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Recyclable Rubber Flooring in Farrowing Crates and Its Influence on the Development and Welfare of Piglets in the Maternity Phase

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Abstract: To boost productivity in pig production, it is essential to improve the litter size per sow. However, achieving this goal requires reducing newborn mortality rates and increasing their weight gain. In this regard, prioritizing animal welfare and adopting practices that promote sustainability in the activity is crucial. The study aimed to evaluate the sustainable flooring coverage of farrowing crates, considering piglet adaptation, thermal comfort, animal development, and increased productivity. Three types of flooring treatments were defined: T1—wood shavings; T2—solid rubber mat; T3—perforated rubber mat, for 12 litters (±50 animals/treatment). Behavior, physiology, piglet production indices, and facility microclimate were assessed. The facility's microclimate indicated the possibility of cold stress. There was a greater preference for the mat treatments among the animals, as they remained on them for longer periods and showed increased activity in the farrowing crates. The presence of mats resulted in lower mortality due to crushing, positively contributing to production. These findings suggest the potential of using recyclable rubber mats in pig production and encourage the exploration of new designs and installation locations.

Keywords: alternative material; animal behavior; thermal comfort; swine farming

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1. Introduction

Pig farming is an activity of great importance to the world economy, being a vital production sector for the agricultural industry [1]. Pork is the most produced and consumed meat globally [2]. In this sense, this production has been evolving in tandem with the market in the search for satisfactory results in productivity, such as an increase in the rate of piglets born per sow [3] and the continuous development of innovative techniques and the implementation of these solutions [4].

In addition, for this result to be even more satisfactory and economically viable for production, it is necessary to use sustainable resources [5,6], reduce mortality rates [7,8], and increase weight gain per litter [9,10]. Pig farming faces a major challenge related to controlling the environment in which the animals are raised, as well as the issue of waste and its environmental impact on production [11]. In this sense, in order to achieve maximum productivity, animals must be provided with a favorable environment, maximizing their welfare and thus reducing production costs. In relation to the favorable environment for animals, studies on thermal and environmental comfort [12,13], facility microclimate [14], and animal welfare [15] have been highlighted due to the associations of these factors with the physiological responses that animals show and, consequently, with their respective production rates.

Maternity is a critical phase when it comes to the thermal comfort of animals, as the thermoneutrality zone of sows differs from that of piglets. Piglets are born with immature physiological thermoregulatory mechanisms, i.e., they are not developed to meet their thermal needs, requiring the use of artificial sources of thermal energy [16]. One of the ways to overcome this challenge and manage the environment for pre-weaned piglets is to provide a small area of the farrowing pen that best meets their thermal needs [17], which is the pen, which has the function of providing shelter and thermal energy to the piglets in an artificial way. The heat sources offered to piglets during pre-weaning allow them to be offered a warmer microenvironment to meet their thermal needs, while at the same time attracting them away from the sow to reduce incidences of crushing [18].

The internal temperature of the pens must be rigorously controlled, as the thermal comfort temperature range varies from 32 to 34 °C for newborn piglets and from 24 to 29 °C for weaned piglets [19]. In addition to temperature, parameters such as relative air humidity are essential to establish criteria that characterize this comfort [20]. From this perspective, several thermal indices have been developed and are used to assess thermal comfort in pigs, including enthalpy and the temperature–humidity index [21].

In addition to environmental conditions, it is crucial to pay attention to the flooring where these animals will be housed, as it can cause variations that exceed the upper range of thermal comfort, leading piglets to choose to stay outside the pen, consequently resulting in hypothermia. Ref. [17] emphasizes that, regardless of the type of flooring, providing a comfortable insulating surface in the piglets' resting area will minimize the loss of heat conducted by the piglets, which can contribute to mitigating hypothermia and reducing animal mortality.

With the growing market demand for products with low environmental impact [22] and the need for research on the thermal comfort of production animals [23], this study aims to combine these factors by using wood shavings and recycled rubber as mats in pens for newborn piglets. Wood shavings are a sustainable material that helps maintain the environmental comfort of piglets. Recycled rubber, on the other hand, offers various benefits: it is a durable product that absorbs impacts and allows for thermal insulation [24], and it can also have a soft consistency, which can make the environment more comfortable for the animals.

Therefore, the aim of this research was to evaluate the efficiency of covering the floor of pens with ecological rubber compared to using conventional flooring, with the aim of identifying the best adaptation for piglets, observing thermal comfort and, consequently, animal development and increased productivity.

2. Materials and Methods

2.1. Study Location

The experiment was conducted on a commercial pig farm, which produces piglets up to the nursery stage, from July to August (winter) 2015. The property is located in the municipality of Mogi-Mirim, SP, Brazil, with geographical coordinates of 22°32′37″ latitude and 46°58′15″ longitude, and a 607 m altitude. According to the Köppen classification, the region's climate is considered to be humid subtropical (Cfa). It is worth noting that two weeks before the start of the study, equipment calibration and experimenter training were conducted for the behavioral and physiological assessment, first-day handling, and piglets cleaning management on animals prior to those used in the study, as well as becoming acquainted with and adapting to the farm's work routine.

2.2. Facilities

The maternity shed was 15.0 m long and 10.0 m wide, with a ceiling height of 3.5 m. It had a pitched roof, covered with French ceramic tiles and 0.60 m eaves. The shed was constructed of masonry walls, with a 2.0 m opening on the sides, delimited by a screen extending the entire length of the room, with a 1.50 m high sill (Figure 1). The side curtains remained closed during the morning and evening and was opened only from 12 noon to 3 pm.

Figure 1. Interior view of the maternity shed room on the property.

The stalls were divided with wooden tops and concrete floors, partially covered with hollow plastic flooring on the sides of the stall. The stalls had the following dimensions: 1.8 m wide, 2.7 m long, and 1.20 m high, totaling 4.86 m^2. The sows were housed randomly in each pen. The pens were made of masonry with a wooden lid (0.52 m $\times$ 1.12 m) with a central door measuring 0.25 $\times$ 0.55 m, so that the piglets' behavior could be assessed inside the pen. Heating was provided by mixed 220-volt, 160-watt lamps. The animals' heating system was activated according to the curtains, i.e., only switched off between 12 pm and 3 pm. In addition, the feeding troughs for the piglets and sows were made of masonry and the drinking troughs for the piglets were nipple-type and for the sows were made of masonry.

2.3. Treatments

The analysis of the three types of cover for hatcheries (Figure 2) was carried out with the following treatments: Treatment 1—concrete floor covered by wood shavings; Treatment 2—floor covered by one-piece recyclable rubber matting; and Treatment 3—floor covered by hollow recyclable rubber matting, with each treatment consisting of 4 replicates, totaling 12 experimental stalls, being randomly distributed in the maternity rooms.

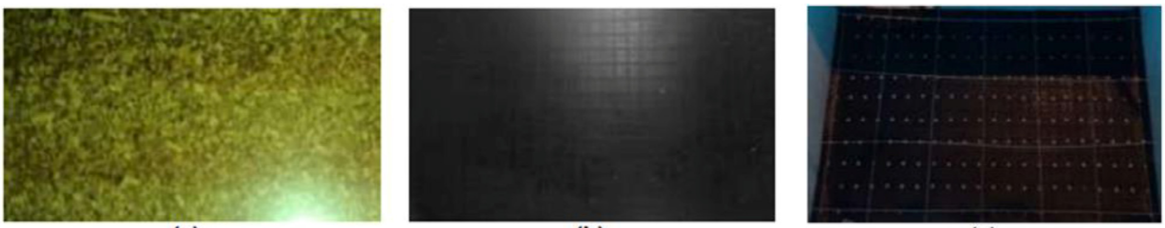

Figure 2. The floor of the shelter covered with wood shavings (**a**), a one-piece recyclable rubber mat (**b**), and a hollow recyclable rubber mat (**c**).

2.4. Animals

This research was approved by the Ethics Committee on Animal Use (CEUA) of the Luiz de Queiroz College of Agriculture, University of São Paulo (Esalq/USP), under protocol number 2015-4. Animals from the Pernalan $\times$ Dalland crossbreeding were used. Twelve sows were selected, with four sows per treatment, from those available at the experimental farm. They were chosen under normal health conditions, with homogeneous ages and weights, and with a parity order between 1 and 3 (number of births the sow has had) in order to maintain homogeneity between treatments. Piglets were relocated based on number of animals per litter, ensuring that all pens contained the same fixed number of 12 piglets per litter, totaling 48 piglets per treatment and 144 in the experiment. The mean birth weight of the piglets was 1.34 ± 0.29 kg. Sows during the maternity period were fed according to farm management practices. Feed was provided in the morning and evening, and only from the seventh day of the study onwards for piglets.

2.5. Microclimate Variables

To characterize the microclimate of the facilities, dry bulb temperature and relative humidity data were collected every 15 min throughout the experimental period. To do this, the hatching shelters and the maternity room were equipped with a HOBO® model H08-00X-02 datalogger (Onset, Bourne, MA, USA). Each datalogger was installed inside the cages in the center of each wooden lid at a height of 0.55 m. Three dataloggers were installed throughout the maternity room, in the central area, evenly distributed at a height of 1.5 m.

Using the microclimate data records, the specific enthalpy of air (Equation (1)) [25] and the temperature and humidity index (*THI*) (Equation (2)) [26] were calculated.

$$h = 1.006.t + \frac{RH}{PB} 10^{\left(\frac{7.5t}{237.3+t}\right)} \cdot (71.28 + 0.052t) \quad (1)$$

$$THI = t + 0.36Tdp + 0.42 \quad (2)$$

Definitions are as follows: h = specific enthalpy (KJ/kg of dry air); t = ambient temperature (dry bulb) (°C); PB = local barometric pressure (considered the value of 706.79 mmHg); RH = relative humidity (%); Tdp = dew point temperature (°C).

2.6. Piglet Behavior

For the piglets' behavior, the posture and frequency of each sow's piglets were evaluated. The piglets were individually identified by tags, either inside or outside the creep areas, for subsequent analysis of the efficiency of different types of creep area covers and their correlation with thermal comfort and welfare. An ethogram was drawn up (Table 1), adapted from studies [27–31] in addition to observations made in a pre-experimental period, on a batch of animals housed in the maternity room in a period prior to the start of the studies.

Table 1. Work ethogram drawn up for piglet behavior analysis.

Behavior	Activity	Description
Physiological	Physiological (1)	Piglet awake, standing or lying on the sow's udder, displaying sucking movements or engaged in competition for teat access.
	Eating (1)	Piglet standing near the feeder, chewing.
Maintenance	Near the mother (1)	Piglet lying, awake or sleeping, near the mother, with some part of the body close to the sow.
	Huddled near the mother (1)	Piglets lying, awake or sleeping, huddled together, with parts of their bodies in contact with each other and with the sow.
	Huddled away from the mother (1)	Piglets lying, awake or sleeping, huddled together, with parts of their bodies in contact with each other, without contact with the sow.
	Huddled near the light (2)	Piglets lying, awake or sleeping, huddled together, with parts of their bodies in contact with each other. Underneath the light.
	Crouched alone (1,2)	Piglet lying in ventral recumbency alone, awake or asleep, with all four limbs tucked close to the body, without any contact with other animals.
	Huddled away from the light (2)	Piglets lying, awake or sleeping, huddled together, with parts of their bodies in contact with each other. In the background, away from the light.
	Stretched out alone (1,2)	Piglet lying in lateral recumbency, alone, awake or asleep. Without any contact with other animals.
	Lying uniformly (1,2)	Animals lying down, awake or sleeping, stretched out or curled up, either close to each other or not, but not huddled together.

Table 1. *Cont.*

Behavior	Activity	Description
Social	Interacting (1,2)	Piglets standing or sitting awake. Interacting with other piglets or the environment.
Outside the farrowing crate (1); Inside the farrowing crate (2)		

The behavioral assessment schedule was adjusted according to the other assessments, due to the piglets' farrowing schedule. The behavioral assessments took place on the 10th, 12th, 14th, 16th, 20th, 23rd, and 26th days of the experiment. The records were taken using the sweep method (recording the behavior of all individuals in the enclosure at the defined moment) by a single trained researcher. The observation periods were divided into morning (8:00 to 11:00 am), afternoon (12:00 to 3:00 pm), and evening (4:00 to 6:00 pm); the recordings took place every hour, totaling eleven daily collections. The choice of periods was based on the expectation of different behaviors influenced mainly by environmental variables.

2.7. Physiological Assessments

For the evaluation of physiological parameters in piglets, five animals were randomly selected from each pen on the 15th and 20th day of the experiment. This selection was balanced between male and female piglets. Records of ocular and auricular temperatures were taken at three time points during the day: 7:00 am, 2:00 pm, and 6:00 pm. Images of lesions were captured after the last temperature recording. The physiological assessments in this study aimed to evaluate the comfort condition or heat stress, and lesions of the piglets.

The recording of ocular temperature, auricular temperature, and lesions in piglets was carried out through images captured using a FLUKE® thermal camera, model Ti29 (Fluke, Everett, DC, USA). For ocular temperature, the images were captured at a distance of 0.25 m from the target (right eye, with the point of interest at the lacrimal caruncle) with an emissivity of 0.98 [32]. For auricular temperature, the images were captured at a distance of 0.25 m from the target (ear, tympanic region) with an emissivity of 0.98, following the manufacturer's recommendation for measuring temperature in biological tissues. For the analysis of animal lesions, images were captured at a distance of 1 m from the target, with an emissivity of 0.95 [33], collecting two images per animal in the tarsal and carpal regions, on the left and right sides.

Additionally, a FLUKE® infrared thermometer, model 566, was used at a distance of 0.30 m from the target point for recording tympanic auricular temperature [34], with an emissivity of 0.98, as recommended by the manufacturer.

The captured images were subsequently generated and analyzed (Figure 3) using SmartView® software version 3.14. For image analysis, the eclipse marker tool from SmartView® software was utilized, obtaining values for maximum temperature (Tmax), minimum temperature (Tmin), and mean temperature (Tmean) [35,36].

2.8. Performance of Piglets

The performance analyses involved the initial and final weight of the piglets, the average daily weight gain, and the number of piglet deaths per treatment during the experimental period. To facilitate weighing of the animals, a plastic box was used on the Toledo model 2098 digital scale, properly calibrated before each weighing. Each animal was identified according to the treatment using adhesive tapes.

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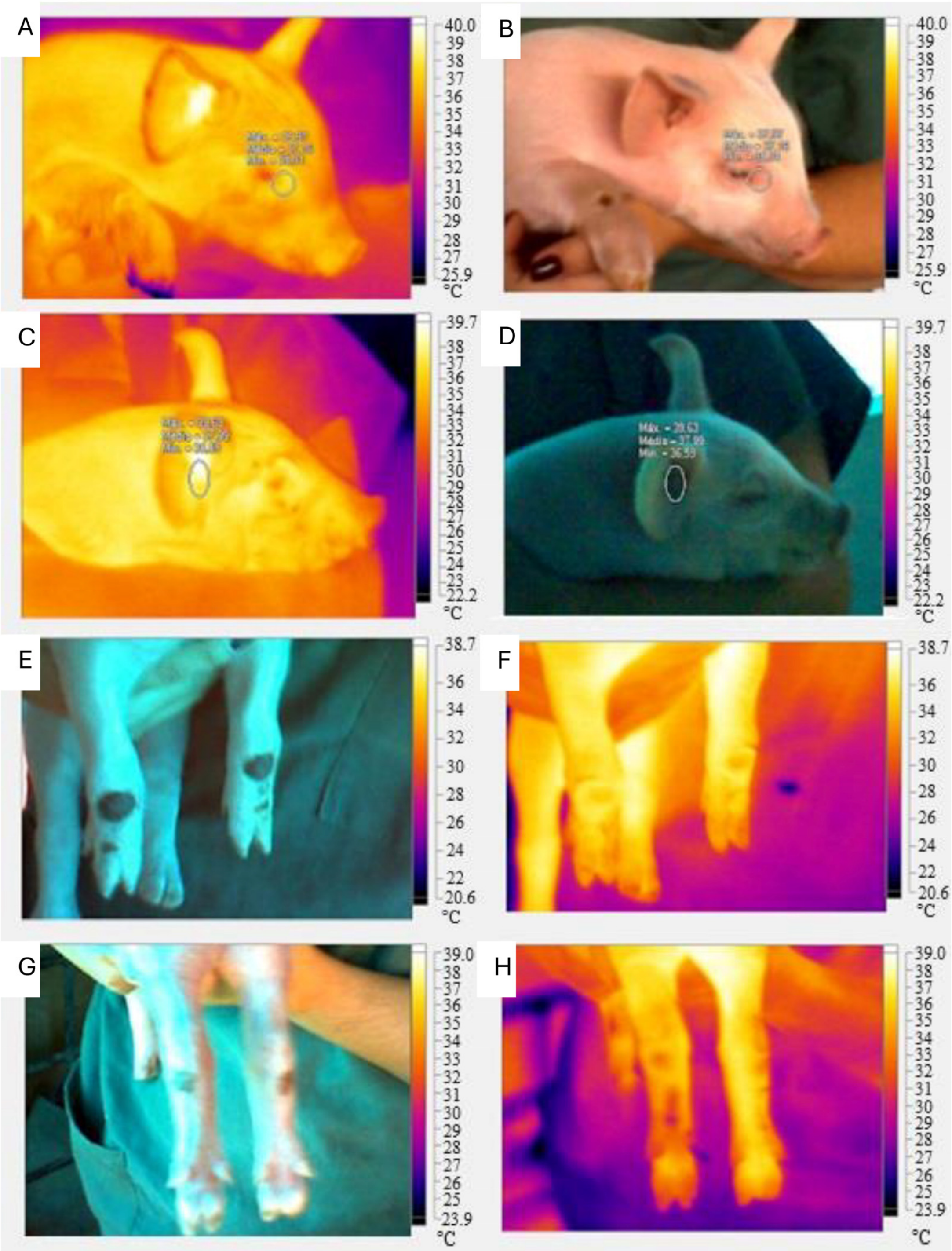

Figure 3. Right lateral view of the piglet for the lacrimal caruncle region in the thermographic image (**A**) and visual image (**B**). Right lateral view of the piglet for the auricular region in the thermographic image (**C**) and visual image (**D**). Visual image of the front limbs (**E**) and thermographic image of the front limbs (**F**). Visual image of the hind limbs (**G**) and thermographic image of the hind limbs (**H**).

2.9. Statistical Analysis

The experimental design adopted for thermal comfort indices and piglet behavior was a randomized block design (RBD), with different collection days representing the blocks and the experimental unit being the pen. As for physiological and performance evaluations, the experimental design adopted was a completely randomized design (CRD), with piglets being the experimental unit. Meanwhile, the experimental design adopted for physiological and performance assessments was a completely randomized design (CRD), with piglets being the experimental unit. Due to being a count, behavioral variables were subjected to transformation using Square Root(y + 0.5) and Log(y + 1). For all variables, an analysis of variance (ANOVA) was performed. For those with statistically significant differences, means were compared using the Tukey test at a significance level of 5% using SAS.

3. Results and Discussion

3.1. Installation Microclimate

In Table 2, it is possible to observe that both enthalpy and THI showed statistical differences among treatments. The floor covered with perforated rubber (T3) displayed the highest values of enthalpy and THI, while the floor covered with wood shavings (T1) showed the lowest values statistically.

Table 2. Mean values of enthalpy (kJ/kg of dry air) and THI recorded in treatments T1 (wood shavings), T2 (solid rubber mat), and T3 (perforated rubber mat) in the experimental period.

Treatments	Enthalpy	THI
T1	59.79 b	74.20 b
T2	61.12 ab	74.91 ab
T3	62.66 a	75.20 a
p value	0.0007	0.0123

Means followed by different letters differ statistically from each other ($p < 0.05$) by the Tukey test between treatments.

From the enthalpy perspective, it highlights a situation below the thermal comfort zone of the piglets, characterized by values below the lower limit compared to the thermal comfort zone range defined by [34] (68.40 to 91.20). The enthalpy values presented were above the thermal comfort zone range compared to the enthalpy values (48 to 56) reported by [37] in a study conducted with piglets in the nursery phase (35 days). The same authors report that values above the range of 56–80 indicate that the animals are in a state of alert.

For animals to express their productive potential, they must be kept within the thermal comfort zone [38], which is defined as the optimal ambient temperature range for the animal, without minimal thermoregulatory effort required for the animal to adapt to the environment. Thermal stress in the early life of piglets can affect the intestinal health of the animals [39], leading to a decline in immune function, making them susceptible to gastrointestinal diseases, respiratory system issues, and swine diarrhea, directly interfering with growth and consequently causing losses in productivity.

The THI values ranged from 74.20 to 75.20, which could be considered within the comfort zone for piglets. Ref. [40] considers recommended THI values for piglets in the first week of life to be within thermal comfort between 83.5 and 87.6, with critical values being below 66.4 and above 92.1. However, Ref. [20] suggests that THI values between 61 and 65 provide better comfort for sow litters. In general, even though there were statistical differences among the treatments, the results showed that all of them fell within the same comfort range, meaning they promoted an environment ranging from comfortable to mildly cold-stressed, as recommended for pre-weaning piglets. Therefore, it would be necessary to use other lamps that generate more heat to maintain these animals, which would promote more comfort and contribute to improvements in productive performance.

3.2. Animal Behavior

Physiological behaviors were classified when piglets were eating or suckling, with no significant differences between treatments for these variables. It is worth noting that the mean values of eating behavior frequency were 2.33, 3.85, and 4.23 for the H1, H2, and H3 periods, respectively. Similarly, the mean values of suckling behavior frequency were 59.66, 106.19, and 153.05 for the H1, H2, and H3 periods, respectively. Furthermore, the frequency of behaviors such as huddling near the light (APL) and huddled alone (ENCOS2) also did not show significant differences between treatments in different periods. The mean values of APL were 25.43, 29.33, and 25.62 in the H1, H2, and H3 periods, respectively. Meanwhile, the mean values of ENCOS2 were 5.76, 7.09, and 8.14 in the H1, H2, and H3 periods, respectively.

Throughout the experiment, it was observed that a portion of the animals preferred to spend a significant amount of time suckling rather than engaging in other types of behaviors. Similar to the findings of this study, Ref. [41] concluded that piglets in the maternity phase spend 47.49% of their time outside the farrowing crate, with this time divided into suckling (33.77%), other activities (18.28%), interacting (0.35%), eating (0.057%), and drinking (0.047%). According to [42], in their natural habitat piglets may suckle up to thirty times a day. During this maternity phase, they spend a large part of their time suckling/massaging the mother's udder.

Table 3 presents the behaviors of animals huddled near the mother (APM), huddled away from the mother (ALM), huddled alone outside the farrowing crate (ENCOS1), huddled away from the light (ALL), stretched out alone outside the farrowing crate (ES1), stretched out alone inside the farrowing crate (ES2), interacting outside the farrowing crate (I1), and interacting inside the farrowing crate (I2) for the different treatments in the periods.

Table 3. Frequency of behaviors recorded in the maternity room for the treatments in different periods.

Periods	**H1**				**H2**				**H3**			
Treatment	**T1**	**T2**	**T3**	***p* Value**	**T1**	**T2**	**T3**	***p* Value**	**T1**	**T2**	**T3**	***p* Value**
APM	22.71	15.71	20.28	0.1560	47.14	38.00	38.85	0.1065	71.00 a	62.00 ab	49.85 b	0.0216
ALM	15.57 a	8.42 ab	3.00 b	0.0245	42.85	37.00	28.57	0.0519	68.43 a	65.57 ab	43.14 b	0.0014
ENCOS1	7.00	4.14	3.57	0.0522	17.28	10.71	6.85	0.0585	23.00 a	19.71 b	7.71 b	0.0253
ALL	15.85	25.85	19.28	0.0716	15.85	30.57	23.85	0.0652	16.42 b	33.14 a	25.57 ab	0.0318
ES1	14.57 a	6.71 b	11.42 ab	0.0364	58.28 a	50.00 ab	27.57 b	0.0008	115.86 a	56.14 b	70.29 b	0.0001
ES2	22.57 b	30.28 ab	34.71 a	0.0255	30.71 b	50.00 a	55.71 a	0.0097	30.00 b	66.57 a	67.85 a	0.0157
I1	51.00 a	31.28 b	37.14 ab	0.0001	89.14 a	69.28 b	64.28 b	0.0035	111.57 a	89.14 ab	72.00 b	0.0003
I2	13.00 b	19.85 ab	21.57 a	0.0318	20.28	24.85	29.57	0.7664	22.14	27.00	32.00	0.8873

Means followed by different letters differ statistically from each other ($p < 0.05$) by Tukey's test among treatments at different times; APM—huddled near the mother; ALM—huddled away from the mother; ENCOS1—curled alone outside the pen; ALL—huddled away from the light; ES1—stretched alone outside the pen; ES2—stretched alone inside the pen; I1—interacting outside the pen; I2—interacting inside the pen; T1—wood shavings; T2—solid mat; T3—perforated mat; H1—7:00 AM to 11:00 AM; H2—12:00 PM to 3:00 PM; and H3—4:00 PM to 6:00 PM.

In the behavior of clustering near the mother (APM), there were no statistically significant differences between the morning (H1) and afternoon (H2) periods. However, during the night (H3) period, APM behavior was observed 29.78% more often in the treatment with bedding covered with wood shavings (T1) compared to the treatment with flooring covered with perforated rubber (T3), being significantly higher than the latter, and equal to the treatment with flooring covered with solid rubber (T2). This may have occurred because the rubber floors were more comfortable for the piglets during the colder period, which is consistent with the values found in the THI for the perforated rubber floor, which showed the highest values, indicating a warmer environment for the animals.

The behavior of clustering away from the mother (ALM) showed statistical differences between the treatments of bedding covered with wood shavings and bedding covered with solid rubber during the morning and night periods, such that the values presented by T1 were higher than those presented by T3 and significantly equal to the treatment of flooring covered with solid rubber.

In the morning and afternoon periods, the behavior of animals curled up alone outside the creep area (ENCOS1) did not show significant differences between treatments. However, during the night period, ENCOS1 behavior in the treatment with bedding covered with wood shavings was significantly higher compared to treatments with flooring covered with solid rubber and flooring covered with perforated rubber.

Upon observing the count values, a higher frequency of behaviors (APM, ALM, ENCOS1) was found in the treatment with bedding covered with wood shavings (T1).

Several hypotheses may explain the frequency of these behaviors, such as the high humidity observed by the researcher inside the creep area during the experiment and the enthalpy values below the thermal comfort zone limit (68.40 to 91.20) for piglets, indicating cold stress. According to [17,43], piglets outside their thermal comfort zone, experiencing cold stress and seeking a heat source, tend to huddle together and/or stay closer to the sow, increasing the risk of death from crushing.

For the behavior of clustering away from light (ALL), there was no difference between treatments during the morning and afternoon periods. However, during the night period, the treatment with bedding covered with wood shavings differed from the treatment with flooring covered with solid rubber, with the frequency of the ALL behavior being 50.45% higher in treatment T2.

During the experiment, it was observed that animals in the treatment with flooring covered with solid rubber mats remained inside the creep area for most of the time, indicating the creep area as the most comfortable spot. In their studies, [44] evaluated the behavior of piglets in different types of heating sources within creep areas, and found that animals choose their resting location based on the level of thermal comfort. In lower ambient temperatures, animals tend to stay closer to the heat source, while in higher temperatures they tend to seek locations away from the heat source.

In the behavior of animals stretched out alone outside the creep area (ES1), the treatment with bedding covered with wood shavings showed a 53.94% higher frequency when compared to the treatment with flooring covered with solid rubber mats during the morning period. In the afternoon period, there was a difference in the frequency of the ES1 behavior between treatment (T1) ($\geq$52.69%) and the treatment with flooring covered with perforated rubber mats (T3), and during the night period, treatment (T1) significantly differed from the other treatments. Thus, there is evidence of a higher frequency of animals from the treatment with bedding covered with wood shavings outside the creep area during period H3.

The behavior of lying stretched out alone inside the creep area (ES2), indicative of discomfort, showed significant differences across all three periods between treatments T1, T2, and T3. Animals in treatment T1 were found to maintain a lower frequency inside the creep area compared to treatment T3 ($\geq$65.02%) during the morning and afternoon periods and compared to T2 ($\geq$55.12% and $\geq$57.47%, respectively) during the night period.

This behavior of lying stretched out alone, indicative of discomfort, may suggest that piglets, when above the limit of their thermal comfort range and exposed to heat, tend to exhibit such behavior, either lying side by side, spaced out, or alone. High temperatures on the creep area floor can directly influence the thermal comfort of the animals [17], as piglets tend to spend most of their time lying down inside the shelter, thus maintaining a larger area for heat exchange between the animal and the floor, causing discomfort and reducing the frequency and duration of the animals inside the shelter. This situation can pose risks, as piglets experiencing cold stress in areas outside the shelter tend to seek heat sources near the mother, which can increase the likelihood of death by crushing. It was observed that this characteristic was more common with the wood-shaving flooring.

The maintenance behavior of animals lying uniformly did not show differences between treatments, with average values of 9.71, 10.09, and 11.57 for the times H1, H2, and H3, respectively. According to [45], piglets within their thermoneutral zone tend to stay grouped together, while piglets exposed to heat may lie side by side, spaced out, or alone.

In the behavior of interaction outside the creep area (I1), during the morning period, T1 was significantly higher than the treatment with flooring covered with solid rubber mats, and during the night period it was significantly higher than the treatment with flooring covered with perforated rubber mats. In the second period (H2), treatment (T1) was significantly higher than the other treatments.

The behavior of interaction inside the creep area (I2) showed no statistical difference during the afternoon and night periods between treatments. However, during the morning period the treatment with flooring covered with perforated rubber mats was significantly higher than the treatment with bedding covered with wood shavings.

According to [28,46], piglets from the tenth day of age spend most of their time in social contact with other piglets, interacting, sniffing, and exploring the environment. It is noticeable that the behavior of interaction outside the creep area (I1) showed a higher frequency probability in all periods in the treatment with bedding covered with wood shavings (T1), while the behavior of interaction inside the creep area (I2) tended to be higher in the treatment with flooring covered with perforated rubber mats (T3). These facts indicate that the type of flooring influences the interactions of the animals inside and outside the farrowing crate. Consistent with other observed behaviors, it was noted that on the wood-shaving flooring, piglets spent more time outside the farrowing crate and near the mother, while on the rubber flooring the opposite was observed.

According to [47,48], piglets at approximately 10 days of age begin to become more independent. During this phase, they spend most of their time interacting with other animals and exploring the environment, gradually reducing their contact with the sow and developing social and feeding independence to the point where they no longer rely on the mother.

Monotonous environments, lack of substrates, or insufficient space can lead to frustration in piglets, which may result in the execution of stereotyped behaviors [49]. In a study conducted with piglets, [50] compared the behavior of animals raised on straw bedding and concrete flooring during the growing phase. They observed that the rooting behavior was higher in the treatment where animals were housed in pens with concrete flooring. This is because the act of 'rooting' encompasses the entire behavior of 'excavation,' whether it is directed towards another animal or the environment. Thus, stereotyped behavior became evident, as animals in this treatment spent most of their time rooting the environment and other animals.

3.3. Physiological Evaluation

The variables of infrared ear temperature (°C), thermographic ear temperature (°C), and ocular temperature (°C) did not show statistically significant differences between treatments throughout the experiment for the different time periods. For infrared ear temperature, the mean values were 35.18, 36.18, and 36.38 °C for the times H1, H2, and H3, respectively. Thermographic ear temperature showed values of 38.38, 38.54, and 38.48 for the times H1, H2, and H3, respectively. Ocular temperature presented values of 37.18, 37.28, and 37.36 for the times H1, H2, and H3, respectively.

The ideal body temperature for piglets from birth to the third week of age is in the range of 39.5 °C to 40.1 °C, and below this value the animal tends to suffer from cold thermal stress [51]. It is noticeable throughout the experiment, as already evidenced in the enthalpy and THI results, that the animals remained outside the thermal comfort zone range, indicating a tendency towards cold thermal stress.

Table 4 presents the results of the physiological assessment of injury, based on the analysis of anterior and posterior limb injuries with images recorded by a thermal camera (°C).

Many injuries can leave piglets with arthritis, resulting in difficulty in their mobility and abnormal posture. Studying the thermal image of these conditions is relevant because joints tend to swell with the presence of exudate, in addition to experiencing an increase in local temperature [35]. To heal these injuries, a series of biochemical events are triggered to repair tissue damage, so that the damaged tissue is replaced by new vascularized connective tissue [52,53], which also results in temperature changes.

Table 4. Temperature (°C) of anterior and posterior limbs (right and left), recorded in animals from treatments T1 (wood shavings), T2 (solid rubber mat), and T3 (perforated rubber mat), on two different evaluation days.

Treatments	Temperature of Anterior Limbs (°C)				Temperature of Posterior Limbs (°C)			
	Right		Left		Right		Left	
	1	2	1	2	1	2	1	2
T1	36.19	34.25	36.41	34.80	35.69	33.81	35.43 b	34.22
T2	36.61	34.04	36.98	34.40	36.33	33.63	36.50 a	34.02
T3	36.38	34.39	36.54	34.65	35.97	33.90	36.00 ab	34.02
p value	0.4308	0.7637	0.2777	0.3732	0.2767	0.7452	0.0493	0.8290

Means followed by different letters differ statistically from each other ($p < 0.05$) by Tukey's test among treatments.

Temperature analyses of injuries on the right posterior limbs did not show any difference between treatments on the first and second evaluation days; they remained statistically equal. However, the left posterior limbs showed a significant difference on the first evaluation day, where animals in the treatment with flooring covered with solid rubber mats (T2) had a significantly higher temperature in the region compared to animals in the treatment with bedding covered with wood shavings (T1).

In the remaining results of injuries on the right and left anterior limbs, on the first and second evaluation days there were no differences between treatments. This outcome could be directly related to the fact that the different materials studied are restricted only to the creep area, while the other areas of the pen are the same for all treatments.

Facilities without minimal welfare conditions, besides causing behavioral disturbances in piglets, can lead to bruises, wounds, and exposed fractures that favor the action of pathogens, consequently causing joint problems and infectious diseases at this stage [54]. Therefore, a rigorous assessment of influential variables such as environment, nutrition, health, reproduction, and animal behavior becomes essential, along with diagnosing production failures and subsequently correcting the problems.

3.4. Performance

The performance results are presented in Table 5. It is observed that the initial weight of the piglets does not differ statistically among treatments, although the treatment with wood-shaving flooring (T1) presents a higher average than the others. On the other hand, the final weight and daily weight gain were higher in the piglets from the treatment with wood-shaving flooring. The lower weight gain of the animals in the treatments with rubber flooring can be evidenced by behavioral analysis, in which the animals spent less time with the sows and more time in the creep areas, which influenced the decrease in animal feeding.

Table 5. Mean initial weight (IW) (Kg), final weight (FW) (Kg), weight gain per period (WGP) (Kg), and mortality (%) of treatments T1 (wood shavings), T2 (solid rubber mat), and T3 (perforated rubber mat).

Treatments	IW (kg)	FW (kg)	WGP (kg)	Mortality (%)	
				Crushing	Other
T_1	1.54	7.11 a	0.24 a	12.0	2.0
T_2	1.27	4.94 b	0.15 b	1.9	3.9
T_3	1.27	5.73 ab	0.18 b	3.8	1.9
p value	0.2084	0.0062	0.0017	-	-

Means followed by different letters differ statistically from each other ($p < 0.05$) by Tukey's test among treatments.

On the other hand, the percentage of piglet mortality due to crushing during the experiment was higher in the animals of treatment T1, followed by treatments T3 and T2. It is noticeable in the behavior analyses that there is a higher frequency of piglets close to the mother in treatment T1 during the three studied periods (H1, H2, and H3) compared to the other treatments, followed by treatment T3 during the morning (H1) and afternoon

(H2) periods. The latter maintained a higher frequency of animals close to the mother, which in turn showed the second-highest average of crushing deaths compared to the other treatments.

The pre-weaning mortality of piglets ranges between 11 and 13%, with crushing being the major contributing factor [55]. In this regard, the percentage observed in T1 falls within this range; however, for T2 and T3 the mortality rate is lower. This is evidenced by behavioral analyses, where animals spent more time in the farrowing crates in treatments containing recycled rubber flooring. On the other hand, despite experiencing lower mortality rates, they gained less weight, as evidenced by spending more time away from the sow and consequently consuming less milk. Ref. [56] highlights that piglet weight gain during pre-weaning is highly correlated with sow milk intake due to its constituents essential for piglet development.

4. Conclusions

The wood-shaving flooring exhibited the best productivity performances in terms of weight gain and the worst in terms of crushing mortality rate. On the other hand, rubber mats proved to be a sustainable and effective alternative to improve animal welfare. Piglets that remained on the mats exhibited a higher frequency of behaviors within the creep areas, indicating greater comfort at the location due to the heat source. Treatments with rubber mat-covered flooring did not show an accumulation of moisture or waste, eliminating the need for material replacement during the experimental period.

This research opens up new possibilities to evaluate the use of recycled rubber mats in pig production, allowing for the exploration of new designs and installation locations to establish an innovative and sustainable product. The data characterization was based on the observed responses to the conditions faced by the animals in production, highlighting the relevance of the information for the conducted study.

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