of the loggers is marked with red crosses in Figure 3. The temperature loggers recorded the temperature in 10-min. recording intervals. Temperature data was recorded for the first three days of the piglets' life. Temperature data was transferred from the loggers via an adapter and saved as excel file.

7.3.4 Evaluation of piglet (birth weight, number of liveborn and dead piglets, crushing losses) and sow related data (age, parity number, farrowing date)

After farrowing, each liveborn piglet was weighed within 24 hours post natum. For each litter the proportion of small (<1 kg), medium (1-1.8 kg) and big (>1.8 kg) piglets was calculated. Data of birth weight of the piglets was recorded not for all of the 41 litters, but only for 27 litters, because video material from another study in Wels was also analyzed. For this study, which evaluated the effect of light in the creep area, the piglets were not weighed on the first day of life, so the impact of birth weight on creep area usage and the proportion of crushed piglets could not be evaluated. For each litter, a data sheet was used (see Appendix), which comprised the sow number, birth date of the sow, the parity number, the farrowing date, the number of liveborn and dead piglets, birthweight of each piglet, temperature setting in the creep area, camera number, number of temperature logger and pen number. Medical interventions (date and kind of intervention) as well as the piglet losses for each day with the assumed cause of loss (at the two private farms) were also documented on this data sheet. In Wels each dead piglet was subjected to post mortem analysis.

Farm routine management practices were done on each farm as usual, with the exception that piglets were not locked in the creep area, to avoid forced habituation to the creep area. If necessary (e.g. for iron supplementation, ear tagging or weighing), piglets were locked into the piglet feeding area. Every medical intervention was documented by the farmers or the employees on the litter data sheet for the respective sow.

7.4 Data processing and statistical analyses

Data were analysed using Microsoft Excel 2010, SPSS Statistics Version 24 and SAS Version 9.4.

For each day, the effective litter size per litter was calculated. The effective litter size is the average litter size on one day considering daily losses. The proportion of crushing losses for each day was calculated based on the effective litter size of each day.

$$Crushing\ losses\ [\%] = \frac{Crushing\ losses\ [number\ of\ piglets]}{Effective\ litter\ size\ [number\ of\ piglets]}$$

To calculate the average number of piglets inside the creep area and the average creep area usage per piglet, a scan sampling of 10-minute intervals was implemented based on the outcome of the continuous observation.

$$Average\ number\ of\ piglets\ in\ the\ creep\ area\ [\%] = \frac{Average\ number\ of\ piglets\ in\ the\ creep\ area}{Effective\ litter\ size}$$

$$Average\ creep\ area\ usage\ [min/piglet] = \frac{Sum\ number\ of\ piglets\ in\ the\ creep\ area * 10\ minutes}{Average\ effective\ litter\ size}$$

For each litter the average temperature in the creep area, in the sow area, in the outdoor run, the average temperature difference and the average temperature quotient was calculated for the individual first three days of the piglets' lives as well as the sum of the average temperatures of day 1-3.

Table 3 shows an example to highlight the importance for not only taking the temperature difference into consideration. If temperature difference is equal, as in the example, but temperature in the sow area and creep area are not the same, the temperature quotient clarifies the distinction. If the temperature in the sow area is lower, the temperature quotient is higher.

$$Temperature\ quotient = \frac{Temperature\ difference\ [°C]}{Temperature\ in\ the\ sow\ area\ [°C]}$$

Table 3. Example calculation temperature quotient.

Temperature in the creep area	Temperature in the sow area	Temperature difference	Temperature quotient
30 °C	20 °C	10 °C	10 / 20 = **0,5**
20 °C	10 °C	10 °C	10 / 10 = **1**

Continuous data, e.g. temperature data, were recorded in numbers. Data of birth weight (small <1 kg, medium 1-1.8 kg, big > 1.8kg) and parity were categorised (1-2 litters, > 2 litters). For each litter the proportion of small, medium and big piglets was calculated. To evaluate the influence of the proportion of small piglets per litter on creep area usage and proportion of crushed piglets limited data of 27 litters with the information of the proportion of small piglets per litter were investigated.

A generalised mixed-effects model was used for the evaluation, if a latency of 75 % was reached or not, taking the effect of temperature difference and temperature quotient into consideration. For each litter, the latency from the end of farrowing until 75 % of the piglets of the litter stayed in the creep area was calculated. To evaluate the effect of the temperature difference respectively temperature quotient on the creep area usage and the effect of creep area usage on proportion of crushed piglets linear mixed-effects models were run.

In Table 4 the outcome variables, fixed and random effects of all models are given. Each model for the complete data set is given and additionally "sub-models" in which only the litters with information on birth weight of the piglets were tested. Fixed effects are those variables which are of importance to answer the research questions. Random effects reflect the dependencies of the data. The models were tested for normal distribution of the residuals. The level of significance was set at $P < 0.05$.

Table 4. Overview of the research questions with outcome variables, fixed and random effects.

Research question	Outcome variable	Fixed effects	Random effects
Relationship between the temperature difference in the sow area and creep area and the piglets' usage of the creep area	Creep area usage [min / piglet]	Temperature difference Day Day*Temperature difference Sub-model: Small piglets/litter (%) Day*Small piglets/ litter (%) Temperature difference*Small piglets/litter (%)	Sow nested in Batch nested in Farm
Relationship between the temperature quotient and the piglets' usage of the creep area	Creep area usage [min / piglet]	Temperature quotient Day Day*Temperature quotient Sub-model: Small piglets/litter (%) Day*Small piglets/ litter (%) Temperature quotient* Small piglets/litter (%)	Sow nested in Batch nested in Farm
Latency until 75 % of the litter are in the creep area	Latency 75 % reached [Yes / No]	Temperature difference Temperature quotient	Batch nested in Farm
Influence of temperature difference day 1-3 on latency 75%	Latency [h]	Temperature difference day 1-3	Batch nested in Farm
Influence of temperature quotient day 1-3 on latency 75%	Latency [h]	Temperature quotient day 1-3	Batch nested in Farm
Relationship between piglets' usage of the creep area and the proportion of crushed piglets	Proportion of crushed piglets [%]	Day Creep area usage Day*creep area usage Sub-model: Small piglets/litter (%) Day*Small piglets/ litter (%) Creep area usage* Small piglets/litter	Sow nested in Batch nested in Farm

8 Results

8.1 Inter- and Intra-observer reliability

Comparison of the observations from the two observers of the events “End of farrowing” and “Piglet enters creep area” revealed mean differences in the onset time of 0 to 2 seconds and thus high inter-observer reliability (Inter-OR). Similarly, the first intra-observer reliability (Intra-OR I) test (before starting video analysis) and the second intra-observer reliability (Intra-OR II) test (after finishing video analysis) revealed high intra-observer reliability (mean difference 0 to 1 second; Table 5).

Table 5. Maximum, minimum and mean difference onset time for the events "End of farrowing" and "Piglet enters/leaves creep area" for the Inter-OR as well as the Intra-OR I and Intra-OR II tests.

	Inter-observer reliability (Inter-OR)	Intra-observer reliability 1 (Intra-OR I)	Intra-observer reliability 2 (Intra-OR II)
End of farrowing	*5 events*	*5 events*	*5 events*
Max. difference onset	00:00:07	00:00:05	-00:00:07
Min. difference onset	00:00:00	-00:00:01	00:00:02
Mean difference onset	00:00:02	00:00:01	-00:00:01
Piglet enters creep area	*154 events*	*153 events*	*151 events*
Max. difference onset	00:00:03	00:00:02	00:00:07
Min. difference onset	-00:00:11	-00:00:06	-00:00:16
Mean difference onset	00:00:00	00:00:00	00:00:00

The difference of the onset times was calculated by subtracting the onset time from Observation 2 from the onset time from Observation 1. A negative difference of the onset time means that Observation 2 started earlier than Observation 1.

To check inter- and intra-observer reliability for the duration piglets spent within the creep area, the onset times (piglet entered creep area) and offset times (piglet left creep area) were recorded and the duration of the stay in the creep area was calculated. The relationship between the observations from observer A and B (Inter-OR) and between observations 1 and 2 (Intra-OR I and II) was analysed using Spearman rank correlations. The correlation coefficients always exceeded 0.81 and thus revealed good to very good agreements between and within observer(s) (Table 6 and Figure 11).

The minimum creep area usage for all reliability tests was zero seconds, meaning that the piglet entered and left the creep area during the same second. The maximum creep area usage for Inter-OR and Intra-OR I was 55:23 minutes and for Intra-OR II it was 46:06 minutes.

Table 6. Correlation coefficients and p-values for the durations of the creep area usage for Inter-OR I, Intra-OR I and Intra-OR II.

Piglets' usage of the creep area (duration)	**Inter-OR** n = 154	**Intra-OR I** n = 153	**Intra-OR II** n = 151
Correlation coefficient	r_s = 0.819	r_s = 0.879	r_s = 0.967
p-value	p = <0.001	p = <0.001	p = <0.001

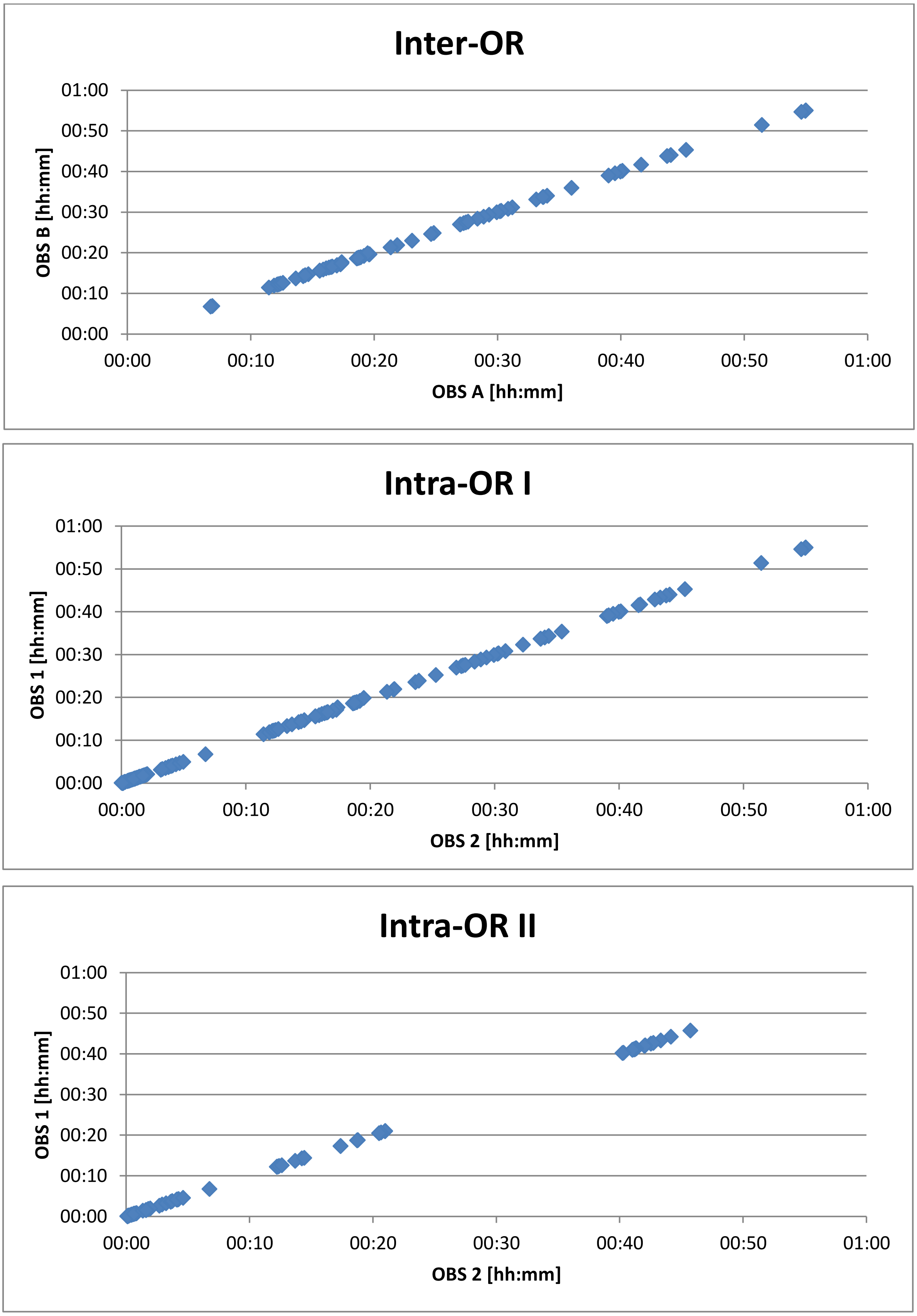

Figure 11. Creep area usage: Relationship between the durations recorded by observer A and B (Inter-OR) and observations 1 and 2 (Intra-OR I and II). OBS A = observation of the author, of whom data were partly used for this study; OBS B = observation of the author of the present study; OBS 1 = first observation for Intra-OR I and II; OBS 2 = second observation for Intra-OR I and II.

8.2 Latency until 75 % of the litter are in the creep area

Twenty-two litters reached the criterion "latency 75 %" (= 75 % of the piglets were observed in the creep area at the same time), which corresponds to 54 % of all litters. The temperature difference between sow area and creep area and the temperature quotient (quotient of temperature difference and temperature in the sow area) had a significant influence on reaching the criterion (temperature difference: Z = 2.18, p = 0.03; temperature quotient: Z = 2.65, p = 0.01). The higher the temperature difference and the higher the temperature quotient, the more litters reached the "latency 75 %" criterion (Figure 12).

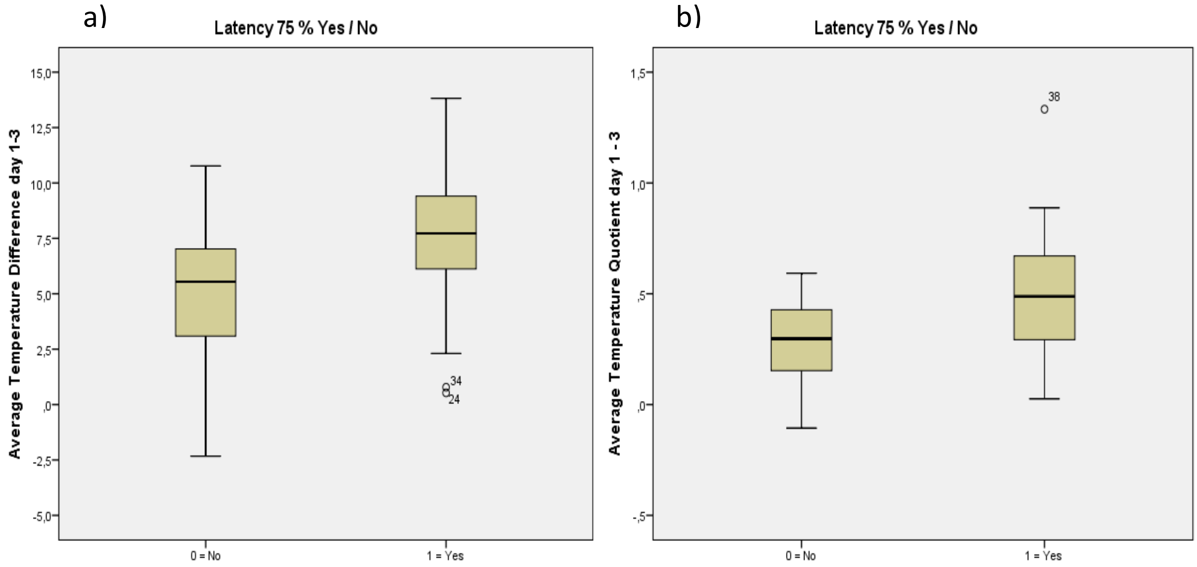

Figure 12. Average temperature difference (a) and average temperature quotient (b) in the first three days of the piglets' lives for litters which did not reach the 75 % criterion (0 = No) and for litters which reached the 75 % criterion (1 = Yes).

The average latency of the 22 litters, which reached the 75 % criterion, was 26.29 ± 20.46 hours. For litters which reached the 75 % criterion, temperature difference ($F_{1,17}$ = 0.17, p = 0.69) as well as temperature quotient ($F_{1,20}$ = 0.55, p = 0.47) did not affect the latency.

8.3 Association between temperature difference as well as temperature quotient and piglets' usage of the creep area during the first three days

The piglets' creep area usage increased from day 1 to day 3 from on average 1.94 ± 3.47 hours on day 1 to 4.57 ± 6.69 hours on day 3. The average total time a piglet spent in the creep area during the first three days was 9.97 ± 14.87 hours. An increasing temperature difference tended to lead to a higher creep area usage during the first three days ($F_{1,26}$ = 3.83, p = 0.06). The temperature quotient had a significant effect on the average creep area usage per piglet in the first three days of the piglets' lives ($F_{1,39}$ = 12.65, p = 0.001). The higher the average temperature quotient and the average temperature difference were, the higher was the average creep area usage during the first three days (Figure 13).

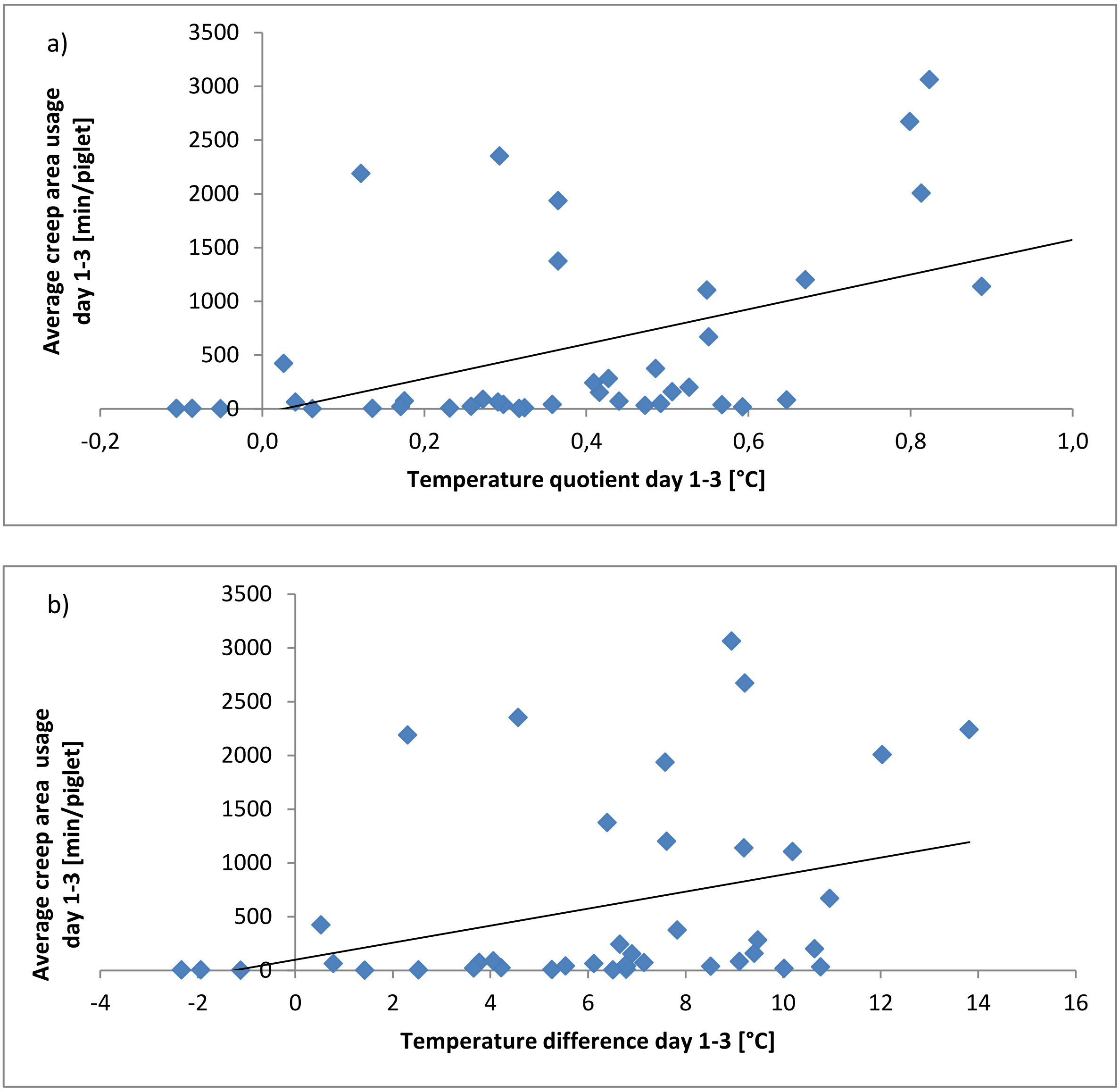

Figure 13. Association between average creep area usage per piglet and average temperature quotient (a) and average temperature difference (b) on days 1 to 3.

For consideration of the proportion of small piglets (<1 kg birth weight), we only had a reduced data set (27 litters) since information on the birth weight of the other litters was not available. The proportion of small piglets per litter had no significant effect on creep area usage during the first three days of the piglets' lives ($F_{1,18} = 3.54$, $p = 0.08$), while the effect of the temperature difference ($F_{1,18} = 4.84$, $p = 0.04$) and the temperature quotient ($F_{1,23} = 8.81$, $p = 0.01$) again had a significant influence on creep area usage similar to the one observed for all litters.

8.4 Association between temperature difference and temperature quotient with piglets' usage of the creep area analysed separately for day 1, 2 and 3

With additional consideration of the time since end of farrowing (days), there was a significant interaction between temperature difference and day regarding the usage of the creep area ($F_{2,79} = 6.30$, $p = 0.003$). With increasing age of the piglets a higher temperature difference led to a higher creep area usage (Figure 14).

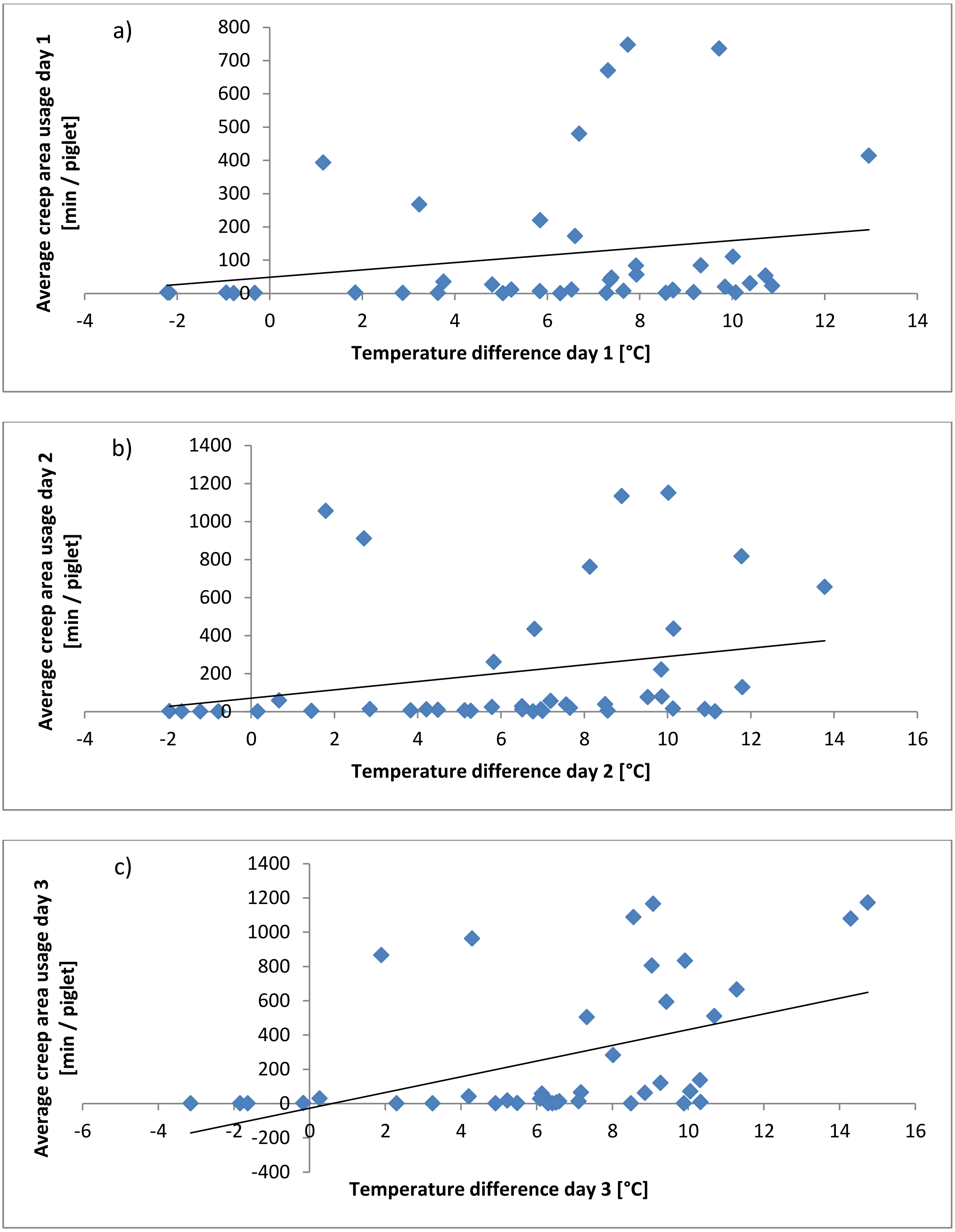

Figure 14. Association between average creep area usage and temperature difference on day 1 (a), day 2 (b) and day 3 (c).

A similar interaction effect was found for temperature quotient and day ($F_{2,80} = 7.66$, $p = 0.001$). Creep area usage per day increased with increasing temperature quotient and age of the piglets (Figure 15).

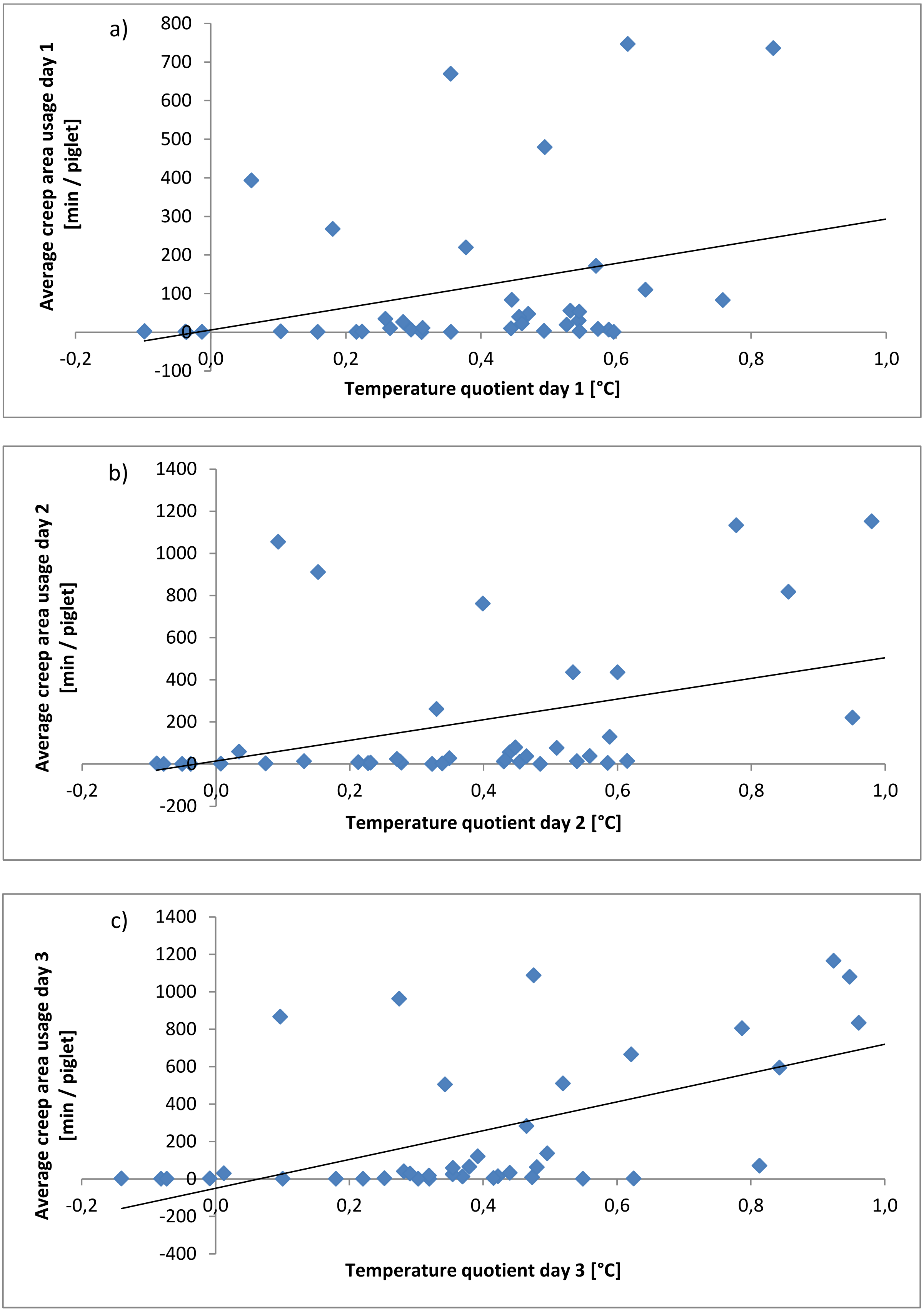

Figure 15. Association between average creep area usage and temperature quotient on day 1 (a), day 2 (b) and day 3 (c).

The usage of the creep area of the small piglets only was influenced by the temperature difference ($F_{4,48} = 4.48$, $p = 0.04$) and the temperature quotient ($F_{1,36} = 7.36$, $p = 0.01$). It increased per day with increasing temperature difference and increasing temperature quotient. The interaction between temperature difference and day ($F_{2,46} = 2.48$, $p = 0.10$) and the interaction between temperature quotient and day ($F_{2,48} = 3.03$, $p = 0.06$) tended to lead to a higher usage of the creep area of the small piglets. Neither day nor the proportion of small piglets per litter had a significant influence on creep area usage when the temperature difference (day $F_{2,45} = 0.15$, $p = 0.86$, proportion of small piglets per litter $F_{1,41} = 0.87$, $p = 0.36$) or the temperature quotient were considered (day $F_{2,47} = 0.20$, $p = 0.82$, proportion of small piglets per litter $F_{1,44} = 1.24$, $p = 0.27$).

8.5 Creep area usage and crushing losses

Overall, 107 out of 606 liveborn piglets were crushed, which corresponds to 17.7 %. Crushing losses ranged from 0 to 10 crushed piglets per litter during the first three days with an average of 2.71 crushed piglets per litter. Most piglets were crushed on day 1 (2 ± 2.07), whereas on day 3 only very few piglets were crushed (0 ± 0.42) (Figure 16). Crushing losses decreased significantly from day 1 to day 3 ($F_{2,83} = 5.99$, $p = 0.004$). Neither creep area usage ($F_{1,66} = 0.03$, $p = 0.87$), nor the interaction between day and creep area usage had a significant effect on crushing losses ($F_{2,93} = 0.12$, $p = 0.89$).

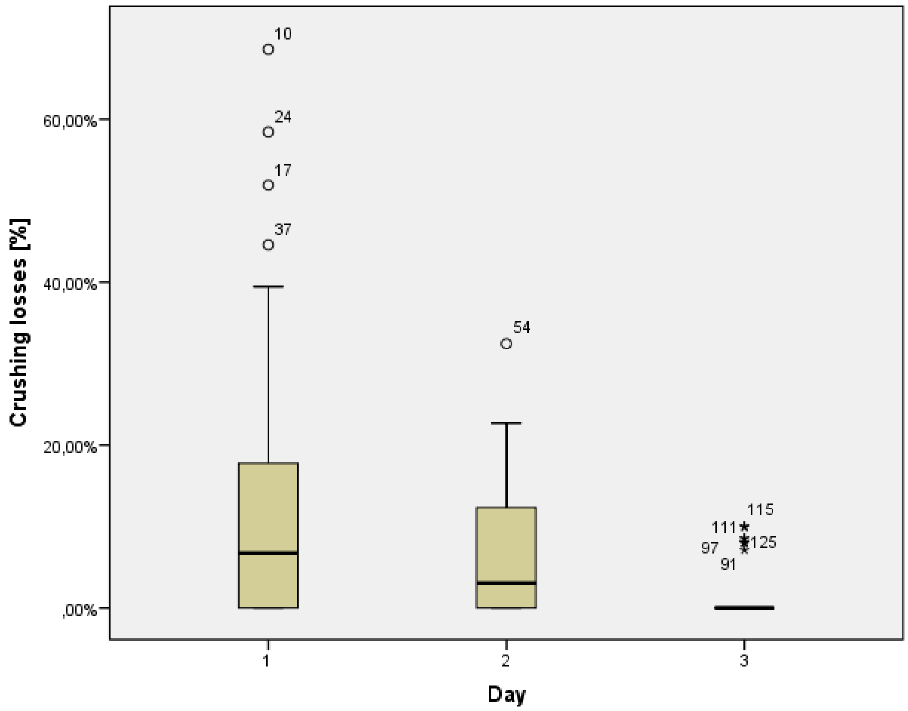

Figure 16. Crushing losses (in % of liveborn piglets) on day 1, day 2 and day 3.

However, there was a significant interaction between day and the proportion of small piglets per litter ($F_{2,74} = 4.95$, $p = 0.01$). The proportion of crushed piglets decreased over the course of the first three days and the higher the proportion of small piglets in a litter, the more crushing losses occurred. Figure 17 displays this relationship graphically. Creep area usage of the small piglets had no significant effect on crushing losses ($F_{1,74} = 0.62$, $p = 0.43$).

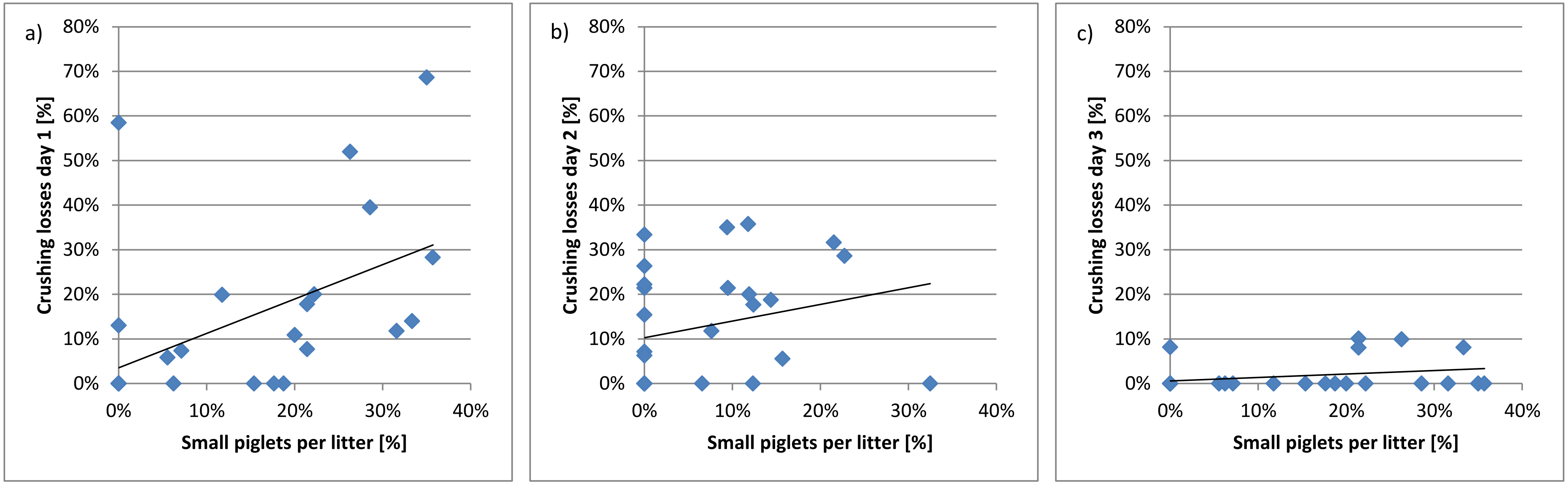

Figure 17. Association between crushing losses on day 1 (a), day 2 (b) and day 3 (c) and the proportion of small piglets per litter.

9 Discussion

The aim of the present study was to investigate the effect of temperature difference between creep area and sow area on creep area usage of suckling piglets and the influence of creep area usage on piglet losses due to crushing. The higher the temperature difference and the higher the temperature quotient (temperature difference divided by temperature in the sow area), the more litters reached the "75 % criterion" (i.e., at least 75 % of the piglets of the litter were observed in the creep area at the same time). For litters which reached the 75 % criterion, temperature difference as well as temperature quotient did not affect the latency. The piglets' creep area usage increased from day 1 to day 3, and with increasing age of the piglets, an increasing temperature difference / temperature quotient resulted in an increased creep area usage. Crushing losses decreased significantly from day 1 to day 3, but creep area usage had no significant effect on the percentage of crushed piglets.

Discussion of the methods

According to previous findings from Larsen and Pedersen (2015), it is important to investigate the effect of heat on creep area usage under controlled conditions (i.e. constant temperatures in the creep area and in the sow area, no large temperature fluctuations, suitable measuring technology), but these conditions were difficult to achieve with the available infrared heating plates. The biggest challenges at the beginning of the experiment were the temperature settings and temperature measurements in the creep area. It was initially planned to distinguish between two temperature settings in the creep area: a high temperature (36 °C) versus a low temperature (20 °C). There were two main reasons why the distinction between the two different temperature settings in the creep area was not possible in practice. First, the set temperature of 36 °C could not be constantly reached, especially when the room temperature in the stable was low during winter. Second, the temperature in the creep area could not be kept constant, but markedly fluctuated in the creep area. As high temperatures were not reached and temperature fluctuations appeared, the two different temperature settings of high and low temperatures overlapped. Thus, for the analysis, we did not distinguish between two treatments with different distinct temperature settings, but instead used the measured temperatures (and the calculated temperature difference and quotient) as continuous variables to investigate the relationship between thermal conditions and the outcome measures.

The infrared heating plates require regular monitoring of actual temperatures in the creep areas by the farmers. However, air temperature might be an inadequate indicator of the thermal environment piglets experience in the creep area when infrared heating plates are used (Vasdal et al., 2009). Consequently, we performed some pilot trials aiming to find an adequate method for the temperature measurement. Pilot trials with different temperature settings, examinations with a dead piglet (to get an idea how infrared rays act on the piglets) and measurements with a thermal imaging camera (explained in chapter 7.3.3 Temperature setting and temperature recording) ultimately led to the decision to set the thermostat of the creep area heating panels at 20 °C and 36 °C, alternating between neighbouring pens, to create a bigger range of temperature differences. For further research it would be important to find a more advantageous measuring method, which provides information how piglets experience the infrared rays or more precisely the temperature released by the infrared heating plates when entering and staying in the creep area.

In order to be able to compare different studies, attention must be paid to the type and location of the heat source in the creep area. Heat lamps produce an uneven heat distribution (Zhang & Xin, 2001), whereas radiant cover heating plates, which were used in the present study, provide an almost regular heat distribution and piglets may perceive radiant heat more readily on their skin (Morello et al., 2019). However, as discussed above, it is difficult to know how the heat emitted from infrared heating plates is perceived. Besides the type of the heat source, its location may have an important effect on the creep area usage as well – heat sources close to the sow are preferred regardless of their type (mat, lamp or plate) (Zhang & Xin, 2001).

The most important criteria for selection of the farms were that farms had WelCon farrowing pens and infrared cover heating plates in the creep area. There were not many organic farms that fulfilled these criteria. In addition to the Institute of Organic Farming and Farm Animal Biodiversity, data were recorded on two private organic farms. However, on these two farms only few breeding sows were available, which resulted in an uneven distribution of the number of observed litters across the three farms. Moreover, the extent to which the three farms can be compared is limited with respect to differences in the management of cold and weak piglets and the assessment of the cause of death in dead piglets. One difference between farms was that the farmers of the two private farms manually placed cold and weak piglets into the creep area, whereas this was not done at the Institute of Organic Farming and Farm Animal Biodiversity. This might have influenced the further creep area usage, as the piglets already explored the warm and comfortable creep area, which may have led to a higher creep area usage. Indeed, at the two private farms, the average creep area usage per piglet tended to be higher than at the Institute in Wels. In addition, it might have led to reduced losses, as especially cold and weak piglets are at high risk to be crushed by the sow. Crushing losses tended to be lower on the two farms than at the Institute in Wels. A second difference between farms was that at the Institute of Organic Farming and Farm Animal Biodiversity, each dead piglet was subjected to a post mortem examination, whereas on the two private farms, the farmers only noted the presumed cause for each loss, which might not have reflected the true cause of death. Edwards (2002), for example, described in her study that farm diagnosis of cause of mortality is often unreliable, e.g. in terms of incorrect diagnosis of stillbirth and overestimation of crushing. In contrast, the results from Schwarz (2008) showed, that 86 % of crushing losses were without post mortem examination correctly diagnosed.

For the present study, the creep area usage of the piglets was evaluated for the first three days of the piglets' lives since these days are considered to be particularly critical for piglet survival (Marchant et al., 2001). However, especially in the first days after birth, it is difficult to lure the piglets away from the mother sow into a heated creep area. Piglets increase the usage of the creep area from the third day of life, when they would naturally leave the nest with the sow to explore the environment (Hrupka et al., 1998, Berg et al., 2006) and the further course of the creep area usage would thus be interesting to evaluate in future studies.

Discussion of the results

Relationship between the temperature difference / temperature quotient, latency and the piglets' usage of the creep area

In accordance with the Burri et al. (2009) study, in which the time until at least 75 % of the piglets of a litter stayed in the creep area increased with increasing temperatures in the sow area. In addition, the higher the temperature in the sow area, the less time piglets spent in the creep area during the first three days. It can thus be summarised that the time until piglets enter the creep area and the duration for which they stay there was significantly affected by room temperature: With increasing room temperature, it took the piglets longer to visit the creep area and the time piglets spent in the creep area decreased (Burri et al., 2009). It is assumed, that the piglets feel comfortable at higher temperatures in the sow area and are therefore not motivated to enter a heated creep area. In line with Morello et al. (2019), piglets' usage of the creep area increased with increasing temperature difference between the creep and the sow area: The higher the temperature difference, the higher was the creep area usage. In addition, Schormann and Hoy (2006) reported that the time piglets spent in a heated nesting site was much higher if the temperature in the sow area was low (18 °C) when compared with a temperature of 26 °C. Thus, the results of our study are comparable with data from previous investigations.

In our study, creep area usage increased with an increasing temperature quotient. Most other studies did not take the temperature quotient into account, however, those studies were carried out under controlled barn climate conditions. In the present study, the experiment was carried out on organic farms with uninsulated barns and without room heating and it was therefore important to consider not only the temperature difference. In contrast to conventional barns, the temperatures in the sow area thus fluctuated over the course of the year and the temperature quotient takes this fluctuation into account: A higher temperature quotient indicates a higher temperature in the creep area (assuming constant temperature in the sow area) or a lower temperature in the sow area (assuming constant temperature in the creep area).

Moreover, the effect of the number of small piglets per litter on creep area usage was investigated. The results of the present study did not indicate an influence of the proportion of small piglets per litter on creep area usage. It may be presumed that particularly small piglets search for body contact with the sow due to hunger and need for warmth. No comparable study was found, which took also the proportion of small piglets into account. However, Vasdal et al. (2010) investigated the effect of birth weight on creep area usage. In line with the present study, birth weight had no statistically significant effect on creep area usage, even though the effect of birth weight and proportion of small piglets per litter cannot be directly compared, as they are two different parameters.

Relationship between the piglets' usage of the creep area and the crushing losses of the piglets

A high usage of the creep area is generally desired as it is assumed that an increased usage leads to a decreased mortality rate due to reduced crushing losses (Vasdal et al., 2009). However, there was no relationship between creep area usage and crushing losses in the present study. This result is in line with Vasdal et al. (2009, 2010), who did not find such a relation either. However, in accordance with several studies (e.g. Marchant et al., 2001; Andersen et al., 2009), crushing losses decreased significantly from day 1 to day 3 with most crushing losses occurring on day 1.

The higher the proportion of small piglets in a litter, the more crushing losses occurred in the present study. Perinatal piglet mortality may be underlain by a reproductive strategy of producing a large number of offspring, which has had evolutionary advantage, and will therefore be difficult to reduce. A level of piglet mortality of 10 % to 20 % could therefore be considered normal for the reproductive biology of the pig (Edwards, 2002). In the present study, 17.7 % of the liveborn piglets were crushed (without consideration of other mortality causes). For example in the study of Nicolaisen et al. (2019) the proportion of crushed piglets in free farrowing systems (18.1 %) was higher compared to pens with farrowing crate (4.4 %). Thus, the proportion of crushed piglets in the present study is comparable to other results. Attempts to reduce piglet mortality under free farrowing conditions have yielded limited success. Reducing piglet mortality has been a consequence of increasing the number of born piglets rather than a reduction in mortality. However, this trend goes along with challenges in maintaining piglet survival. It is well established that the probability of survival decreases with increasing litter size (e.g. Dyck & Swierstra, 1986; Roehe & Kalm, 2000) as a result of the associated reduction in individual birth weight (Edwards, 2002). Piglets' birth weight is an important influencing factor, which has direct influence on the thermoregulatory capacity and the growth of the piglets (Muns et al., 2016).

9.1 Conclusion

Temperature difference and temperature quotient do have an effect on creep area usage: The higher the temperature difference / temperature quotient in the first three days, the earlier 75 % of the piglets are in the creep area and the longer they stay there. The influence of temperature difference / temperature quotient on creep area usage becomes increasingly relevant with increasing age of the piglets in the first three days of the piglets' live. A heated creep area should be available for the piglets especially at cold temperatures in the sow area, as it seems to be more comfortable in the warm creep area. Unfortunately, a higher creep area usage did not lead to reduced crushing losses, which take place especially in the first few days. It seems that other factors such as litter size, birth weight, maternal behaviour etc. have a greater impact on crushing losses.

10 References

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11 Appendix

Sau Nummer:	Geburtsdatum der Sau:	Wurfnummer der Sau:	BETRIEB:
Abferkeldatum:	**Ferkel gesamt:**	**Lebend geboren:**	**Tot geboren:**

	Geburtsgewicht:
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Sonstige Anmerkungen:

Temperatureinstellung im Ferkelnest:

Bucht Nummer:

Cam Nummer:

HOBO Nest:
Seriennummer
Description

HOBO Sauenbereich:
Seriennummer
Description

Behandlungen von Sau und Ferkel:

Lebenstag / Datum	Anzahl der Verluste	Vermutete Verlustursache(n)
1. Lebenstag /		
2. Lebenstag /		
3. Lebenstag /		