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DEEP LITTER PIG PRODUCTION SYSTEM AS A SUSTAINABLE ALTERNATIVE FOR SMALL FARMERS

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ABSTRACT

Small backyard farmers produce pigs mainly on concrete floors, which generates wastewater rich in nitrogenous substances created by the continuous washing of the sheds. The objective of this study was to integrate a systematic review of the information on the deep litter pig production system (SPCCP) as an environmentally sustainable alternative for small farmers in Mexico. The SPCCP uses a layer of absorbent organic matter on which the animals are kept. This technology is considered economical to implement, as it requires less infrastructure. The height of the bedding that favours the transformation of organic matter is 50 to 60 cm. Agricultural by-products such as plant debris or stubble can be used for bedding. The productive parameters of pigs in deep litter (CP) are adequate, with lower labour costs, and the animals have more time to eat, drink and play, which improves animal welfare. The product obtained from the deep bed at the end of the productive cycle has desirable properties to regenerate degraded soils or to enrich soils and can be used in agricultural crops. The SPCCP is simple and efficient, the infrastructure and equipment required are more economical; this production system improves feed conversion and daily weight gain, and benefits animal health and comfort. Since this system does not require washing the sheds, it reduces labour, as well as water needs, and does not generate wastewater. Therefore, the SPCCP complies with technical, financial, environmental, and animal welfare characteristics; it is an alternative for small backyard producers.

Keywords: water savings, deep litter materials, litter bedding compost, animal welfare.

INTRODUCTION

Pork meat is in high demand worldwide. However, its production has an impact on the environment, especially traditional pig farming, which generates greenhouse gases, acidifies soils and causes eutrophication in natural wetlands (Ottosen *et al*., 2021).

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In Mexico in 2021, 1 523 540 Mg of pork carcasses were produced. The state of Veracruz is the fifth largest producer with 137 602 Mg. As a complement, it is estimated that 1 025 000 Mg were imported in the same year, which cast an opportunity to increase the supply of the product in the country (SIAP, 2021). To achieve this production, the Livestock Development Program (Fomento Ganadero) created in 2014 provided economic incentives for the expansion of farms in communities of high and very high marginalization. This increased the number of backyard pig production farms (IICA, 2016).

Pig production in Mexico is usually done in traditional systems (TS) on a firm cement floor; this characteristic prevails in small backyard producers. The TS generates continuous wastewater from washing the sheds. Swine wastewater contains urine, excrement, food waste and various cleaning chemicals. This water is indiscriminately discharged untreated into soils, water bodies or drains not designed for this type of discharge. Small backyard pig producers are not officially identified, and since they do not have wastewater treatment systems, it can be assumed that they do not comply with regulations (Solís-Tejeda *et al*., 2021a). The current Mexican standards that regulate wastewater discharges in Mexico are NOM-001-SEMARNAT-2021 and NOM-002-SEMARNAT-1996 (Solís-Tejeda *et al*., 2021b).

In order to avoid impact on the environment, especially to water bodies, land evaluation models are designed for pig farming. With these models it is technically possible to design land management programs and to minimize the impact on water bodies (Bautista-Zuñiga and Aguilar-Duarte, 2021). However, it is difficult to limit the establishment of small backyard farms, although their size is not yet considered to have a significant impact, they have increased in number in some Mexican towns in recent years (Solís-Tejeda *et al*., 2021b).

The interest in reducing the polluting effect of pig farming worldwide has led to the development of precision livestock systems. The purpose of these systems is to improve efficiency in the supply of inputs, reduce waste and improve sustainability. An alternative to achieve that is to implement automatized monitoring and control systems that allow the evaluation of production, reproduction, health, animal welfare and environmental impact in real-time. With this technology, it is possible to provide the optimal amount of nutrients that the individual animal requires, considering the immediate changes in animal needs, and reducing waste to the environment (Rauw *et al*., 2020). This form of production can reduce up to 37 % the global warming potential, 21 % of land acidification, and 22 % eutrophication of freshwater bodies (Ottosen *et al*., 2021). However, high investment and the need for training make it difficult for this technology to reach small backyard producers.

Biodigesters can reduce methane (CH_4) production and provide electric power to farms; however, they do not recover investment costs, so producers lose interest in them. In addition, biodigesters do not contribute to the reduction of water consumption and pollution (Pérez-Espejo and Cervantes-Hernández, 2018).

Pig production contributes various nitrogen products to natural water bodies, including nitrates and nitrites (Solís-Tejeda *et al.*, 2021b). Nitrogen products cause eutrophication in water bodies and their high concentration in air and soil cause environmental imbalances. However, nitrogen is an indispensable part of living beings and is the key element for agricultural fertilization; it is found in abundance in the excrement of animals such as pigs. Crop fertilization with organic products, such as pig faeces, is an opportunity to reduce the use of chemical fertilizers, while reducing nitrogen inputs into the environment (Ndue and Pál, 2022).

Backyard TS pig farms in Mexico are characterized by being a fraction of the producer family household. This type of small farms has basic productive infrastructure such as sheds with concrete, block, brick or wood walls, a solid cement floor; tin roofs; scarce equipment, and untreated direct drainage to municipal drains or paddocks (Santos-Barrios *et al*., 2017; Solís-Tejeda *et al*., 2021a). It is possible to adapt those TS to SPCCP. The CP is a vegetal substrate that replaces the concrete pavement where the organic nitrogen from animal urine and faeces decompose onto an *in situ* compost. This process results in a compost with agricultural characteristics (Rondón *et al*., 2014). However, it is necessary to compile and order the information that has been generated on pig production in CP in order to identify its potential and facilitate its technological transfer to the small scale pig producers.

Since it is hypothesized that CP improves animal welfare and reduces the environmental impact of pig farming, without affecting the productive behaviour of pigs. Therefore, the objective of the study was to integrate a systematic review of the information on the deep litter pig production system (SPCCP) as an environmentally sustainable alternative for small producers in Mexico.

MATERIALS AND METHODS

Information for this systematic review was extracted from Google Scholar, Scielo and Scopus databases. The search terms used in English and Spanish were deep litter pig production (58 results), and deep litter pig composting (1160 results).

As exclusion criteria, it was decided to consider not only scientific articles, but also books, book chapters and updated official pages of the Mexican government that complied with certain quality criteria.

In addition, the "snowball" methodology was used where one literature led to others (Munn *et al*., 2018). Literature from the last ten years was prioritized; however, older works were accepted according to the relevance of information generated for this review.

The selected articles were grouped into the following topics: CP characteristics, productive parameters of pigs in CP, organic matter degradation process, contribution of CP to water conservation and animal welfare.

RESULTS AND DISCUSSION

The CP is a technology used for the production of various farm animals, including pigs; it consists of using a layer of absorbent organic debris as a support on which the animals are kept. On this material the animals deposit their excrement and urine during the entire productive cycle. The microorganisms responsible for the decomposition of organic matter grow on the substrate and decompose animal excrement, urine and food residues, very similar to a composting process. The rate at which the litter composting process occur depends on the substrate, nutrient availability and temperature (Campiño-Espinosa and Ocampo, 2007).

This pig production technology is considered not expensive to implement, as it requires less infrastructure than floor-based TS. It is possible to reuse and adapt disused production facilities through small adjustments with materials from the region (Cruz *et al.*, 2010).

The CP use in swine production originated in China in the 1970s. It is adopted in Europe, United States, Venezuela, Mexico, among other countries; where it is an environmental-friendly production alternative. This system does not require washing the floor of the sheds, thus avoiding the generation of contaminated wastewater, the presence of flies and unpleasant odours in the farms (Robert-Pullés *et al*., 2010).

The SPCCP reduces operating costs, solves the problem of excreta and slurry generation, and promotes better animal welfare. All of which results in the improvement of their productive parameters and meat quality. Therefore, this system is considered an option to achieve technical, economical and environmental feasibility, along with animal welfare in swine production (Li *et al*., 2017).

Density, feeding programs and production management in SPCCP are similar to TS management. However, with SPCCP technology, financial and environmental advantages are obtained due to lower feed conversion (FC) and the absence of wastewater. Hence, SPCCP is a feasible alternative to be adopted in small-scale pig production (Cruz and Almaguel, 2013). The decrease in feed consumption and FC is due to the fact that pigs require less energy in CP systems than in floor systems in order to regulate their temperature.

Characteristics of deep litter for pig production

The basis of this system is to raise the animals on a substrate of plant debris called bedding. The necessary height of the bedding to favour the transformation process of organic matter is between 50 and 60 cm (Rondón *et al*., 2014; Cruz *et al*., 2017; Caicedo *et al*., 2021). For this purpose, it is feasible to use agricultural by-products such as plant debris or stubble, which are bulking agents with low moisture content and high organic carbon content (Bernal *et al*., 2008). The amount in kg of CP per animal varies according to the material and height to be managed. For example, for a height of 50 cm, 107.32 kg of grass hay or 84.15 kg of rice husk should be provided (Rondón *et al*., 2014).

For the choice of bedding material, the comfort of the animals should be considered. The friction of the material is important to avoid slipping and bumping. High or low abrasiveness and hardness may cause hoof deformities, asymmetric growth and injuries. The material should lack sharp edges that can penetrate the skin and should have good insulation and thermal conduction that favour the natural posture of the animals (Lensink *et al*., 2013). Some materials studied as CP in swine production are presented in Table 1.

Campiño-Espinoza and Ocampo (2007) evaluated two densities of CP material, 350 and 450 kg per animal, with empty oil palm bunches; they concluded that the higher the amount of material, the higher the temperature, which favours bioxidative processes. In addition, SPCCP has been tested in a dual maternity pen. For this purpose, dried sugarcane bagasse, rice plants, corn plants, hay and wood shavings were used as bedding materials. In-calf mortality was recorded below 3 %, and weaning weights of 7 kg were obtained at 26 days after birth (Cruz *et al*., 2017).

Other materials that can be efficient for the establishment of CP are hay, rice or coffee husks, corn husks, dry sugarcane bagasse, wheat straw, soybean straw or a mixture of these. It is important to consider that the materials must be dry (Cruz *et al*., 2011). However, it is necessary to consider factors such as ammonium emission that may vary according to the bedding material. Rondón *et al*. (2014) found that a bed of grass hay can emit 6.59 mg m^{-3} of ammonium; while a bed of rice husk 2.31 mg m^{-3}. The fibrous tissue of grass hay absorbs more ammonium-rich urine and accelerates the composting of the bedding hay itself. This results in a greater emission of ammonium into the environment. Therefore, rice husks are considered an excellent material, with adequate particle size for the composting process occurring at CP. In contrast, grass hay provides more useful nutrients for agriculture because rice hulls are made up of cellulose, lignin, and minerals such as silica.

The shavings, as bedding material, store moisture and dirt. Moisture in CP promotes the formation of *Listeria monocytogenes* spore-forming bacteria and *Escherichia coli*, among others. These pathogens can be harmful to animals (Johanssen *et al*., 2018). Pine wood shavings contain resins that inhibit bacterial growth, which can affect the composting process (Lensink *et al*., 2013); because of this it is not highly recommended for the purpose.

Table 1. Materials used and height of deep litter evaluated in pig production.

Material	Bedding height (cm)	Author
80 % cane bagasse, 20 % grass	55	Cruz *et al*., 2010; 2011
Grass hay	55	Cruz *et al*., 2010
Grass hay	60	Tepper *et al*., 2012
Grass hay	55	Cruz and Almaguel, 2013
Grass hay	50	Rondón *et al*., 2014
Rice husk	50	Rondón *et al*., 2014
Grass hay	50 y 55	Cruz *et al*., 2017
Star grass hay	50	Cruz *et al*., 2017
Pangola hay	50	Cruz *et al*., 2017
50 % sugarcane bagasse, and 50 % star grass hay	50	Cruz *et al*., 2017
50 % King Grass, 30 % sugarcane bagasse, and 20 % star grass hay	50	Cruz *et al*., 2017

It is important to consider the size of the plant particle. A particle of 5 mm in length favours the composting process in the CP and bacteria formation is minimized (Li *et al*., 2017). This improves urine infiltration and air circulation through the bedding. Also, the pigs stir up the small particles easily when rooting. The continuous movement of the bedding oxygenates the material and hinders undesirable fermentation of organic matter; as well as limits the development of parasites and pathogens (Rondón *et al*., 2014).

Bedding has a life span, which depends on the material from which it was made, among other factors. Although for cost reasons we try to keep the same bed as long as possible, its duration will depend on the degradation of the material. For example, a bed made with wheat straw can be maintained for three fattening periods with positive results, while those made with sugarcane bagasse are usually changed at the end of each production cycle (Arango *et al*., 2012). In addition, it has been observed that pigs in the SPCCP tend to define three zones in a pen: the dirty zone, where most of their depositions occur; the wet zone, close to the water intakes; and the clean zone, which is the space used for resting (Campiño-Espinosa and Ocampo, 2007).

As the production process progresses, the pigs move the CP material from the clean to the dirty zone, highlighting the limits of the zones as opposed to traditional production (Rondón *et al*., 2014). This should be monitored, and the material required should be supplied to ensure the height of the bedding. On the other hand, the safety of the bedding material should be considered. Siroca *et al*. (2019) reported a case of poisoning of 50 pigs on a commercial farm by consumption of material contaminated with diquat, among the intended CP material. Diquat is an herbicide used for drying clover.

Production parameters of pigs in the deep litter system (CP).

It is also important to consider the number of animals in the shed, as the animal load determines the amount of nitrogen-rich organic matter that will be produced. Animal densities in the SPCCP are similar to those in the concrete-floored TS (Cruz *et al*., 2011; Cruz and Almaguel, 2013; Rondón *et al*., 2014). The productive parameters of pigs in the SPCCP demonstrate an adequate productive viability at high densities (Table 2).

The results by Cruz *et al*. (2010) showed a better productive performance of pigs in the SPCCP compared to the TS. Pigs in CP decreased feed intake as well as energy requirements; the authors showed that CP improved FC between 0.25 and 0.21 compared to TS, and DWG was 14 g d^{-1} higher compared to TS. This differs from the study by Arango *et al*. (2012) who found no difference in DWG or FC between systems; however, daily feed intake was 300 g d^{-1} lower per animal in the fattening phase. In addition, the TS presented a high morbidity of 27.7 %, in contrast to 16.6 % of the animals developed on hay bedding, and 11.1 % of the animals produced on bedding of a mixture of 80 % bagasse and 20 % hay. The results are consistent with the SPCCP evaluated by Cruz *et al*. (2011) who presented FC indicators of 0.12, and DWG of 23 g d^{-1} higher than those in TS with concrete floor. They also agree with Cruz and

Table 2. Productive indicators of pigs in the deep litter system.

Productive indicators							
AA	AD	FC (kg)	DWG (g)	IW (kg)	FW (kg)	PT (d)	Author
1.50	0.67	2.69	652	24.86	96.58	110	Campiño-Espinoza and Ocampo, 2007
1.35	0.74	2.71	611	24.86	92.04	110	Campiño-Espinoza and Ocampo, 2007
1.44	0.69	3.38	740	21.21	99.60	106	Cruz *et al*., 2010
1.44	0.69	3.42	739	21.18	99.51	106	Cruz *et al*., 2010
1.40	0.71	2.84	727	22.60	95.30	100	Cruz *et al*., 2011
4.50	0.22	1.76	745	22.27	43.19	28	Tepper *et al*., 2012
1.44	0.69	3.08	747	-	-	-	Cruz and Almaguel, 2013
1.37	0.73	-	-	30.00	110.00	90	Rondón *et al*., 2014
1.40	0.71	3.42	739	21.18	99.51	106	Cruz *et al*., 2017
1.40	0.71	3.40	650	21.18	99.00	120	Cruz *et al*., 2017

AA: available area, m^2 per animal, AD: animal density, number of animals per m^2, FC: feed conversion, DWG: daily weight gain, IW: initial weight, FW: final weight, PT: production time.

Almaguel (2013) who recorded a morbidity of 22.2 % in the CP, in contrast to 55.5 % morbidity and one dead animal in the TS.

Cruz *et al*. (2017) recorded the growth of pigs in the SPCCP in three private farms. The values obtained by the producers were on average a FC of 3.4, a DWG of 650 g d^{-1}, and a final weight of 99 kg for 120 d. Also, they provided records on the development of a herd from weaning with 8.2 kg in the SPCCP. The latter animals reached 95 kg with a DWG of 600 g d^{-1}. The CP residue was used as fertilizer on the crops in the farm.

Aké-Chalé *et al.* (2014) found no significant differences in the number of piglets alive and weaned at 28 d for pig wombs in TS, and with corn stubble CP. However, the initial (22 g) and weaning weights (1.12 kg) of piglets were higher. Hurtado *et al.* (2021) developed nonlinear statistical models for pig production on rice husk and corn stubble CP. These models can predict swine herd development; in this way it is possible to determine in advance the physiological needs of the animals. The models reflect the feeding requirements and growth decline when the maximum genetic standard is reached. This helps to achieve accurate production of pigs at CP.

Regarding SPCCP carcass characteristics, according to the literature review by Caicedo *et al*. (2021), the meat yield of pigs produced in CP did not indicate significant difference compared to those produced in TS. The 110 kg finishing pigs had 21.8 mm backfat, 41.3 cm^2 of chop, 51.1 % lean meat, and 74.9 % carcass yield; in contrast to the TS pigs which had 20.8 mm backfat, 43 cm^2 of chop, 52.1 % lean meat, and 75.8 % carcass yield. However, the labour cost per animal care was reduced by a quarter with CP and animals spend 133 % more time eating, drinking and playing (Honeyman and Harmon, 2003), which could benefit animal welfare.

Kidega *et al*. (2021) found that inoculating daily a solution of indigenous microorganisms from the decomposition of the bottom of the CP onto the litter material reduced the litter temperature. This resulted in a reduction of backfat in the neck of the animals by 1.7 cm, and 1.8 cm above their shoulders compared to the TS. The effect of inoculated litter bed on fat reduction in swine agrees with Zhou *et al*. (2014) who reported 2.19 % less fat and 1.96 % more lean meat for pigs on a sawdust and straw CP at 5:7 ratio inoculated with Saccharomycetes, *Bacillus subtilis* and Actinomycetes in contrast to TS.

Degradation process of organic matter in deep litter during the stay of pigs.

During pigs farming, the material composing the CP on the shed is subjected to a bioxidative process (in the presence of oxygen). Bacteria, fungi and other microorganisms that arise in organic decomposition partially mineralize and humify (generate humus) the excrement, urine and bedding material. This results in a stable product with desirable properties for the regeneration of degraded soils or the enrichment of cultivated soils (Figure 1) (Bernal *et al*., 2008).

Composting occurs in two stages, the first or mesophilic stage is determined by the concentration of nutrients and microorganisms, generally carbohydrate degraders. The microorganisms present in the faeces degrade the nutrients available in the fibrous substrate and in the food remains. In the second or thermophilic stage, microbial activity generates a rise in compost temperature. The speed of this process and the temperature differ between the zones of the bed. The clean zone has the highest temperature up to 52 °C, followed by the wet zone at 48 °C, and the dirty zone at 43 °C. During this phase, due to thermal action, the number of present microorganisms, such as *Pseudomonas* and *Flexibacter*, is reduced (Campiño-Espinosa and Ocampo, 2007).

Because of the heterogeneity of the process, in terms of the humidity and temperature reached, it is not possible to guarantee an appropriate sterilization of the substrate.

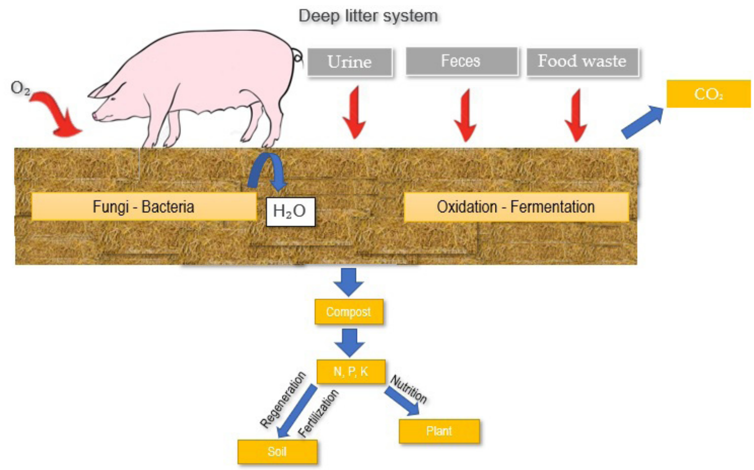

Figure 1. Compost generation from deep litter.

In addition, Rober-Pullés *et al*. (2010) recommended that the system requires sanitary surveillance for its safe implementation, in order to control the presence in the substrate of faecal coliforms, fungi and yeasts, viable mesophilic aerobes and the possible presence of unstudied pathogens. For such reasons, this process should be considered as pre-composting and the product should undergo a proper composting process, in accordance with Standard NMX-AA-180-SCFI-2018, for its safe use in agricultural systems. Finally, there is the cooling and maturation stage, or maturity and stability of the resulting compost, in which fungi and yeasts develop. In this phase, the presence of members of the bacterial families Pseudonocardiaceae, Streptomycetaceae, Brevibacteriaceae (Actinobacteria) and Bacillaceae (Firmicutes) is correlated. These microorganisms are associated with the degradation and mineralization of organic matter for the generation of humic substances (Vásquez-Castro and Millones-Chanamé, 2021).

For the development of the composting phases of the bedding materials, the relationship of the substrate with the microorganisms is very important. The composition of the microbial communities that develop will depend on the physicochemical parameters of the organic matter. Thus, fungi of the genera *Ascomycota*, *Basidiomycota,* and *Zygomycota* have been identified in pig excrement and rice straw compost, while *Ascomycota*, *Basidiomycota*, *Mortierellomycota,* and *Mucoromycota* were found in a mixture of pig excrement with fine coal gasification slag (Vásquez-Castro and Millones-Chanamé, 2021).

Organic nitrogen contained in animal excrement and urine is degraded by microorganisms into ammonium (NH_4^+). Part of the nitrogen is released to the environment as ammonia gas (NH_3) or continues its oxidation through the nitrification-denitrification process to nitrous oxide (N_2O) or dinitrogen (N_2), which are released to the environment as gases (Figure 2). Nitrogen volatilizes up to 77 % as NH_3 and N_2. Nitrogen loss will depend on factors such as initial litter concentration, moisture, C:N ratio, and the oxygenation generated mainly by animal movement on the litter (Maeda *et al*., 2011).

The end result of the CP substrates decomposing is a stabilized mixture of nutrients for agriculture. For example, the properties of a grass hay bed are 9.75 % crude protein, 30.99 % crude fibre, 0.52 % crude fat, 9.29 % ash, 1.55 % nitrogen, and 0.65 % phosphorus (Rondón *et al*., 2014).

The addition of organic residues, in particular pig excreta, has shown to improve soil quality indicators. It is possible to improve carbon and nitrogen levels, in addition to humic substances. Humic substances interact with the soil, and improve its structure and fertility (Ventura *et al*., 2018). Adding CP output to the soil may be a feasible strategy for the regeneration and enrichment of agricultural soils.

Regarding gaseous pollution, Zhou *et al.* (2014) found that NH_3 emission in the CP (3.3 mg m^{-3}) is lower than in the TS (19.8 mg m^{-3}). The same occurs with CO_2 produced in the CP (1443.3 mg m^{-3}) in contrast to the solid floor system (3223.3 mg m^{-3}).

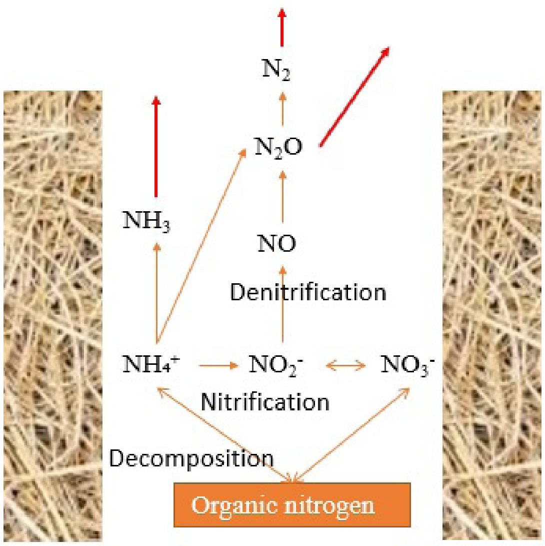

Figure 2. Organic nitrogen degradation process in deep litter production system (Modified from Maeda *et al*., 2011).

Contribution of deep litter to water care

Water is an indispensable element for pigs, representing 50 % of the body of a finishing animal. Water consumption (L d^{-1}) in pigs differs by physiological stage: a lactating sow with litter consumes 30.4, developing and finishing pigs 15.2, pregnant sows 22.8, and boars 30.43 (García-Contreras *et al*., 2012). In addition, the TS with concrete floor requires water daily for cleaning the floors of the sheds. This expense is difficult to estimate in small-scale (backyard) producers, since there is a large standard deviation between farm consumptions (Solís-Tejeda *et al*., 2021a). One of the advantages of the SPCCP is the total water saved for a non-frequent shed washing.

The water consumption saved by the SPCCP in contrast to the concrete floor TS has been estimated. Cruz *et al*. (2010) estimated water savings of 2.45 m^3 water per animal. In a 104 d trial, Cruz and Almaguel (2013) saved 2.36 m^3 of water per animal. In turn, Cruz *et al*. (2017) estimated the water savings by SPCCP at 4.91 m^3 per animal.

The result of water consumption for cleaning the sheds is wastewater containing various pollutants, such as nitrogen derivatives, which is often discharged into water bodies without treatment (Solís-Tejeda *et al*., 2021a). Cruz *et al*. (2010) quantified the pollution generated by wastewater from the TS and contrasted it with the SPCCP. The swine wastewater generated in the floor system has a high organic matter content quantified as chemical oxygen demand (COD) of 49 383.33 mg L^{-1} and biological oxygen demand (BOD) of 24 166.67 mg L^{-1}; in addition to 3.9 × 10^4 most probable number (MPN) (100)$^{-1}$ faecal coliforms, 1.9 × 10^4 colony forming units (CFU) ml^{-1} *Salmonella* sp. and helminth eggs. These indicators remain absent in the SPCCP after two production cycles, 106 d in total.

Animal welfare in deep litter pig production system

Globally, awareness and interest in animal welfare is increasing (Cruz *et al*., 2017; Fernandez *et al*., 2018). Producers are responsible for providing welfare to pigs. Therefore, various ethical, productive and economic opinions have been generated about intensive production systems. Intensive production has ignored this interest under the pretext of increasing the amount of food available; animals are subjected to stress and medications for their control (Caicedo *et al*., 2021).

In intensive production on concrete floors, stress in pigs has resulted in aggression among herd members, with the emergence of tail biting and various injuries. CP has succeeded in avoiding these social disorders at high production densities of 1.4 m^2 per animal. Pigs in CP show a more natural and relaxed attitude. They use the bedding material for rooting, and play can be perceived among them (Cruz *et al*., 2011). On the other hand, with CP humidity is avoided, and the incidence of respiratory diseases is reduced. Limb injuries due to falls are also avoided, as well as hoof softening due to humidity (Cruz and Almaguel, 2013).

Flies are often a problem for producers, the surrounding community, and the pigs (Caicedo *et al*., 2021). Flies can be vectors of disease. The increase in temperature of the bedding material during the composting process kills fly eggs and larvae, as well as other insects that cause injury to the animals. Rice husk bedding has shown to be more effective in reducing parasites compared to grass hay bedding and traditional floor management (Rondón *et al*., 2014).

In general, skin diseases in pigs caused by ectoparasites are common and affect animal welfare; in addition, they cause reduced growth rates, affect FC, and increase morbidity and mortality. The SPCCP benefits animal health; to achieve this it is necessary to keep CP dry and renew the entire bedding before saturation by faeces. A CP saturated with faeces benefits the reproduction and transmission of parasites such as sarcoptic mange (Fernandez *et al*., 2018).

Another advantage of CP is that it provides comfort to the animals by raising their temperature during cold days. The dry and warm substrate improves welfare in contrast to a wet and cold floor. This feature improves the occupancy rate of the pens and provides a larger desirable area for the animals to lie down (Milera-Rodriguez, 2022). However, it is a factor to consider on hot days, where it will be necessary to ventilate the area for the welfare of the animals (Cruz *et al*., 2011).

CONCLUSIONS

Deep litter pig production is a simple and efficient technology. It is possible to use various agricultural by-products, available in the region where the farms are established, as bedding material. The infrastructure and equipment required for this production system are less expensive than in the traditional concrete floor system.

Productive indicators such as feed conversion and daily weight gain are higher in the deep litter production system in equal time and density than those in the traditional backyard system. There is no need to wash the sheds, labour is reduced, as well as water requirements, and no wastewater is generated. According to the literature analysed, the animals show more natural behaviours, and stress is avoided. At the end of the productive cycle, the bedding is an excellent product that can be used in agriculture.

The deep litter meets technical, financial, environmental and animal welfare characteristics for its adoption by small-scale backyard pig producers with traditional systems in Mexico. However, for its efficient technology transfer to producers, it is necessary the study of its function in the different climatic regions of the Mexican tropics, as well as to provide information on available materials for the making of deep litter beds appropriate for each region.

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