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Development of a Group-Adapted Housing System for Pregnant Sows: A Field Study on Performance and Welfare Aspects

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Abstract: A Sow-Welfare-Optimized-Feeding (SWOF) system with group-adapted ad libitum liquid feeding was developed to ensure that both optimal nutritional and behavioral needs are met in group-housed pregnant sows. This system comprises functional areas and allows sows to have either a low- or high-energy diet according to their current weight in relation to their parity. This field study aimed to investigate how this new system influences sows' body weight, health status (lameness), aggression parameters (integument injuries, vulva injuries, and displacements at the trough), feed intake rhythm, and litter performance. In parallel, these parameters were also recorded in the existing system (group-housed sows restrictively fed a dry diet). In the SWOF system, the probability of displacements at the trough and occurrence of vulva injuries were reduced, whereas sows could follow a natural biphasic feed intake rhythm. Though lameness scores and litter performance were not affected, lower body weights and more integument injuries were, however, observed. Yet, results can only partially be attributed to the feeding system per se due to confounding effects such as management practices and group size differences (larger dynamic group vs. stable group). Hence, the SWOF system seems promising with regard to animal welfare but remains to be further validated.

Keywords: group housing; pigs; feed intake rhythm; ad libitum feeding; integument injuries; Sow-Welfare-Optimized-Feeding system

Citation: Angermann, E.; Raoult, C.M.C.; Wensch-Dorendorf, M.; Frenking, S.; Kemper, N.; von Borell, E. Development of a Group-Adapted Housing System for Pregnant Sows: A Field Study on Performance and Welfare Aspects. *Agriculture* **2021**, *11*, 28. https://doi.org/10.3390/agriculture11010028

Received: 30 October 2020
Accepted: 30 December 2020
Published: 3 January 2021

1. Introduction

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. To ensure animals with a good welfare, three aspects should be considered: (1) the health and biological functioning, (2) the ability to express a natural behavior, and (3) the affective state [1]. Consequently, in our view, an optimal feeding system for pregnant sows during gestation should (1) provide sows with optimal nutrients allowing the best body condition for farrowing and avoid production-related diseases, as well as (2) enable sows to follow their natural feeding behavior. The main feeding systems for pregnant sows used in Germany during the time of group housing are the restrictive electronic sow-feeding stations (32%) and self-locking feeders (27%) [2]. Yet, these conventional feeding systems do not meet the requirements for a good welfare. 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 [3]. In addition, the feed intake capacity or individual need for satiety cannot be fully met in both systems [4,5]. 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 a natural biphasic feeding rhythm of the sows [6–8]. The sows' welfare is also enhanced by the absence of persistent feeling of hunger [9,10] and the reduced frequency of agonistic interactions, as food competition is minimized [11,12]. However, an ad libitum supply of feed can lead to excessive feed intake and weight gain [4,5,13].

To combine the positive aspects of ad libitum feeding with low variability in the growing performance of group-housed sows, a Sow-Welfare-Optimized-Feeding (SWOF) system with group-adapted ad libitum liquid feeding was developed (Hölscher + Leuschner GmbH & Co. KG, Emsbüren, Germany) and evaluated in a field study. The herein newly developed feeding 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 current weight in relation to their parity, passing through a sorting gate. The aim of this study was to gain first insights into group-adapted ad libitum feeding for pregnant sows under practical conditions. Therefore, the effects on sows' body weight, health status (lameness), aggression parameters (integument injuries, vulva injuries, and displacements at the trough), feed intake rhythm, and litter performance were evaluated. In parallel, data were also collected from the existing system in which group-housed sows were restrictively fed with dry rations. The SWOF system was expected to result in similar weight development, lameness prevalence, and litter performance compared to the existing system, but enable specific biphasic feed intake rhythm and reduce aggressions in sows (i.e., fewer displacements at the trough and injuries).

2. Materials and Methods

2.1. Animals

The study was conducted between January and June 2018 at a commercial breeding farm with 1200 sows (Danish genetic) in Brandenburg, Germany. The production was set to a 1-week-rhythm. Sows were transferred to the group-housing systems approximatively 4 weeks after service.

A total of 114 pregnant sows (second to eleventh parity) were included in this study as focus animals, i.e., measurements were conducted on 58 sows from the existing system (restrictive feeding) and 56 sows from the SWOF system (group-adapted ad libitum feeding). The study was carried out in two successive batches. In the first and second batch, 31 and 27 focus sows from the existing system, and 31 and 25 focus sows from the SWOF system, respectively, were semi-randomly selected (i.e., taking into account the sows' parity number).

This field study was notified to the Saxony-Anhalt Regional Administrative Office (Veterinary Affairs) but required no 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.

2.2. Existing System

In the existing system, sows were kept in a stable group of 46 sows on average divided by the trough in the middle into two groups of 18–25 sows each. Sows stayed on a fully slatted floor with a slot width of 20 mm without functional areas (Figure 1). The compartment was equipped with negative pressure ventilation with one exhaust air duct (Stienen Bedrijfselektronica B.V., RT Nederweert, The Netherlands).

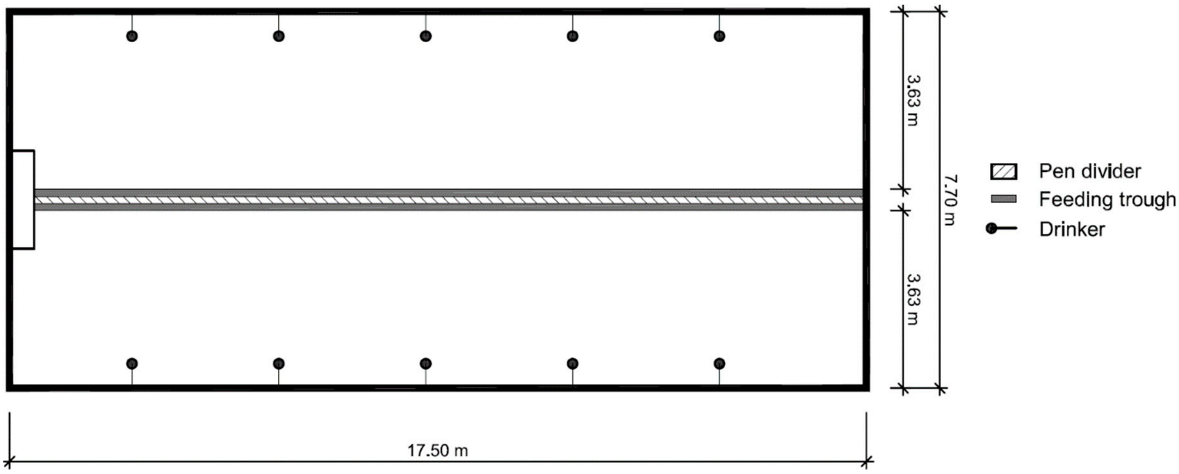

Figure 1. Floor plan of the existing system.

In the existing system, sows were restrictively fed with a dry diet (for details see the diets' description section) provided by feed dispensers at a long trough (Figure 1). The feed was delivered once or twice between 6 a.m. and 10 a.m. The amount of feed delivered by the feeders was considered as the amount of feed consumed by the sows, since no food was visible anymore in the trough.

2.3. SWOF System

In the SWOF system, sows were kept in large dynamic groups of 105 sows on average. During the experimental period, at two time-points 35 days apart, approximatively 40 sows were admitted while 40 other sows exited the compartment. Sows stayed on a partially slatted floor with a slot width of 20 mm. The SWOF system had functional areas comprising an activity and lying area and two ad libitum liquid feeding areas (Figure 2). The SWOF compartment was equipped with negative pressure ventilation with three exhaust air ducts (Stienen Bedrijfselektronica B.V.).

In the group-adapted ad libitum feeding SWOF system, sows had access to either the feeding area A or B (Figure 2). Sows entered the feeding area only passing through a sorting gate (Hölscher + Leuschner GmbH & Co. KG) that assigned them to a low- (area A) or high-energy liquid ad libitum diet (area B) based on their current weight in relation to their parity (for more detail, see Supplementary Table S1). Sows could then return to the activity and lying area via a reverse door. The feed was pumped via stub lines to two 4.5 m long longitudinal troughs (without feeding place dividers and attached to the wall) in each feeding areas. This allowed a synchronized feed intake of a maximum of 9 sows per trough at all times in each feeding area. A sensor installed in each trough measured the filling level and feed was automatically refilled when the level was too low. Although the floor was visibly soiled with food and/or feces, the amount of feed delivered by the feeders was considered as the amount of feed consumed by the sows as the wasted food could not be measured.

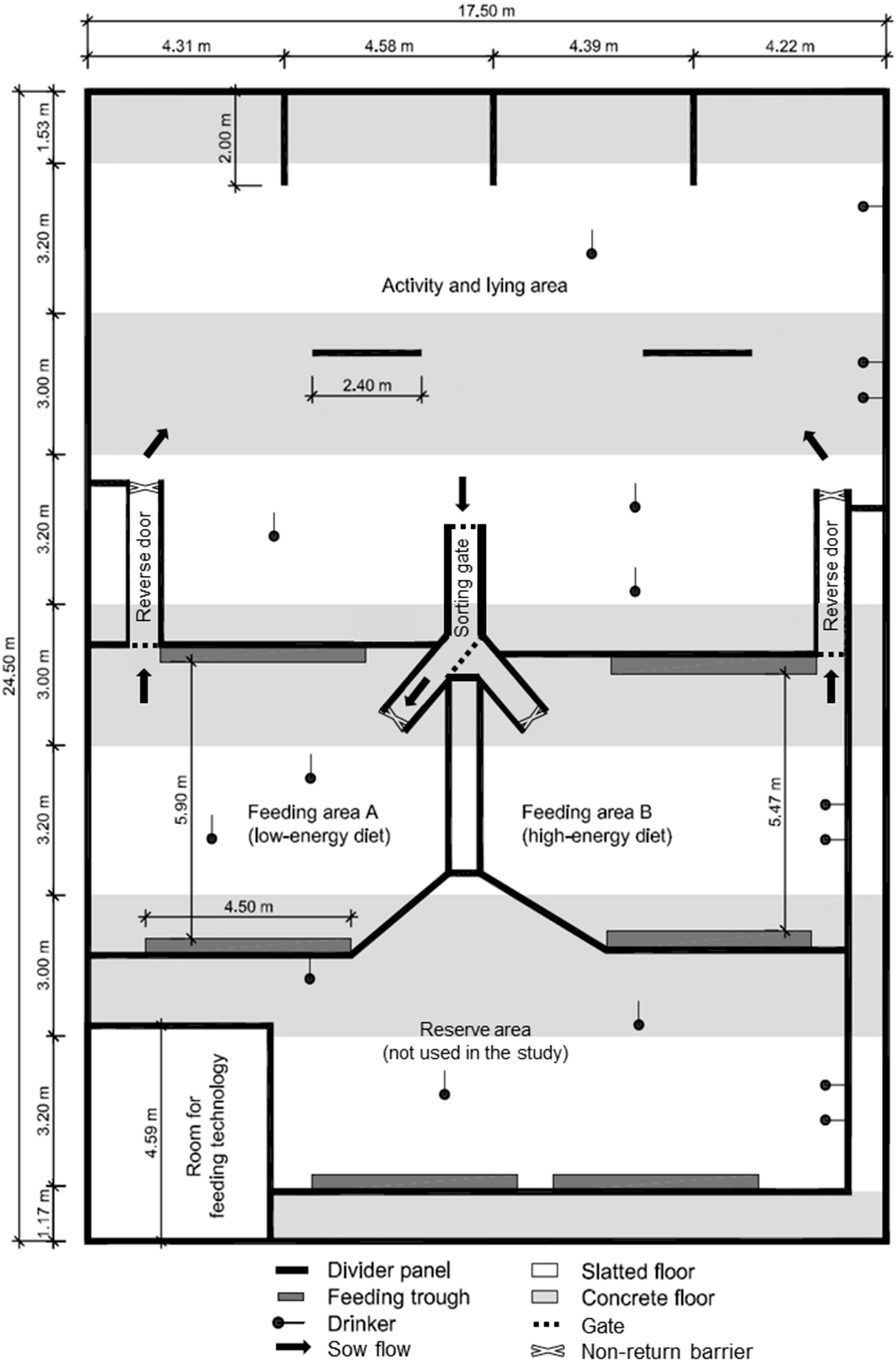

Figure 2. Floor plan of the Sow-Welfare-Optimized-Feeding system.

Table 1 presents the main characteristics of the two systems evaluated in the study.

Table 1. Main characteristics of the existing and the Sow-Welfare-Optimized-Feeding (SWOF) system.

	Existing System	SWOF System
Feed type	Dry	Liquid
Feed access	Restricted	Ad libitum and group-adapted
Animal-feeding-place ratio	1:1	4:1
Group size (on average)	46 sows	105 sows
Group management	Stable group	Dynamic group
Animal-place ratio	2.8 m^2/sow	3.0 m^2/sow

SWOF: Sow-Welfare-Optimized-Feeding.

2.4. Diets' Description

Table 2 presents the chemical composition and energy content of the conventional pellet feed under restrictive feeding (existing system), as well as of the low-energy and high-energy feed under ad libitum feeding (SWOF system).

Table 2. Chemical composition and energy content of the diets in the existing and the SWOF system.

Analytical Components (% of DM)	Existing System	SWOF System	
	Dry 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 fiber	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/kg DM)	13.31	11.54	13.15

DM: day matter.

Conventional pellet feed (NT Vital crumbled pellets, FGL Handelsgesellschaft mbH, Fürstenwalde, Germany) given as a ration in the existing system was purchased.

In the SWOF system, the liquid feed was calculated based on whole plant wheat silage (WPWS). The WPWS was mixed with other supplemented feed components (Table 3) and water with a water-to-feed ratio of 3.5:1 on a dry matter (DM) basis.

Table 3. Botanical composition of ad libitum liquid feeding in the low- and high-energy diets.

Components (% of DM)	Low-Energy Diet	High-Energy Diet
Barley	30.93	48.54
Whole plant wheat silage	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.

2.5. Measurements

Sows' feed consumption in both systems was recorded. In addition, the following indicators were assessed on 114 focus sows, i.e., 58 focus sows from the existing system and 56 focus sows from the SWOF system: body weight, integument injuries, lameness, vulva injury, litter performance characteristics, and displacements at the through. In addition, feed intake rhythm of all the sows in the SWOF system was evaluated.

In both systems, the amount of feed delivered by the feeders was considered as the amount of feed consumed by the sows. Feed consumption is expressed in kg of dry matter (DM) per sow per day. This average feed consumption per sow was estimated based on the total amount of food delivered divided by the number of sows allocated to the feeding area. In the SWOF system, the total amount of food delivered was recorded every day. In the existing system, the feed dispensers were calibrated (to control this calibration, the food delivered was weighed at two time-point during the study period).

The sows' 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 sides (from the back of the shoulders to hindquarters), and hindquarters (based on the Welfare Quality® assessment protocol [14]). 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); and (3) high number of superficial injuries (>10 injuries) or medium to high number of deep injuries (>5 deep injuries). For each sow, eight marks (between 0 and 3) from the eight locations were thus attributed, and from these, an averaged value (between 0 and 3) for each body part and for the whole body (as in [15,16]) was calculated to represent the animal degree of injury. This "whole body" score 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. Sows were observed from the side when walking at least 10 steps on concrete floor. The assessor, a trained veterinarian, was not further than 4 m away and had a clear and unobstructed view of the moving sow as recommending in the Welfare Quality protocol [14]. Depending on the affected limbs, one of the following scores was assigned (based on [14]): 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 injury (existent or nonexistent) and litter performance characteristics, i.e., number of piglets alive, dead, and mummified, and litter weight of piglets born alive as taken within the first 12 h after birth, were recorded.

To record the sows' behavior (i.e., displacements at the trough and feed intake rhythm), three to four 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) were placed throughout the compartment of the existing system. In the SWOF system, the activity and lying area and the two feeding areas were each equipped with two cameras. Two days of video material were collected and evaluated following each assessment of the integument and lameness (on the 31st, 38th, 45th, 52nd, 71st, 94th, and 109th day of gestation). In both systems, displacements at troughs with focal sampling between 6 a.m. and 10 a.m. (during the feed intake) were evaluated from the videos. Displacements were documented (occurred or not occurred) if at least one focus sow was involved. Furthermore, in the SWOF system, the video material was evaluated with a 20 min time sampling over 24 h as regards to the feed intake rhythm. All sows in the feeding area of the SWOF system that showed visible chewing movements or had their head above the trough were included in the evaluation.

2.6. Statistical Analyses

Data were prepared using Microsoft Excel (version 2016, Microsoft Corporation, Redmont, Washington, DC, USA) and statistical analyses were carried out using Statistical Analysis System 9.4 (SAS Institute Inc., Cary, NC, USA). Due to the small number of sows in higher parities, sows were categorized into four parity classes: (1) second gestation (existing system: $n = 10$; SWOF system: $n = 12$); (2) third gestation (existing system: $n = 13$; SWOF system: $n = 10$); (3) fourth gestation (existing system: $n = 10$; SWOF system: $n = 9$); and (4) fifth to eleventh gestation (existing system: $n = 25$; SWOF system: $n = 25$). Because sows from the two systems showed very different initial weights and integument injuries, and to facilitate the comparison, the weight and injury scores were corrected according to first assessments (i.e., 31st day of gestation) and included as covariables in the linear mixed effects models. For the lameness, no initial difference was found between the two systems and therefore no correction was necessary. Nine focus sows were removed from the systems during the period studied due to, e.g., illness or injury, i.e., 4 (batch 1) and 2 (batch 2) sows from the existing system and 2 (batch 1) and 1 (batch 2) sows from the SWOF system. For these sows, measurements for later time-points are, therefore missing for the analyses.

Sow lameness score distribution was calculated for each system using the FREQ Procedure.

The MIXED and GLIMMIX procedures were used for continuous and binary outcome variables, respectively. The models included the system (factor with two levels: existing, SWOF), batch (factor with two levels: 1 and 2), parity class (factor with four levels: 1–4), measurement time-point (factor with seven levels: 1–7), and all the interactions between these variables as fixed effects. F-test of overall significance ($p < 0.05$) were calculated for each model in order to retain meaningful variables and interactions only.

The MIXED procedure was used to examine the body weight, injury index, and different litter performance characteristics. The body weight and injury index models included the system, batch, parity class, measurement time-point, and their interactions as fixed effects, and because of repeated measurements, the sow identity was included as a random effect. The litter performance characteristics were evaluated through five different models. The litter weight model included the feeding system, batch, and parity class as fixed effects and numbers of weighed piglets as a covariable. The number of born/born alive/stillborn/mummified piglets' models included the system, batch, and parity class as fixed effects, the number of born piglets as a covariable (except for the number of born piglets' model), and the residuals as random effects.

Due to low number of severely lame sows (score 2), sows were further considered as either healthy (score 0) or lame (scores 1 and 2) and evaluated as a binomial variable. The GLIMMIX procedure was used for the binary traits lameness, vulva injuries, and displacements at the trough. The lameness model included the system, batch, parity class, measurement time-point, and the interaction between the system and measurement time-point only as fixed effects. The vulva injuries model included the system, batch, and parity class as fixed effects. The displacements at the trough model included the system, time of day (factor with five levels: 6 a.m., 7 a.m., 8 a.m., 9 a.m., and 10 a.m.), and their interaction as fixed effects. Since repeated observations of the sows were made for all binary traits, the sow identity was included as a random effect in all these models.

3. Results

3.1. Feed Consumption

Overall, sows in the SWOF system consumed on average of 4.67 $\pm$ 2.14 kg of DM/sow/day in feeding area A (low-energy diet) and 4.52 $\pm$ 2.03 kg of DM/sow/day in feeding area B (high-energy diet), whereas sows in the existing system consumed on average of 2.54 $\pm$ 0.23 kg of DM/sow/day.

3.2. Body Weight

Initial weights of the focus sows in the existing and SWOF systems greatly differed, though final body weights (at day of gestation 109) were approximately the same in both systems (Table 4).

Table 4. Focus sows' body weight (in kg; mean ± SD) during gestation in the existing and SWOF systems.

Day of Gestation	Weight (kg; Mean ± SD)			
	Existing System		SWOF System	
31	*n* = 56	261.3 ± 53.6	*n* = 58	238.6 ± 41.3
71	*n* = 53	294.0 ± 47.3	*n* = 56	289.0 ± 47.9
109	*n* = 51	317.5 ± 52.0	*n* = 57	313.2 ± 50.1

With *n* = number of focus sows weighed.

After initial body weight correction (at day of gestation 31), sows in the SWOF system were lighter ($p < 0.001$), with on average of 296.4 ± 2.6 kg (least square mean ± standard error (LSM ± SE)), than sows in the existing system, with on average of 310.7 ± 2.5 kg. Sows' weight increases with days in gestation ($p < 0.001$), with on average 290.9 ± 2.0 kg (LSM ± SE) at day 71 and 316.2 ± 2.0 kg at day 109. Parity classes did not seem to have an effect on sows' weight ($p = 0.075$) (with 302.6 ± 4.6 kg (LSM ± SE) in first parity class, 298.9 ± 4.0 kg in second parity class, 312.0 ± 4.0 kg in third parity class, and 300.8 ± 3.1 kg in fourth parity class), but an interaction between the system and parity class was found ($p = 0.007$; see Supplementary Table S2). An interaction between the batch, measurement time-point and system on sows' body weight was also detected ($p = 0.002$). However, no batch effect was found on sows' body weight ($p = 0.288$).

3.3. Integument Injuries and Injury Index

Integument injuries were most frequently located on the neck area, followed by the lateral abdominal sides, then the hindquarters, and finally the head (Table 5). The system had an effect on the sows' injury index ($p < 0.001$), e.g., a higher injury index was observed in the SWOF system compared to the existing system (Table 5).

Table 5. Sows' integument injury score per body part (mean ± SD) and injury index (LSM ± SE) in the existing and SWOF systems.

	Integument Injury Score * (Mean ± SD)				Injury Index (LSM ± SE)
	Head	Neck	Lateral Abdominal Sides	Hindquarters	
Existing System	0.07 ± 0.27	0.94 ± 0.75	0.66 ± 0.75	0.44 ± 0.61	0.54 ± 0.03
SWOF System	0.22 ± 0.46	1.32 ± 0.88	0.98 ± 0.87	0.44 ± 0.59	0.74 ± 0.04

* Based on the observation of 797 injuries, rated between 0 and 3, from the 114 focus sows.

When considering the two systems together, the injury index was affected by the batch (0.72 ± 0.04 (LSM ± SE) in batch 1 and 0.55 ± 0.04 in batch 2; $p = 0.004$) and measurement time-point ($p < 0.001$). The injury index was found to be higher at 38 days of gestation than later in the gestation (see Supplementary Table S3). The injury index was additionally found to be negatively correlated with the sow parity class ($p < 0.01$). The injury index was the highest in parity class 1 [0.77 ± 0.05 (LSM ± SE)] and the lowest in parity class 4 (0.56 ± 0.04 (LSM ± SE); see Supplementary Table S4).

In addition, the interaction between the measurement time-point during gestation and the system had an effect on the injury index ($p < 0.001$). In the SWOF system, the injury index on the 38th day of gestation was higher than in the later measurements (Table 6).

Table 6. Sows' injury index (LSM ± SE) during gestation in the existing and SWOF systems.

Day of Gestation	Injury Index * (LSM ± SE)	
	Existing System	SWOF System
38	0.58 ^{bc,B} ± 0.05	1.13 ^{a,A} ± 0.05
45	0.44 ^{a,B} ± 0.04	0.90 ^{b,A} ± 0.06
52	0.51 ^{b,B} ± 0.04	0.83 ^{b,A} ± 0.07
71	0.53 ^{bc} ± 0.05	0.60 ^{c} ± 0.05
94	0.65 ^{c} ± 0.05	0.56 ^{c} ± 0.06
109	0.51 ^{b} ± 0.05	0.39 ^{d} ± 0.05

* Based on the observation of 679 injuries, rated between 0 and 3, from the 114 focus sows. LSM with different superscript lowercase letters within one column and capital letters within one line are statistically different with $p < 0.05$.

The injury index was not found to be influenced by the interaction of the system with the batch ($p = 0.525$) nor by the interaction of the system with the parity class ($p = 0.284$).

3.4. Lameness

No difference in lameness during gestation was found between the existing and SWOF systems ($p = 0.181$; Table 7).

Table 7. Lameness score probability (in % of focus sows in the system) in the existing and SWOF systems.

Lameness Score (% of Sows *)	Existing System	SWOF System
0—no lameness	93.78	88.08
1—moderate lameness	5.47	10.02
2—serious lameness	0.75	1.90

* Based on the observation of 680 observations from the 114 focus sows.

However, when considering the two systems together, the measurement time-point during gestation had an influence on the lameness score ($p < 0.001$). The highest risk of lameness was found on the 38th day of gestation, with 21.64 ± 4.75% (LSM ± SE) of sows being moderately to seriously lame (see Supplementary Table S5). No general difference in lameness was found with regard to the parity class ($p = 0.071$) nor with the batch ($p = 0.111$).

3.5. Vulva Injuries

The system was found to have an effect ($p = 0.015$) on the occurrence of vulva injuries. In the existing system, 35.77% ± 6.81% (back-transformed LSM ± SE) of the focus sows had a vulva injury, whereas 14.51% ± 4.95% (back-transformed LSM ± SE) of the focus sows in the SWOF system had a vulva injury.

The parity class ($p = 0.570$) and batch ($p = 0.818$) had, however, no influence on the probability of vulva injuries.

3.6. Litter Performance Characteristics

The system had no effect on the sows' litter performance characteristics ($p = 0.344$; Table 8). The parity class ($p = 0.375$) and batch ($p = 0.135$) had no effect either on the litter performance.

Table 8. Sows' litter performance characteristics (LSM ± SE; except for litter weight in kg, mean ± SD) in the existing and SWOF systems.

	n	Litter Weight	Number of Born Piglets	Number of Piglets Born Alive	Number of Stillborn Piglets	Number of Mummified Piglets
Existing System	50	22.14 ± 0.45	20.28 ± 0.62	17.53 ± 0.34	1.94 ± 0.26	1.03 ± 0.25
SWOF System	51	22.74 ± 0.46	21.15 ± 0.63	18.38 ± 0.35	1.36 ± 0.27	0.75 ± 0.26

With *n*= number of focus sows evaluated in each system.

3.7. Displacements at the Trough

An effect of the system and of the time of day was observed on the displacements at the through. Overall, the probability that a displacement occurred was of 74.83 ± 1.93% (back-transformed LSM ± SE) in the existing system and 40.98 ± 0.70% in the SWOF system. The highest probabilities of displacements at the trough were found to occur at 6 a.m. and 10 a.m. in the existing system, i.e., at the beginning and toward the end of the restrictive feeding period (Table 9).

Table 9. Probability of displacements at the trough while feeding in the existing and SWOF systems (in %; back-transformed LSM ± SE).

Time of the Day	Probability of Displacement at the Through * (%)	
	Existing System	**SWOF System**
6 a.m.	80.31 ^{b,B} ± 0.66	40.12 ^{b,A} ± 1.71
7 a.m.	75.16 ^{c,B} ± 1.16	42.59 ^{b,A} ± 1.74
8 a.m.	65.15 ^{d} ± 1.89	44.16 ^{b} ± 1.55
9 a.m.	69.75 ^{d} ± 2.00	51.85 ^{a} ± 1.58
10 a.m.	92.86 ^{a,B} ± 1.78	31.11 ^{c,A} ± 1.63

* Based on 11,638 observations from the 114 focus sows. Data are presented as back-transformed LSM and different superscript lowercase letters within one column and capital letters within one line are statistically different with $p < 0.05$.

3.8. Feed Intake Rhythm in the SWOF System

Contrary to the existing system, in which sows have a restricted access to feed, sows in the SWOF system had a group-adapted ad libitum feed access. This allows to establish their feed intake rhythm over 24 h. The analysis of the feed intake rhythm of all the sows in the SWOF system (i.e., on average 105 sows) revealed a higher activity level in both feeding areas between 6 a.m. and 6 p.m. (Figure 3a,b). When looking at the mean values, it can be graphically seen that sows that can freely access the troughs have an activity peak between 8 a.m. and 10 a.m. (feeding area A) or 6 a.m. and 10 a.m. (feeding area B) and another peak between 2 p.m. and 4 p.m. (Figure 3a,b).

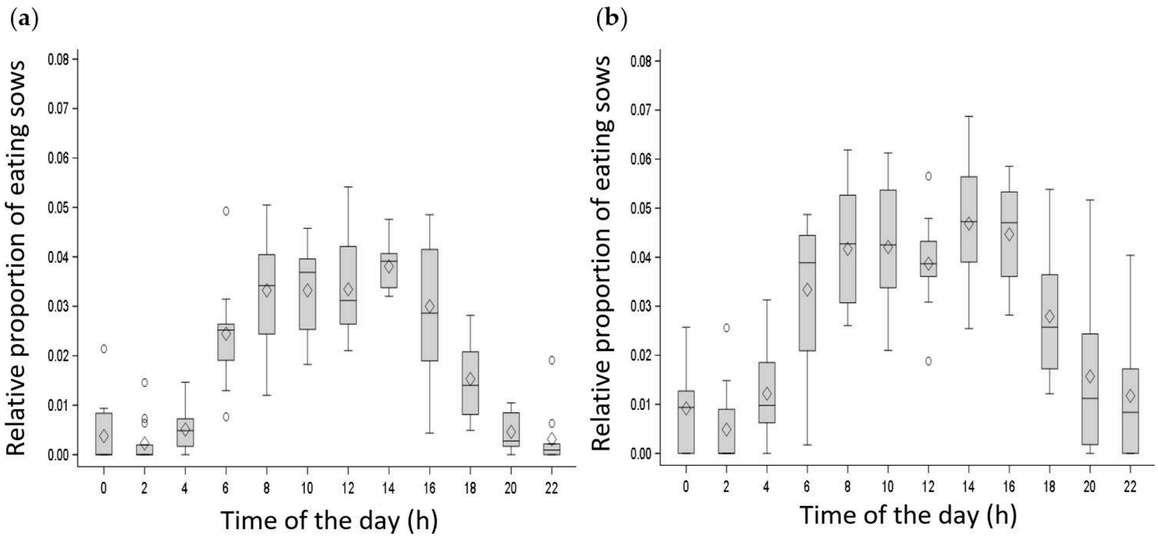

Figure 3. Feed intake rhythm in (**a**) the low-energy and (**b**) high-energy feeding areas of the Sow-Welfare-Optimized-Feeding (SWOF) system expressed as the relative part of eating sows from all the sows in the system. Boxplots indicate data range as well as median and lower and upper quartiles. The diamonds indicate the means. Thick gray lines are the 95% confidence intervals, whereas gray circles represent individual sows.

4. Discussion

The aim of this field study was to evaluate the performance and welfare aspects of sows under a newly developed Sow-Welfare-Optimized-Feeding system (SWOF; i.e., a group-adapted ad libitum liquid feeding system) for group-housed pregnant sows, and to determine whether this system is advantageous compared to the existing system. In particular, the SWOF system was expected to enable a natural biphasic feed intake rhythm, reduce integument injuries, vulva injuries, and displacements at the trough (i.e., aggression parameters), as well as maintain the weight development, health status (lameness prevalence), and litter performance characteristics of the sows. In this on-farm study, animal performance and welfare indicators from two systems differing in terms of diet type (dry vs. liquid diet) and composition, feed access (restricted with a 1:1 place ratio vs. group-adapted and ad libitum with a 4:1 place ratio), group management (small stable vs. large dynamic group), and group size (on average per batch: 46 sows subdivided in two groups vs. 105 sows in one group) were analyzed. Though several confounding factors have, therefore, to be taken into account when interpreting the results, and further experiments controlling for on-farm housing management specificities should thus be conducted, this study is the first, to our knowledge, to gain insights into group-adapted ad libitum feeding for pregnant sows.

Contrary to our expectations, sows in both systems had (after initial body weight correction) different weight developments. Sows in the existing system that were fed restrictively were on average heavier than sows from the SWOF system that were group-adapted ad libitum fed. Though sows in the SWOF system ate almost twice more than sows in the existing system, feed losses could not be measured and an incalculable uncertainty remains as regards to energy and nutrient supply for these sows. Previous studies that investigated pregnant sows' weight development under (nongroup-adapted) ad libitum and restrictive feeding observed higher weight gains in ad libitum fed sows [4,5,11]. The lower (corrected) weight observed in sows in the SWOF system might thus result from the group-adapted diet that could have been inadequate or from the increased activity caused by more rank fights in the dynamic group [16] and the pen structure. Obviously, the measurement time-point had an effect in both systems on sows' body weight: the later the gestation, the higher the weight. It could be further noted that sows in the existing system had higher weights as parity increases, up to the fourth parity, which is in agreement with Ziron [11], who found that weights increase with parity up to the third one. It remains, however, unclear why sows in the SWOF system did not follow this pattern, with lower body weights recorded for sows in their second and fifth or higher parities.

The crude fiber in the silages in the SWOF system led to visible larger amount of feces on the floor [17]. According to Ebertz et al. [18], crude fibers caused more smeared slots on the slatted floor and the increased excrements produced poor floor cleanliness. Contrary to Maes et al. [19], who observed a 2.8 times higher risk of lameness in pens with dirty, wet slatted floors, than in pens with good floor hygiene, we observed no difference of the lameness prevalence between the two systems. Contrary to Willgert et al. [20] who reported higher risk of lameness for younger sows (two parities or less), we did not find a parity effect on lameness. However, we recorded a low lameness prevalence (11.92% in the SWOF and 6.22% in the existing system) in the 114 focus sows studied. Therefore, it is possible that the statistical power might have been too low to detect a difference between the two systems. Previous studies reported similar lameness prevalence in pregnant sows, i.e., between 6% and 17% (for a review, see [21] and [19]). Maes et al. [19] and Bos et al. [22] reported a general higher lameness prevalence in group-housed sows compared to individually housed sows. Bos et al. [22] also observed a higher lameness risk within the first 3 days after grouping sows. When looking at our results, considering both systems, the highest lameness prevalence was detected on the 38th day of gestation, i.e., the first measured time-point after group-housing. This higher lameness prevalence also concurs with higher injury index, and both are assumed to result from increased hierarchy fights due to grouping. Ziron [11] and Pluym et al. [23] drew the same conclusion, the former specifying that rank fights increase the danger of claw injuries that can thus lead to serious foundation problems. Although Bos et al. [22] as well report lower lameness scores in sows housed in static groups compared to dynamic groups (where more hierarchical fights occur), Pluym et al. [23] found no difference.

Concerning the litter performance characteristics, we did not find any effect of the system on the mean litter weight or the number of born, born alive, stillborn, or mummified piglets. This is in agreement with Petherick and Blackshaw [10], Whittaker et al. [13], and van der Peet-Schwering [24] who looked at restrictively vs. (nongroup-adapted) ad libitum fed group-housed pregnant sows. On the contrary, Cools et al. [25] documented a greater number of total born and born alive piglets for sows fed restrictively. Moreover, such as Whittaker et al. [13], we found no effect of the parity on the litter performance, whereas Petherick and Blackshaw [10] observed that sows in their 7th parity and over had fewer born alive and more stillborn piglets compared with sows in their 2nd to 6th parity.

Sows in the SWOF system showed more integument injuries than sows in the existing system, which translated to higher injury indexes. Moreover, these sows were slightly more soiled (with feces) than sows in the existing system, which might have hidden superficial injuries and therefore led to even higher injury indexes. The observed higher number of integument injuries probably result from more frequent and/or intensive confrontations occurring in the SWOF system due to the dynamic group management practices. Indeed, Barnett et al. [26] explain that integument scores can serve as indirect parameters for the extent of agonistic interactions. Sows' social organization is characterized by stable dominance hierarchies [27], therefore, the regular integration of new groups of sows, which requires the formation of a new social group and re-establishment of the dominance hierarchy, might lead to more aggressive behaviors and hence more injuries [16,28,29]. Moreover, in our focus sows, the highest injury index was found on the 38th day of gestation, i.e., 10 days after housing the sows together in a group, which is consistent with other studies [30–34]. In particular, Borberg [33] found that after grouping unknown sows, 78% of all agonistic interactions were completed within 48 h. When grouping growing pigs, Arey and Franklin [31] observed that over 85% of all fights took place within the first 48 h. According to Arey [16], the number of aggressive interactions associated with rank fights fell steadily and reached a stable level 1 week after grouping sows. However, although new groups of sows were admitted twice in the SWOF system during the period assessed, the injury index decreased steadily over time. It should nonetheless be highlighted that the injury index variation range throughout the gestation was broader in the SWOF system compared to the existing system (i.e., 1.13–0.39 and 0.65–0.44, respectively). Finally, it was found that the injury index decreased with increasing parity, which is also consistent with previous studies [33,35,36].

As expected, a lower occurrence of vulva injuries was observed in sows in the SWOF system, which is in line with the lower probability of displacements at the trough observed. Vulva biting is an effective method of displacing sows without being bitten in return [30]. With a restricted feed supply, competition for the limited resource feed becomes a central cause for agonistic interactions, which lead to more injuries and displacement of low-ranking sows [37]. In addition, the lack of partition walls at the trough also leads to more frequent sow displacements [38]. In particular, vulva injuries were mainly seen in systems equipped with electronic sow-feeding stations [39], that were highly attractive, resulting in increased animal encounters and agonistic conflicts [3,40]. Yet, vulva injuries are thought to be reduced by the use of controlled entrance doors. In the SWOF system, an automatic entrance door at the sorting gate was designed to protect the animals from the attacks of other sows, and could explain the lower occurrence of vulva injuries. In addition, Ziron [11] suspected that under ad libitum feeding, the equalization of the competitive situation at the through reduces the number of encounters, as well as the frequency of agonistic interactions. Amon [3] observed that under restrictive feeding, 88.2% of all recorded agonistic interactions between sows of a group occurred in the feeding area.

Kelley et al. [12] also found that pigs fasten for 24 h were engaged in more biting activity than pigs fed ad libitum. Thus, the feed restriction seems to favor the competitive behavior in sows and becomes a central cause for fights.

Contrary to sows fed restrictively, where the onset of restrictive feeding period determined the start of the feed intake [3], sows in the SWOF system had a permanent and ad libitum access to feed and could therefore freely choose their feeding times. Sow feeding reached a main feeding phase between 6 a.m. and 6 p.m. in both (low- and high-energy diets) feeding areas. This is consistent with Brouns and Edwards [41] findings, which observed a main feeding phase between 6 a.m. and 8 p.m. Moreover, we found that these sows, which had free access to the trough at all times, took the opportunity to follow a biphasic feed intake rhythm, as seen in previous studies [6,11]. This biphasic feed intake rhythm is a species-specific and natural feeding behavior in pigs. The ability to behave naturally is an indicator of good welfare [1] and should be taken into account when evaluating a husbandry system.

5. Conclusions

The Sow-Welfare-Optimized-Feeding (SWOF) system resulted in a lower probability of displacements at the trough and occurrence of vulva injuries, as well as the ability for sows to follow their natural biphasic feed intake rhythm. In addition, though the system did not seem to affect the lameness prevalence nor the litter performance characteristics, sows were found to have a lower body weight and more integument injuries. Therefore, while group-adapted ad libitum feeding seems promising for the welfare of pregnant sows, keeping sows in large dynamic groups requires to adapt the husbandry and housing system (e.g., add divider panels) and should be the subject of further research.

This field study aimed to gather first insights into the SWOF system. However, due to the specific on-farm conditions, the effect of the feeding system per se could not be separated from other confounding effects, such as group management practices (e.g., larger dynamic group vs. stable group). As a consequence, the results presented in this study, in particular as regards to the injury index and the low lameness prevalence, remain to be further validated taking into account the group sizes and management practices.

Supplementary Materials: The following are available online at https://www.mdpi.com/2077-0472/11/1/28/s1, Supplementary Table S1. Sorting of the SWOF sows to the low- or high-energy diet according to their parity and body weight (kg), Table S2: Effect of the parity class on focus sows' body weight (in kg; LSM ± SE) in the existing and SWOF systems, Table S3: Sows' injury index (LSM ± SE) during gestation, Supplementary Table S4: Effect of the parity class on sows' injury index (LSM ± SE); and Table S5: Effect of the day of gestation on the percentage of lame sows (in %; back-transformed LSM ± SE). The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions: Conceptualization, E.v.B. and E.A.; methodology, E.A.; validation, C.M.C.R.; formal analysis, E.A. and M.W.-D.; investigation, E.A. and S.F.; data curation, E.A. and M.W.-D.; writing—original draft preparation, E.A.; writing—review and editing, E.A., C.M.C.R., N.K., and E.v.B.; visualization, E.A. and C.M.C.R.; supervision, N.K. and E.v.B.; project administration, E.A.; funding acquisition, E.v.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out as part of the SWOF project. The project was supported by the German Government's Special Purpose Fund held at Landwirtschaftliche Rentenbank (Grant No. 28-RF-3-72.065).

Institutional Review Board Statement: Ethical review and approval were waived for this study, because it was an on-farm field study intending to improve the welfare of pigs. Therefore no ethical statement was required.

Data Availability Statement: The data presented in this study is available on reasonable request from the corresponding author. Data are not publicly available due to privacy reason for the farm involved.

Acknowledgments: We would like to thank H. Nitzer and M. Zühl for their technical support during the experiments, three anonymous reviewers, as well as the staff from the farm where the experiment was conducted.

Conflicts of Interest: The authors declare no conflict of interest.

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