Group-Adapted ad Libitum Feeding vs. Conventional Restrictive Feeding: Impact on Health, Behavior, and Reproductive Performance of Group-Housed Pregnant Sows

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Abstract

Background

Common feeding systems for pregnant group-housed sows meet the nutritional demand but do not sufficiently consider their natural feeding behavior. A new group-adapted ad libitum feeding system called “SWOF” (Hölscher + Leuschner GmbH & Co. KG®, Emsbüren, Germany) was developed to ensure that both optimal nutritional and behavioral needs are met. This feeding system comprises an activity and lying area and two areas with ad libitum liquid feeding on the basis of whole plant wheat silage. Passing through a sorting gate, sows could be given either a low- or high-energy diet according to their weight and parity. The study’s aim was to investigate the effects of this new system on sows’ body weight, health status (lameness), aggression parameters (integument injuries, vulva injuries, displacements at the trough), feed intake rhythm, and litter performance, and to compare these with restrictively fed group-housed sows, which is the common standard in Germany.

Results

In the group-adapted ad libitum feeding system, significantly less risk for displacements at the trough and vulva injuries were observed, and sows followed their natural biphasic feed intake rhythm. This system also resulted in lower body weight and more integument injuries than the restrictively fed group-housed sows. However, these might be due to different management practices and group size between the two systems. No influence of the feeding system was observed, neither on lameness nor litter performance.

Conclusion

The data reported here show the promising effects of the group-adapted ad libitum “SWOF” feeding system with regard to animal welfare, as sows can freely choose when and how much feed they want to consume without taking the risk of over conditioning. The “SWOF” feeding system remains to be further validated, also considering the group size and management practices.

Background

According to the EU/directive, 2001/88/EC pregnant sows must be kept in groups from the 29th day of gestation until 7 days before the calculated farrowing date. Pregnant sows are mainly fed restrictively in electronic sow-feeding stations (32 %) or in self-locking feeders (27 %) during the time of group housing in Germany (Ebertz et al., 2018).

There is a demand for an optimal feeding system during gestation, which should enable the sows to follow their natural feeding behavior and avoid production-related diseases (e.g., lameness). At the same time, sows should have an optimal nutrient supply in order to have the best body condition for farrowing. Common feeding systems do not meet these requirements. Restrictive feeding with an animal-feeding place ratio of 1:1 enables a natural synchronous feeding of sows. However, no individual energy adapted feeding for the sows can be guaranteed. On the other hand, with automatic feeding stations, animal-specific feeding takes place, but the system does not allow synchronous feeding of sows and often provokes fights in front of the feeding stations (Amon, 1990). Besides, the feed intake capacity or individual need for satiety cannot be fully met in both systems (Hoy et al. 2001; Steffens 2005). An alternative would be the ad libitum feeding of pregnant sows. Ad libitum feeding offers some ethological advantages for the sows. Sows can freely choose feeding times because food is available at any time. With sufficient feeding places, ad libitum feeding enables synchronous feeding and the natural biphasic feeding rhythm of the sows (Porzig and Sambraus, 1991; Hoy et al., 2016; Angermann et al., 2018). The sows’ welfare is also enhanced by the absence of persistent feeling of hunger (Petherick and Blackshaw, 1989; Robert et al., 1993) and the reduced frequency of agonistic interactions, as food competition is minimized (Kelley et al., 1980; Ziron 2005). However, an ad libitum supply of feed can lead to excessive feed intake and weight gain (Hoy et al. 2001; Steffens, 2005).

To combine the positive aspects of ad libitum feeding with low variability in the growing performance of group-housed sows, a feeding system with group-adapted ad libitum feeding (named SWOF) was developed (Hölscher + Leuschner GmbH & Co. KG®, Emsbüren, Germany) and evaluated in this study. The experimental system comprised an activity and lying area and two ad libitum feeding areas. Sows were able to access either low- or high-energy diet feeding areas based on their weight in relation to their parity, passing through a sorting gate. This study is a pilot experiment to gain first insights into group-adapted ad libitum feeding for sows under practical conditions. In this on-farm-study, the effects on sows’ body weight, health status (lameness), aggression parameters (integument injuries, vulva injuries, displacements at the trough), feed intake rhythm, and litter performance were evaluated, and compared with restrictively fed group-housed sows. The group-adapted ad libitum feeding system was expected to result in similar weight development, lameness prevalence, and litter performance compared to the restrictive feeding system, but to enable specific biphasic feed intake rhythm and to reduce aggressions in sows (i.e., fewer displacements at the trough and injuries).

Results

A total of 114 pregnant Danish genetic sows (second to eleventh parity) were included in this study, and divided into two differently designed compartments, hereinafter referred to as experimental system (“SWOF”; n = 56) and standard system with restrictive feeding (n = 58).

Since sows showed very different initial weights and integument injuries in the experimental and standard systems, the weight and injury rate were corrected with the first measurement (i.e., 31st day of gestation).

Bodyweight of sows

The average feed consumption in the experimental system reached 4.67 ± 2.14 kg of DM/sow/day in feeding area A (low-energy diet) and 4.52 ± 2.03 kg of DM/sow/day in the feeding area B (high-energy diet). Sows in the standard system consumed, on average, 2.54 ± 0.23 kg of DM/sow/day. Feed losses during feeding were not quantified in either of the systems.

The influence of the system ($p < 0.001$) on the body weights of pregnant sows was detected. Sows in the experimental system were lighter, on average 296.4 ± 2.6 kg [least square mean ± standard error (LSM ± SE)], than sows in the standard system, with on average 310.7 ± 2.5 kg (LSM ± SE). The day of gestation also showed an influence ($p < 0.001$) on the weight of sows [e.g., gestation day 71: 290.9 ± 2.0 kg (LSM ± SE); gestation day 109: 316.2 ± 2.0 kg (LSM ± SE)]. The sows in the first parity class had a weight of 302.6 ± 4.6 kg (LSM ± SE), second parity class of 298.9 ± 4.0 kg (LSM ± SE), third parity class of 312.0 ± 4.0 kg (LSM ± SE), and fourth parity class of 300.8 ± 3.1 kg (LSM ± SE), though these differences did not reach statistical significance ($p = 0.0745$). An interaction between the system and parity class of sows was identified ($p = 0.007$). Sows in the standard system showed a trend towards higher weights in higher parities, but this was not observed in sows of the experimental system (Table 1).

Table 1: Sows' weight in the different parity classes in the experimental (n = 56) and standard systems (n = 58) (LSM ± SE; n_{total} = 114; 217 observations).

Parity classes	Experimental system	Standard system
1	302.7 ± 6.3	302.4 ± 5.2
2	291.0^{a} ± 5.9	306.8^{b} ± 5.2
3	306.5 ± 6.0	317.5 ± 5.2
4	285.5^{a} ± 4.9	316.1^{b} ± 3.3

LSM with different superscript letters within one line is significantly different with $p < 0,05$

An interaction between the batch, time point and feeding system on sows' weight was detected ($p = 0.002$). No batch effect was found on sows' body weight.

Injury index

An injury index based on the average of different body parts' integument injuries was calculated to obtain a characteristic feature over the entire sow injuries. The feeding system showed a significant effect on the sows' injury index ($p < 0.001$). A higher injury index [0.74 ± 0.04 (LSM ± SE)] was documented in the experimental system compared to the standard system [0.54 ± 0.03 (LSM ± SE)]. The injury index was influenced by the batch ($p = 0.004$). In the first batch, an injury index of 0.72 ± 0.04 (LSM ± SE) was determined, while in the second batch, the index was 0.55 ± 0.04 (LSM ± SE). The time point also showed a significant effect on the injury index of the animals (Table 2), the injury index being higher at 38 days of gestation.

Table 2: Injury index during the gestation (LSM ± SE; n_{total} = 114; 679 observations)

Day of gestation	Injury index
38	$0.86^{a} \pm 0.04$
45	$0.67^{b} \pm 0.04$
52	$0.67^{b} \pm 0.04$
71	$0.57^{c} \pm 0.03$
94	$0.60^{bc} \pm 0.04$
109	$0.45^{d} \pm 0.04$

LSM with different superscript letters within one column are significantly different with $p < 0,05$

The interaction between the time point during gestation and the feeding system had a significant effect on the injury index ($p < 0.001$). In the experimental system, the injury index on the 38th day of gestation was significantly higher than in the later measurements (Table 3).

Table 3. Injury index in the experimental (n = 56) and standard systems (n = 58) during the gestation (LSM ± SE; n_{total} = 114; 679 observations)

Day of gestation	Injury index	
Experimental system	Standard system	
38	$1.13^{a,A} \pm 0.05$	$0.58^{bc,B} \pm 0.05$
45	$0.90^{b,A} \pm 0.06$	$0.44^{a,B} \pm 0.04$
52	$0.83^{b,A} \pm 0.07$	$0.51^{b,B} \pm 0.04$
71	$0.60^{c} \pm 0.05$	$0.53^{bc} \pm 0.05$
94	$0.56^{c} \pm 0.06$	$0.65^{c} \pm 0.05$
109	$0.39^{d} \pm 0.05$	$0.51^{b} \pm 0.05$

LSM with different superscript lowercase letters within one column and capital letters within one line is significantly different with $p < 0,05$

The injury index was found to be negatively correlated with the sow parity class ($p < 0.01$)

(Table 4).

Table 4. Injury index according to the parity class (LSM ± SE; n_{total} = 114; 679 observations)

Parity class	Injury index
1	0.77^{a} ± 0.05
2	0.65^{ab} ± 0.05
3	0.57^{b} ± 0.06
4	0.56^{b} ± 0.04

LSM with different superscript letters within one column are significantly different with $p < 0,05$

When looking at the body parts injured, injuries were most frequently located on the neck area (Table 5).

Table 5: Average rating index per body part (Mean ± SE; n_{total} = 114; 797 observations)

	Head	Neck	Lateral abdominal Wall	Hindquarters
Experimental system	0.22 ± 0.46	1.32 ± 0.88	0.98 ± 0.87	0.44 ± 0.59
Standard system	0.07 ± 0.27	0.94 ± 0.75	0.66 ± 0.75	0.44 ± 0.61

The injury index was not influenced by the interaction of the feeding system with the batch and of the feeding system with the parity class.

Lameness

No significant difference in lameness during pregnancy was found between the experimental and standard systems (Table 6).

Table 6: Probability for occurrence of lameness in the experimental (n=56) and standard systems (n = 58) (%; n_{total} = 114; 680 observations)

Score	Experimental system	Standard system
0 – no lameness	88.08	93.78
1 – moderate lameness	10.02	5.47
2 – serious lameness	1.90	0.75

The time point during gestation showed a significant influence on lameness scores ($p < 0.001$). The highest risk of lameness was found on the 38th day of gestation, with 21.64 ± 4.75% (LSM ± SE) of the sows being lame (Table 7).

Table 7: Probability for occurrence of lame sows during gestation (Backtransformed LSM ± SE in %; n_{total} = 114; 680 observations)

Day of gestation	Lameness
31	4.96^{b} ± 2.14
38	21.64^{a} ± 4.75
45	5.80^{b} ± 2.44
52	6.58^{b} ± 2.49
71	5.78^{b} ± 2.46
94	9.76^{b} ± 3.19

Data are presented as back-transformed LS Means with different superscript letters within one column are significantly different with $p < 0.05$

No general difference in lameness was found with regard to the parity class ($p = 0.071$), though a significant difference between the second and fourth parity was observed ($p = 0.02$; Odds ratio: 3.283). Thus, in the parity class one (i.e., second parity), the probability for occurrence of lameness was 10.89 ± 3.95 % (back-transformed LSM ± SE); in parity class two (i.e. third parity) 13.91 ± 4.58% (back-transformed LSM ± SE); in parity class three (i.e. fourth parity) 5.41 ± 2.60% (back-transformed LSM ± SE); and in parity class four (i.e. fifth to eleventh parity) 4.69 ± 1.49 % (back-transformed LSM ± SE). No batch effect was found on lameness.

Vulva injuries

The feeding system was found to have a significant influence ($p = 0.037$) on the probability of the occurrence of vulva injuries. In the standard system, the probability was 28.55 ± 7.11% (back-transformed LSM ± SE), and in the experimental system, 11.14 ± 4.89% (back-transformed LSM ± SE). For a corrected equal initial weight (of 300 kg), sows had a significantly higher risk for the occurrence of vulva injury (34.41 ± 7.25%, back-transformed LSM ± SE) in the standard system compared to the experimental system (14.14 ± 5.51%, back-transformed LSM ± SE). The parity class, batch, and number of piglets weighed showed no influence on the probability of vulva injuries.

Litter performance

In the evaluation of the litter performance, no significant differences between the feeding systems, the parity class, or the batch were found (Table 8).

Table 8: Performance per litter in the experimental (n = 50) and standard systems (n = 51) (LSM ± SE; n_{total} =101)

	Litter weight (kg)	Number of born piglets	Number of piglets born alive	Number of stillborn piglets	Number of mummified piglets
Experimental system	22.74 ± 0.46	21.15 ± 0.63	18.38 ± 0.35	1.36 ± 0.27	0.75 ± 0.26
Standard system	22.14 ± 0.45	20.28 ± 0.62	17.53 ± 0.34	1.94 ± 0.26	1.03 ± 0.25

Displacements at the trough

Comparing the displacements during feeding in both feeding systems, a significant effect of the system and of the time of day was observed. The probability for the occurrence of displacement was 40.98 ± 0.70% (back-transformed LSM ± SE) in the experimental system, and 74.83 ± 1.93% (back-transformed LSM ± SE) in the standard system. The highest probability of the occurrence of displacements at the trough is documented at the beginning of feeding (6:00) and towards the end (10:00) in the standard system (Table 9).

Table 9: Probability for the occurrence of displacements at the trough during feeding time in the experimental (n = 56) and standard systems (n = 58) (back-transformed LSM ± SE in %; n_{total} = 114 sows; 11.638 observations)

Time of the day (am)	Experimental system	Standard system
6	$40.12^{b,A}$ ± 1.71	$80.31^{b,B}$ ± 0.66
7	$42.59^{b,A}$ ± 1.74	$75.16^{c,B}$ ± 1.16
8	44.16^{b} ± 1.55	65.15^{d} ± 1.89
9	51.85^{a} ± 1.58	69.75^{d} ± 2.00
10	$31.11^{c,A}$ ± 1.63	$92.86^{a,B}$ ± 1.78

Data are presented as back-transformed LS Means with different superscript lowercase letters within one column and capital letters within one line are significantly different with $p < 0.05$

Feed intake rhythm

Group-adapted ad libitum feeding (i.e., experimental system) made it possible to establish a feed intake rhythm over 24 h. The graphic presentation of the feed intake rhythm of all feeding sows in the experimental system (n_{total} = 105 sows) over 24 h revealed a maximum activity level in both feeding areas between 6:00 and 18:00 (Fig. 1 a and b). When looking at the mean values, it can be graphically seen that sows with free access to the trough have a peak between 8:00 and 10:00 (area A) or 6:00 and 10:00 (area B) and a peak between 14:00 and 16:00 (Fig. 1 a and b).

Figure 1: Feed intake rhythm in (a) the low-energy and (b) high-energy diet feeding areas of the experimental system (expressed as the relative part of eating sows from all the sows in the system). Boxplots indicate data range as well as median, and lower and upper quartiles. The diamonds indicate the means. Thick grey lines are the 95% confidence intervals, and the grey circles represent individual sows.

Discussion

The aim of this pilot study was to evaluate a new group-adapted ad libitum feeding system (“SWOF”) on-farm and compare it with a standard restrictive feeding system with regard to pregnant sows’ welfare. That includes effects on sows’ body weight, health status (lameness), aggression parameters (integument injuries, vulva injuries, displacements at the trough), litter performance, and feed intake rhythm.

The study showed that sows fed restrictively were on average heavier (by 14.3 kg) than group-adapted ad libitum fed sows. Previous studies that investigated pregnant sows’ weight development under (non-group-adapted) ad libitum and restrictive feeding observed higher weight gains in ad libitum fed sows (Hoy et al., 2001; Steffens, 2005; Ziron, 2005). The lower weight of the sows in the experimental system could result from the increased activity caused by rank fights and the pen structure. Also, the feed losses remain an incalculable uncertainty in the energy and nutrient supply. Therefore, it is not possible to draw conclusions from feed consumption to the actual amount of feed actually eaten by the sows. In this study, all sow weights were corrected (included as a co-variable in the model) due to sow initial weight differences between the two feeding systems being compared. Therefore, no statement can be made on (daily) weight gains during pregnancy. The time point was an expected effect on sows’ weight in both feeding systems: the later the gestation, the higher the weight. Moreover, sows fed restrictively showed higher weights as parity increased. These results are in agreement with Ziron (2005), who found that weights increased with parity up to the third parity, but decreased again from the fourth parity. It remains, however, unclear why sows in the experimental system did not show this pattern, with the lowest body weights recorded in the second and fourth parity classes. The particular low weights observed in these sows in their fourth or higher pregnancy could be the result of a lack of acceptance of the sorting gate (i.e., lower coping ability) and the associated less frequent trough visits.

An injury index based on integument injuries was calculated to obtain a characteristic indication of the entire sow injuries (Arey, 1999; Salak-Johnson et al., 2007). Indeed, integument scores can serve as indirect parameters for the extent of agonistic interactions (Barnett et al., 1996). In this study, higher injury indexes were measured in the group-adapted ad libitum sows showing that more frequent and/or intensive confrontations occurred in the experimental system compared to the standard system. However, this is more likely related to the different group sizes and management practices than the feeding systems themselves. This on-farm-study had limitations in terms of group size and management practices between the two systems being compared that could, unfortunately, not be corrected for this pilot study. Sows in the experimental system were kept in large dynamic groups of about 105 sows, while sows in the standard system were kept in stable groups. Yet, the social organization of sows is characterized by stable dominance hierarchies (Meese and Ewbank, 1973). Hence, the continuous integration of new groups of sows requires the formation of a new social group and the establishment of the dominance hierarchy, which might lead to more aggressive behaviors and hence more injuries (Arey, 1999, Puppe et al., 2008, D'Eath and Turner, 2009). Therefore, due to these different housing managements (dynamic vs. stable), the feeding system alone cannot be considered when looking at the injury index in the present study. The group-adapted ad libitum feeding system remains to be further validated, this time taking into account the group sizes and management practices. The highest injury index was found on the 38th day of gestation in the experimental system (i.e., 10 days after housing the sows together in a group, which is consistent with other studies) (Van Putten and Van de Burgwal, 1990; Arey and Franklin, 1995; Kress et al., 1995; Borberg, 2008, Greenwood et al., 2014). In particular, Borberg (2008) found that after grouping unknown sows, 78% of all agonistic interactions were completed within 48 h, and when grouping growing pigs, Arey and Franklin (1995) observed that over 85% of all fights also took place within the first 48 h. According to Arey (1999), the number of aggressive interactions associated with rank fights fell steadily, and reached a stable level 1 week after grouping sows. In our experimental system, although new groups were admitted on the 74th (first batch) and the 73rd and 107th (second batch) day of gestation, the injury index decreased with a longer duration of stay. In the standard system, the 45th day of gestation was found to be the one with the lowest injury index, but it should be highlighted that the injury index variation range throughout the gestation was narrower in the standard system (0.65–0.44 vs. 1.13–0.39). This difference between the systems could again be due to group management practices. Finally, it was found that the injury index decreased with increasing parity, which is consistent with previous studies (O'Conell et al., 2003; Borberg, 2008; Tönepohl et al., 2013).

In the experimental system, the larger feces masses (due to the lower digestibility of the silages) and the additional processed water of the liquid feeding (leading to a more humid soil environment) could have had a negative influence on claws' health. However, no difference was found between the two feeding systems concerning the probability of lameness incidence. Overweightness under ad libitum feeding (but non-group-adapted) often leads to more lameness compared to restrictive feeding (e.g., Ziron, 2005). In this study, however, the over-conditioning of the experimental sows could be avoided, leading to no difference in lameness between the two systems. The highest probability for the occurrence of lameness was detected 10 days after housing (i.e., on the 38th day of gestation). That time also concurs with the highest injury index, which is caused mainly by increased hierarchy fights due to grouping. Ziron (2005) and Pluym et al. (2013) drew the same conclusion, the former specifying that rank fights increase the danger of claw injuries, which can lead to serious foundation problems and, thus, lameness. Regarding the parity effect on lameness, it was found that sows within their second or third parity (i.e., parity classes 1 and 2) had a higher risk in both systems compared to older sows (i.e., parity classes 3 and 4). Previous studies (Dewey et al., 1993; Pluym et al., 2011; Willgert et al., 2014;) also observed less lameness of sows in higher parity.

The higher probability for the occurrence of vulva injury in the standard system compared to the experimental system could well reflect the feeding situation at the trough. Vulva biting is an effective method of displacing sows without being bitten in return (Van Putten, 1990). With a restricted feed supply, competition for the limited resource feed becomes a central cause for agonistic interactions leading to injuries and displacement of low-ranking sows (Andersen et al., 2000). The lack of partition walls at the trough leads to sow displacements occurring more frequently (Andersen et al., 1999). Vulva injuries were mainly seen with the former electronic sow-feeding stations (Lehmann, 1991), which were highly attractive, resulting in increased animal encounters and more agonistic conflicts (Lehmann and Boxberger, 1988; Amon, 1990). Since vulva injuries have been reduced by the use of entrance doors. In the described experimental system, an automatic entrance door was used at the sorting gate, protecting the animals from the attacks of other sows. In addition, constant feed supply equalizes the competitive situation at the trough and reduces aggressions (Ziron, 2005).

The present study also showed that there was no difference in the litter performance between the experimental and standard feeding systems (see also Petherick and Blackshaw, 1989; Ziron, 2005).

A higher probability for the occurrence of displacements caused by agonistic interactions at the trough was observed in the standard system compared with the experimental system. Ziron (2005) suspected that under ad libitum feeding, the equalization of the competitive situation reduces the number of encounters of the sows at the trough, as well as the frequency of agonistic interactions. Amon (1990) observed that under restrictive feeding, 88.2% of all recorded agonistic interactions between sows of a group occurred in the feeding area. Kelly et al. (1980) also showed that pigs fasted for 24 h engaged in more biting activity than pigs fed ad libitum. Thus, the restriction of feed favors the competitive behavior of the sows and becomes a central cause for fights.

Due to the permanent provision of feed in the experimental system, sows had the possibility to choose their feeding times themselves, in contrast to restrictively fed sows. With this type of feeding, the start of feeding determined the time of feed intake (Amon, 1990). In the experimental system, the feed intake reached a maximum activity level between 6:00 and 18:00 in both (low- and high-energy diets) feeding areas. This corresponds to findings by Brouns and Edwards (1994) with a main feeding phase between 6:00 and 20:00. Moreover, it was found that the sows that had free access to the trough at all times took the opportunity to follow their specific biphasic feed intake rhythm. This is in agreement with previous results (Ziron, 2005; Angermann, 2018).

Conclusion

The group-adapted ad libitum feeding system resulted in a lower probability for the occurrence of displacements at the trough, lessvulva injuries, and the ability for sows to follow their natural biphasic feed intake rhythm. No influence of the feeding system was observed on lameness or litter performance.

It was shown that group-adapted ad libitum feeding resulted in lower body weight and higher integument injuries compared to restrictive feeding.

This study was an on-farm study with the aim of gathering initial results for the “SWOF” feeding system under practical conditions. Due to the specific on-farm condition, the effect of the feeding system could not be separated from the confounding effect of the management practice. As a consequence, the results are less meaningful, especially with regard to the injury index. Therefore, this group-adapted ad libitum feeding system remains to be further validated, taking into account the group sizes and management practices.

Animals, Materials, And Methods

The study was conducted between January and June 2018 at a commercial breeding farm in Brandenburg, Germany. The production was set to a 1-week-rhythm for the 1200 sows of the farm of the Danish genetic. All sows were vaccinated against the porcine parvovirus and Erysipelothrix rhusiopathiae (Parvoruvac®, IDT Biologica GmbH, Dessau-Roßlau, Germany). As prophylaxis against clinical *E. coli* and Clostridia infection of sucking pigs, the pregnant sows received a protective maternity vaccination (Clostricol®, IDT Biologica GmbH, Dessau-Roßlau, Germany). About 1 week before farrowing, the sows were moved to the farrowing compartments and treated against endoparasites (Fenbendatat® 5%, aniMedica GmbH, Senden-Bösensell, Germany; Dosage: 5 mg fenbendazole/kg KM oral).

A total of 114 pregnant Danish genetic sows (second to eleventh parity) were included in this study, and divided into two differently designed compartments, hereinafter referred to as experimental system (with 56 focus sows) and standard system (with 58 focus sows). The experimental system sows were kept in large dynamic groups of 105 sows on average. New groups of around 40 sows were admitted on the 74th (first batch) and the 73rd and 107th (second batch) day of gestation, while 40 sows were brought to the farrowing compartments. In the standard system, sows were kept in a stable group of 44 sows on average divided by the trough in the middle into two groups of 17 to 24 sows. The study was carried out in two successive batches. In the first and second batch, 31 and 25 focus sows from the experimental system, and 31 and 27 focus sows from the standard system, respectively, were semi-randomly selected (i.e., taking into account the sows’ parity number).

The experimental system was composed of an activity and lying area and two ad libitum liquid feeding areas enabling access to an either low- (area A) or high-energy diet (area B). Sows were assigned to one of the two feeding areas based on their weight in relation to their parity, and could enter the feeding area passing through a sorting gate (Hölscher + Leuschner GmbH & Co. KG®, Emsbüren, Germany). Sows could return to the activity and resting areas via a reverse door. This ensured a synchronized feed intake of a maximum of 18 sows in the allocated feeding compartment at all times.

The liquid feed was calculated on the basis of whole plant wheat silage (WPWS). The wheat was sown in 2015 (winter wheat) and harvested as WPWS in July 2016, before being ground and ensiled in a tubular silo. In autumn 2017, the tubular silo was cut, and the WPWS was mixed with water in an external mixing tank. The resulting WPWS-water mixture was pumped into the liquid feed mixing tank in the barn building. In the mixing tank, the feed was mixed with other supplemented feed components (Table 10).

Table 10. Botanical composition of ad libitum feeding (% of DM).

Components	Low-energy diet	High-energy diet
Barley	30.93	48.54
WPWS	51.55	25.89
Soya extraction meal	13.40	21.04
Mineral feed	4.12	4.53

The mineral feed and a feed mix of 30.23% soya extraction meal and 69.77% barley meal were purchased by the farm. Table 11 presents the chemical composition of the low-energy and high-energy feed under ad libitum feeding, as well as conventional pellet feed under restrictive feeding.

Table 11. Chemical composition of the rationed diet (standard system) and ad libitum diets (experimental system) (% of DM).

Analytical components	Rationed diet	Low-energy diet	High-energy diet
Crude protein	17.2	18.5	22.5
Crude fat	4.18	2.18	2.38
Crude fibre	8.48	12.7	9.34
Raw ash	5.9	5.3	5.16
Calcium	0.79	0.76	0.81
Phosphorus	0.8	0.41	0.46
Natrium	0.25	0.15	0.13
Energy (MJ ME/kg TS)	13.31	11.54	13.15

In the experimental system, the diets were pumped via stub lines to the troughs in the respective feeding areas (Hölscher + Leuschner GmbH & Co. KG®, Emsbüren, Germany). Two longitudinal troughs in each feeding area were attached to the wall. The length per trough was 4.5 m without feeding place dividers. A sensor was installed in each trough to measure the filling level: if the level was low, the feed was automatically re-filled. Contrary to the standard system, the floor of the experimental system was visibly soiled with food. The experimental compartment was equipped with negative pressure ventilation with three exhaust air ducts (Stienen Bedrijfselektronica B.V., RT Nederweert, Netherlands), and a partially slatted floor. In the lying area of the sows, as well as in the middle of the compartment in front of the sorting gate, a plain concrete floor was available (Fig. 2). The slatted floor has a slot width of 20 mm.

Figure 2. Floor plan of the experimental system with ad libitum liquid feeding.

Sows under standard restrictive feeding were fed a dry diet (for the chemical composition see Table 11) provided by feed dispensers at a long trough. The amount of feed delivered by the feeders was considered as the amount of feed consumed by the sows, since food was completely eaten on all study days. The standard compartment was equipped with negative pressure ventilation with one exhaust air duct (Stienen Bedrijfselektronica B.V., Ort, Netherlands), and a fully slatted floor with a slot width of 20 mm (Fig. 3).

Figure 3. Floor plan of the standard system with restrictive feeding.

Table 12 presents the main characteristics of the two feeding systems being compared in the study.

Table 12: Main characteristics of the standard and experimental system studied.

	Standard system	Experimental system
Feed type	dry	liquid
Feed access	restricted	ad libitum and group-adapted
Animal-feeding-place-ratio	1:1	4:1 4:1
Group size (average)	44 sows	105 sows
Group management	Stable group	Dynamic group
Animal-place-ratio	2.9 m2 / sow	3.0 m2 / sow

The following indicators were assessed on the focus sows (n_{total} = 114) in the experimental system (n = 56) and in the standard system (n = 58). The body weight was measured at the 31st, 71st, and 109th day of gestation with a mobile animal scale (T.E.L.L. control systems GmbH & Co.KG, Vreden, Germany; weighing range: 65–500 kg).

Scoring of sows' integument was performed at the 31st, 38th, 45th, 52nd, 71st, 94th, and 109th day of gestation. Integument injuries were documented on both sides of the head, neck (from the ears to the back of the shoulders), lateral abdominal wall (from the back of the shoulders to hind-quarters), and hindquarters (according to the Welfare Quality® Protocol, 2009). Depending on the injuries' number and depth, they were classified into four categories:

0, no injuries; 1, low number of superficial injuries (< 5 injuries); 2, medium number of superficial injuries (5–10 injuries) or a low number of deep injuries (< 5 deep injuries); 3, high number of superficial injuries

(> 10 injuries) or medium to high number of deep injuries (> 5 deep injuries). For each sow, eight marks (0–3) were thus documented, and from these, an averaged value of the whole body was calculated to represent the animal degree of injury. This was included in the statistical analysis as “injury index” characteristic feature.

Evaluation of lameness in pregnant sows was performed simultaneously to the integument’s assessment. Depending on the affected limbs, one of the following scores was assigned (according to the Welfare Quality® Protocol, 2009): 0 = physiological gait pattern or small impurities when walking; 1 = asymmetric gait pattern with distinct lameness, with only a minimum of weight on the affected limb; and 2 = distinct lameness with no weight on the affected limb or sow no longer able to walk. When sows were moved to the farrowing compartments, vulva injuries (existent or non-existent) and litter performance (i.e., number of piglets alive, dead and mummified, and litter weight) were recorded.

To record the sows’ behavior (i.e., displacements at the trough and feed intake rhythm), the activity area and the two feeding areas of the experimental system were each equipped with two cameras (Monacor HDCAM-630, Monacor International GmbH & Co. KG, Bremen, Germany; a 2-megapixel HD-SDI color camera with day/night function and 2.8–12 mm varifocal lens). In the standard system with restrictive feeding, a total of three in the first batch and four cameras in the second batch were placed throughout the compartment. After the integument and lameness assessments (31st, 38th, 45th, 52nd, 71st, 94th, and 109th day of gestation), video material was collected for 1 or 2 days of the three following days. The video material was evaluated in both systems with focal sampling between 6:00 and 10:00 (during the feed intake) each day regarding the displacements at troughs between sows. Displacements were considered only when at least one focus animal was involved. Furthermore, in the experimental system, the video material was evaluated with a 20-min time sampling over 24 h regarding the feed intake rhythm. All sows in the system that showed visible chewing movements or had their head above the trough were included in the evaluation.

Data were prepared in Excel 2016 (Microsoft Deutschland GmbH, Munich, Germany), and statistical analyses were carried out with Statistical Analysis System 9.4 (SAS Institute Inc., Cary, USA). The percentage distribution of lameness of the sows in the experimental and standard systems was calculated using the FREQ Procedure. The MIXED procedure was used to examine how the feeding systems affected the body weight, integument injuries (summed as injury index), and litter performance characteristics. The body weight and injury index models included the feeding system (factor with two levels: experimental, standard), batch (factor with two levels: 1, 2), parity class (factor with four levels: 1–4), measurement time-point (factor with seven levels: 1–7), and their interactions as fixed effects. Because of repeated measurements for sows, the sows’ effect was included as a random effect. Since sows from the two feeding systems showed very different initial weights and integument injuries, the weight and injury rate was corrected at the beginning of the study and included as co-variables. The litter performance characteristics contained five models. The litter weight model included the feeding system, batch, and parity class as fixed effects and numbers of weighed piglets as a co-variable. The number of born/born alive/stillborn/mummified piglets’ models included the feeding system, batch, and parity class as fixed effects, and the residuals as random effects. The number of born piglets was additionally included as co-variable (except for the number of born piglets' model). The GLIMMIX procedure was used for the binary traits lameness, vulva injuries, and displacements at a trough. The lameness model included the feeding system, batch, parity class, measurement time-point, and the interaction between the feeding system and time-point as fixed effects. The vulva injuries model included the feeding system, batch, and parity class as fixed effects. The sow body weight, sow initial body weight, and the number of weighed piglets were additionally included as co-variables. The displacements at the trough model included the feeding system, time of day (factor with five levels: 6, 7, 8, 9, 10 h), and their interaction as fixed effects. Due to the small number of sows in higher parities, the focus animals were categorized into four parity classes: 1, second pregnancy (n = 22); 2, third pregnancy (n = 23); 3, fourth pregnancy (n = 19); 4, fifth to eleventh pregnancy (n = 50). Since sows showed very different initial weights and integument injuries in the experimental and standard systems, the weight and injury rate were corrected at the beginning of the study. Since repeated observations were available for the sows for all binary traits, the sow effect was always included as a random effect in the respective model.

Declarations

Ethics approval and consent to participate

The examinations required no announcement or permission with regard to the Animal Protection Law (§ 7, paragraph 2) since no measures inflicting pain, suffering, or injury to these animals were carried out.

Consent for publication

Not applicable

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

EA visited the commercial breeding farm, developed the lameness and integument injuries' scoring, collected and analyzed the data, and drafted the manuscript. MWD performed the statistical analyses and provided support in interpreting the outputs from the data analysis. SF collected the data and calculated the composition of the group-adapted ad libitum feeding sows. EB designed the study and critically revised the paper. NK critically revised the paper. All authors read and approved the final manuscript.

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Figures

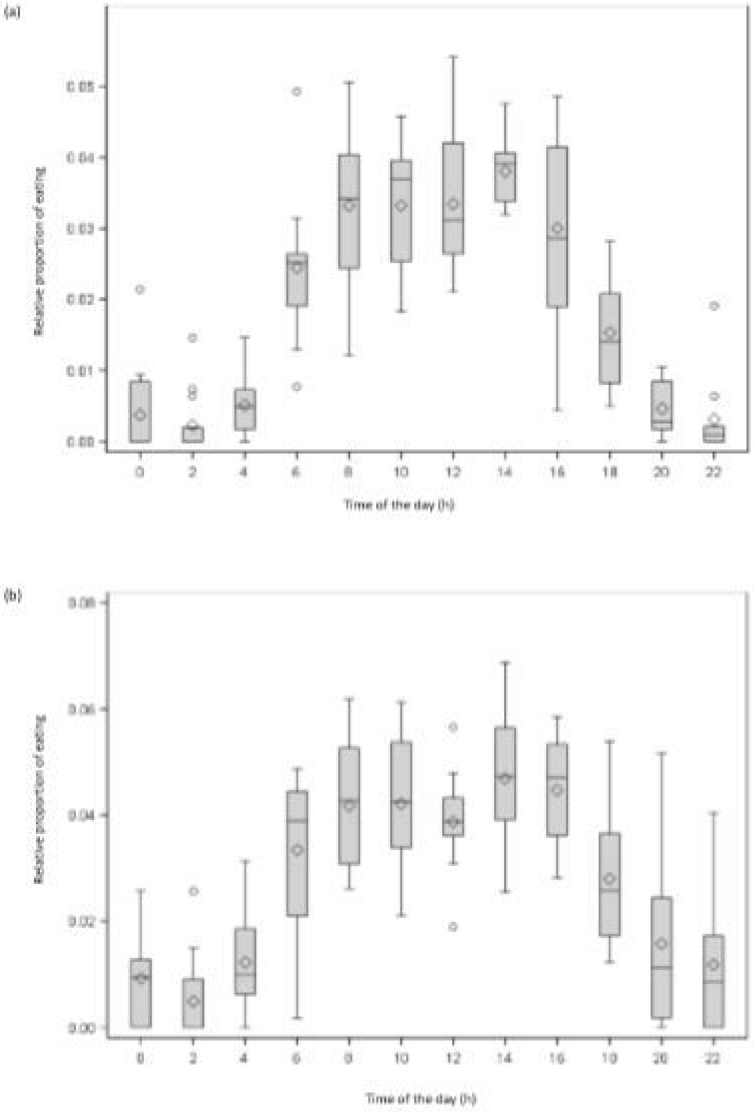

Figure 1

Feed intake rhythm in (a) the low-energy and (b) high-energy diet feeding areas of the experimental system (expressed as the relative part of eating sows from all the sows in the system). Boxplots indicate data range as well as median, and lower and upper quartiles. The diamonds indicate the means. Thick grey lines are the 95% confidence intervals, and the grey circles represent individual sows.

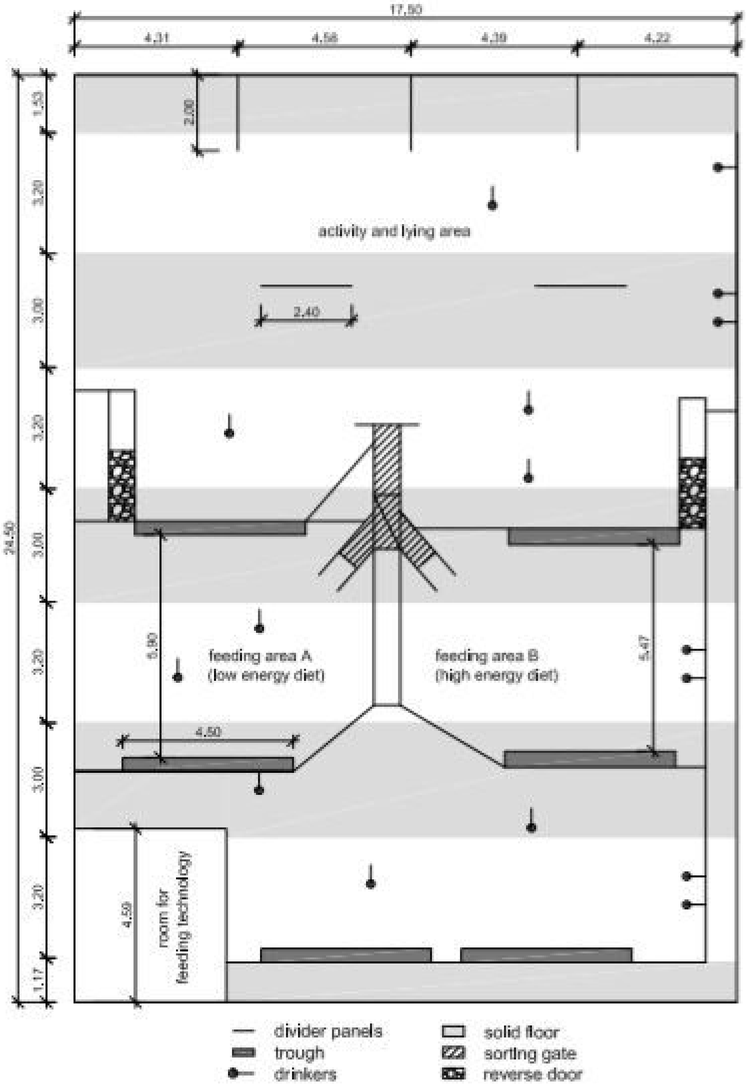

Figure 2

Floor plan of the experimental system with ad libitum liquid feeding.

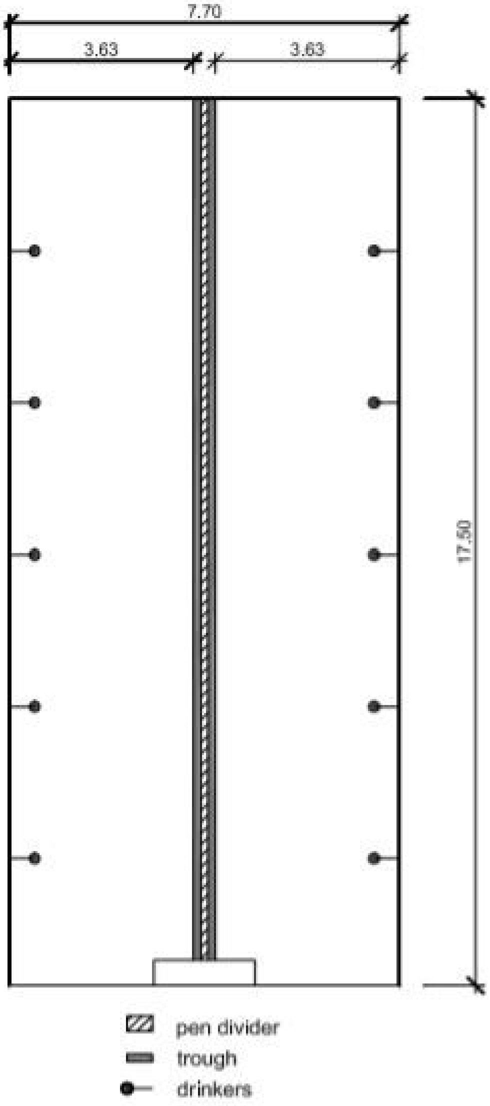

Figure 3

Floor plan of the standard system with restrictive feeding.

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