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FREE-RANGE PIG FARMING AS AN ALTERNATIVE FOR SMALL-SCALE FARMERS IN MEXICO

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ABSTRACT

Backyard pig farming provides income for family production units. The implementation of free-range pig farming systems (FRPFS) improves animal health and well-being, as well as meat quality. In addition, it reduces the environmental impact and dependence on external inputs while increasing profitability through lower production costs and greater access to specialized markets. A review was conducted to identify the FRPFS characteristics that enable and support the implementation of regenerative livestock farming within small-scale production systems. Findings showed that pigs are able to absorb nutrients from tree foliage and grassland plants. Nonetheless, to facilitate digestion, these feeds must be high in protein and low in fiber, requiring the addition of grains or subproducts. In grazing systems, it is necessary to allow long resting periods for the land, since pigs root and disturb the soil. However, their excreta help improve its physical, chemical, and biological properties. FRPFS can be integrated with agricultural systems to strengthen the resilience of small-scale farmers while providing meat with special organoleptic characteristics, which helps produce different products for niche markets at better prices.

Keywords: grazing pigs, regenerative livestock farming, animal welfare, sustainable livestock farming.

INTRODUCTION

In 2017, Mexico produced 1 925 364 Mg of dressed pork. This amount represents the highest value recorded in recent years. However, this figure fell by 22 % during the 2018 change of administration. Following this decline in production, a gradual recovery trend of 1–2 % per year has been observed, culminating in a production level of 1 686

802 Mg in 2021. Out of the entire country's national pork production, 85 % is carried out in semi-intensive and intensive systems, while the remaining 15 % is carried out in backyards (SIAP, 2022). In Mexico, there are 1 046 488 backyard pork production units registered. The state of Veracruz is the most representative of this production system, with 224 598 units. This small-scale production system contributes to the well-being of farmer families by generating income to help cover unforeseen expenses, and it is an activity frequently carried out by women (Solís-Tejeda *et al*., 2024).

Small-scale pork production presents challenges to guarantee sustainability. For instance, backyard production is carried out in pens with concrete floors, which requires constant water cleaning and produces unpleasant odors from manure. As a result, contaminated wastewater is produced and discharged into drains unsuitable for these effluents or onto agricultural land. This causes pollutants, such as nitrites, to infiltrate into water tables, causing negative environmental effects (Solís-Tejeda *et al*., 2022). Although pork has a lower carbon footprint than beef, accounting for only 9 % of greenhouse gas emissions, it is the activity that causes the most acidification in water tables. Additionally, it causes the eutrophication of superficial water bodies due to the discharge of wastewater rich in solid waste, which contains high amounts of nitrogen derivatives (Ottosen *et al*., 2021).

Another challenge for pig farmers is the perception that industrially produced pork is harmful to human health. In addition, there is a growing demand for ethically produced meat, which has led scientists to investigate alternatives such as synthetic meat. Nevertheless, these innovative procedures have not ensured animal well-being, since they still use dubious methods, distancing consumers from a nutritious and natural diet (Moyano-Fernández, 2021). As a response to the challenges of conventional animal production, several paradigms appear, which are contrary to the Green Revolution. Agroecology, holistic livestock farming, and regenerative livestock farming seek to generate products in more natural ways and focus on favoring natural soil processes. These practices help reverse the negative effects of traditional livestock farming, and because they are extensive systems, they produce meat with greater benefits to consumers' health (Velasco *et al*., 2019).

Techniques such as Voisin Rational Grazing (VRG) have been shown to help restore soils by rotating animals in paddocks and practicing ethical management. The use of excrement and urine as organic matter to enrich the soil promotes the richness of edaphic fauna and biological processes that restore the soil (Bautista-García *et al*., 2022). This shows that pigs have productive features that can be implemented in a regenerative livestock farming system, which is feasible for small-scale farmers in Mexico. However, systematizing the available information is necessary for the successful establishment of these systems. Therefore, the aim of this study was to create a review of information about the characteristics of free-range pig farming systems (FRPFS) in order to better understand the advantages and difficulties of implementing this livestock technology in small-scale systems in Mexico.

MATERIALS AND METHODS

The Google Scholar, SciELO, and Scopus databases were consulted to review and synthesize the current knowledge on free-range pig farming The search terms used in English and Spanish were "outdoor pig production" (15 800 results), "pig production in grazing systems" (11 300 results), "free-range pig farming" (16 320), and "extensive pig production" (7 920). As an exclusion criterion, studies published more than 10 years ago were discarded (except for those considered mandatory references and relevant to the development of the sections established in the article), as well as gray literature and works on non-domestic pig species.

The selected articles were clustered by topic, considering relevant topics to propose FRPFS as a current alternative for farmers. These topics included the production system's characteristics, pig productivity parameters in FRPFS, feeding opportunities, feed used, soil and meat quality effects, and system challenges. The "snowball" methodology was used, in which one bibliography leads to others that help to understand the proposed system.

RESULTS AND DISCUSSION

Characteristics of free-range pig farming systems (FRPFS)

The FRPFS is a system in which animals are kept "free" in plots enclosed by fences. This system is based on grazing plot management and the contribution of pastures to animal feeding. With this system, investment capital is reduced by 40 to 70 %, as pigsties and other costly infrastructure are not required. Only shelter huts need to be considered to protect the animals from weather conditions, particularly piglets, so the installation of rustic farrowing huts with heat lamps, insulating materials, and curtains is recommended to protect them during the early stages of life (Parsi *et al.*, 2016).

Outdoor production attempts to simulate the natural conditions of pigs and promotes their inherent behaviors. In this system, pigs can spend up to 6 h a day grazing and rooting. They cool themselves by creating nests in the soil, cover their skin with mud for protection against parasites and the sun, and are encouraged to explore using their sense of smell. It also allows pigs to group together and display positive social behaviors. These behaviors are linked to animal welfare, as they reduce fights between individuals, making techniques such as tail docking unnecessary (Pietrosemoli *et al.*, 2020).

The FRPFS is a feasible alternative for small-scale farmers since it is more accessible for installation (Parsi *et al.*, 2016). In addition, farmers have the opportunity to reduce commercial competition by differentiating their product and accessing new specialized agroecological markets. This benefits from a new trend of consumers that perceive the field system as a favorable way of production for the environment and the well-being of the animals (García-Madrid *et al.*, 2021).

It is important to consider that this system requires animals with greater hardiness than industrialized farm pigs, since they are directly exposed to environmental conditions. Creole and mixed-race pigs have better resistance to diseases and external environmental factors, as well as a greater ability to digest low-quality feed. Backyard pig farming is an opportunity to breed animals with greater adaptive genetic strengths, which may be beneficial for their adaptation in the field (Martínez-Velázquez *et al*., 2016).

The Mexican Hairless Pig (MHP) is a hardy species that lives in warm tropical regions. It is a creole variant that originated from Iberian pigs (*Sus scrofa mediterraneus*) and has adapted to the extreme conditions of the tropics, such as high relative humidity, parasites, and high temperatures. However, it is hardly appreciated by butchers, since it accumulates excess fat after 70 kg. Despite this, it is an opportunity to generate novel products in which their specific characteristics that differentiate them from intensive-production pigs, such as their intense flavor and soft meat, can be exploited (Ramos-Canché *et al*., 2020).

The MHP may accumulate large amounts of fat within and on its carcass, which is very important in the production of high-quality, high-value meat products such as cured hams (Delgado *et al*., 2002). This fat is of higher quality and may have beneficial properties for human health since it comes from animals that eat a variety of plants, and it can be controlled by restricting concentrated feeds and the age of slaughter.

Feeding opportunities in free-range pig farming systems

The use of balanced feeds for animals has been limited due to various circumstances in the global market that raise prices. Small-scale pig farming is an economic challenge, since the production costs tend to be higher than those for semi-intensive and intensive systems. In addition, the sale price established by local markets does not usually cover these costs (Solís-Tejeda *et al*., 2024). Balanced feeds represent between 60 and 70 % of the production costs for small-scale farming, so the use of green feeds available in farmers' plots is an alternative to reduce the consumption of concentrates.

Green feeds of excellent quality, which provide proteins, minerals, vitamins, and energy, are available (Velasco *et al*., 2019). However, pigs are inefficient in utilizing fibrous feeds since they are monogastric; they cannot perform pre-gastric fermentations like ruminants, nor do they have enzymes that help degrade fiber. Despite this, when pigs eat forage, they can assimilate proteins through fermentation in the cecum and the colon of the large intestine.

When pigs are fed high-fiber diets, they modify their microbiota and produce more cellulolytic bacteria in the gastrointestinal tract (González *et al*., 2020). This way, they acquire the ability to use half the hemicellulose consumed and a little less than one-third of the cellulose. Only lignin cannot be digested; therefore, tender pastures, which contain a lower amount of this compound, are better for feeding pigs (Savón, 2002). After the pasture is consumed, fermentation in the large intestine produces volatile fatty acids (VFA), such as acetic, butyric, and propionic acids. The mucosa of the cecum and colon can efficiently transport these nutrients. The VFAs derived from the fermentation of pastures can cover between 5 and 20 % of the animals' energy requirements (Milera-Rodríguez, 2022).

Another characteristic worth considering is the volume of the pigs' gastrointestinal system. In comparison with ruminants, the amount of dry matter from pastures they can process is limited, since they are full before satisfying their nutritional requirements. This is worse in piglets and developing pigs with digestive systems with lower capacities and fewer microorganisms able to digest fiber. Therefore, grazing is more common in gestating and lactating females (Parsi *et al*., 2016).

High-fiber diets in pigs have been shown to reduce nutrient assimilation, decrease flesh weight gain, and increase gut weight. This depends on the soluble-to-insoluble fiber ratio provided, so the pigs should not be fed only pastures. Diets must include easily digestible concentrated elements rich in nutrients that complement the pastures (González *et al*., 2020). On the other hand, a diet with fiber promotes the health and well-being of pigs during gestation and labor, since fiber reduces nervous movements in the sows related to symptoms of discomfort in the days before and after labor (Ramos-Canché *et al*., 2020).

Nutritional characteristics of feeds used

Forage, particularly legumes, is a source of protein that pigs can absorb, and their low lignin content facilitates its assimilation (Table 1). Additionally, it provides minerals such as iron (Fe), which is crucial for the development of piglets in their first stages of development for the formation of hemoglobin. As in conventional systems, it is

Table 1. Nutritional composition of pastures consumed by pigs in free-range production systems.

Pasture	DM	CP (%)	NE$	NDF (%)	LIG (%)	Reference
Alfalfa (*Medicago sativa* L.)	89.7	16.7	NI	45.0	6.5	Araiza-Ponce *et al*. (2020)
Rye grass (*Lolium perenne* L.)	16.2	22.1	1.4	44.6	NI	Cardona-Iglesias *et al*. (2020)
Red clover (*Trifolium pratense* L.)	NI	21.5	NI	27.0	NI	Vallejos-Fernández *et al*. (2021)
White clover (*Trifolium repens* L.)	NI	23.5	NI	23.4	NI	Vallejos-Fernández *et al*. (2021)
Forage wheat (*Triticum aestivum* L.)	NI	17.2	NI	54.7–64.9	NI	Zamora-Villa *et al*. (2016)
Forage oat (*Avena sativa* L.)	27.5	8.6	1.3	47.0	NI	Mamani-Paredes and Cotacallapa-Gutiérrez (2018)
Forage peanut (*Arachis pintoi* Krapov)	NI	24.0	NI	52.5	2.9	Rodríguez *et al*. (2010)

MD: Dry matter; CP: crude protein; NE: net energy; NDF: neutral detergent fiber; LIG: lignin; NI: not indicated.
$Mcal kg^{-1} of DM.

recommended to add iron intravenously, since an iron-rich diet or supply during gestation does not fulfill the iron needs of piglets (Velasco *et al*., 2019).

On average, the voluntary intake of grasses by pigs weighing between 10 and 20 kg fluctuates between 0.08 and 0.1 kg of dry matter (DM) d^{-1}, accounting for 9.5 % of their diet. This value increases slightly for animals weighing 40 to 60 kg at an estimated intake of 0.208 to 0.237 kg DM d^{-1}, accounting for 10.2 % of their diet. This occurs when a balanced feed is supplied with a low restriction of 15 % (Soledad-Carballo *et al*., 2010).

By restricting the availability of concentrate or balanced feed, pigs increase their intake of pasture, and production costs decrease. However, it is important to establish a diet that incorporates grain byproducts like wheat semolina, animal protein like whey, and energy sources such as potato, taro, yuca, and banana. Farmers can generate these complementary feeds in the production unit. Depending on the ingredients used, the fattening time may be longer than expected in the conventional diet, but the farmer's dependence on the purchase of inputs is reduced, improving its profitability (Soledad-Carballo *et al*., 2010; Milera-Rodríguez, 2022). Thus, the intake of pastures depends on the age of the animals and the quality of the grass (González *et al*., 2020); however, it must be complemented (Table 2).

Although FRPFS are an alternative to the impact of pen production, it is necessary to analyze the factors that contribute to the degradation of grass and forage-based farming

Table 2. Grazing techniques and complementary feed in pigs by race, weight, and type of feed (F).

Race	Weight (kg)		F	Cycle (d)	Complementary feed	Grazing technique	Reference
	In	Fin					
Pampa Rocha	10	20	f1, f2, f3	25	CM (75 %), MBM (6.5 %), SBM (17.5 %), NaCl (0.5 %), vitamins and minerals (0.5 %)	Rotational grazing in 300 m^2 strips, 187.5 m^2 per animal	Soledad-Carballo *et al*. (2010)
Duroc × Large White	40	57	f1, f2, f3	25	CM (75 %), MBM (6.5 %), SBM (17.5 %), NaCl (0.5 %), vitamins and minerals (0.5 %)	Rotational grazing in 300 m^2 strips, 187.5 m^2 per animal	Soledad-Carballo *et al*. (2010)
Mestizos (Landrace)	W	70–80	f4, f5, f6, f7	180–210	Corn grain, soybean hulls, rice meal, vitamin supplement, salt, and calcium	Continuous grazing, last 30 d in confinement with commercial feed	Velasco *et al*. (2019)
Gascón	W	170	f2, f4, f8	360–720	Acorns, chestnuts, wheat, oat, barley, rye, triticale, fava bean, peas, colza, or sunflower bran	Grazing system with forest, 500 m^2 per animal	Lebret *et al*. (2021)

In: initial; Fin: final; W: weaning; f1: chicory (*Cichorium intybus* L.); f2: red clover (*Trifolium pratense* L.); f3: annual ryegrass (*Lolium multiflorum* L.); f4: white clover (*Trifolium repens* L.); f5: perennial ryegrass (*Lolium perenne* L.); f6: birdsfoot trefoil (*Lotus corniculatus* L.); f7: orchardgrass (*Dactylis Glomerata* L.); f8: Bermuda grass (*Cynodon* sp.); CM: cornmeal; SBM: soybean meal; MBM: meat and bone meal.

systems. This includes inadequate management of grazing (overgrazing caused by a mismanaged rotation), low-quality pastures, few trees in pens, and insufficient water provided for the animals (Bautista-García *et al*., 2022). A more agroecological approach is necessary, increasing the diversity of plants that are resistant to pests, weed management, and tree-grass integration.

Tree shades provide habitats for various insect species by creating microclimates that encourage their development. They also promote complex relations between plant-eaters and bioregulators, benefitting pollinators, coprophages, and decomposers of organic matter, which help maintain the biological stability of the plots (Milera-Rodríguez, 2013). It is feasible to integrate trees that enhance the stability of the system by capturing nitrogen products in lower soil levels resulting from livestock activity, and using their leaves and fruit as animal feed, which farmers can harvest and provide to the animals, which is particularly important during the dry season (Sarmiento-Franco *et al*., 2022).

Trees also provide other advantages, such as animal protection with shade, soil conservation, water storage, and the extraction of minerals from the deepest layers in the soil to the top layer by means of the leaves (Araiza-Ponce *et al*., 2020). Therefore, it is convenient to integrate trees of high nutritional value into the FRPFS to optimize the diets of the animals (Table 3), the chemical composition of which has been used for its nutritional capacity in the feeding of pigs.

Table 3. Nutritional composition of foliage and tree seeds used to feed pigs in free-range production systems.

Tree	PP*	DM (%)	CP (%)	NDF (%)	LIG (%)	Reference
Ramón (*Brosimum alicastrum* Swarth)	F	40–44	13–17	36–46	3.8–7.9	Sarmiento-Franco *et al*. (2022)
Ramón (*B. alicastrum* Swarth)	S	92	12.8	NI	NI	Sarmiento-Franco *et al*. (2022)
Leucaena (*Leucaena leucocephala* Lam.)	F	89.5	21.3	42.9	8.1	Araiza-Ponce *et al*. (2020)
Moringa (*Moringa oleífera* Lam.)	F	17–25	14–22	35–54	NI	Rivero *et al*. (2020)
Morera (*Morus alba* L.)	F	30.8	14.6	37.8	NI	Rodríguez-Molano *et al*. (2019)

DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; LIG: lignin; NI: not indicated. *Estimated content in foliage (f) or seeds (S).

The effect of replacing concentrated feed with tree leaves is similar to that of grasses, with reduced nutrient assimilation as the percentage of leaf consumption increases. In this regard, *Brosimum alicastrum* Swarth leaves are estimated to provide 1.3 Mcal kg^{-1} of DM of metabolizable energy to pigs, whereas seeds provide 3.7 Mcal kg^{-1} of DM of raw energy (Sarmiento-Franco *et al*., 2022). Pigs can digest fresh *Leucaena leucocephala* Lam. leaves by 60 % of DM, 57.8 % of the organic matter, and 66.5 % of raw NDT; they can also assimilate calcium and phosphorous (Araiza-Ponce *et al*., 2020).

Fresh mulberry (*Morus alba* L.) leaves are a good replacement for Soybean meal and Corn, since they contain a percentage of protein that can surpass 20 % and digestibility values in pigs between 75 and 85 % (Rodríguez-Molano *et al*., 2019). In a study that replaced the soybean meal in the balanced feed (usually standardized with 20 % soybean meal) and supplemented 40 % of the dry base of the diet with mulberry foliage, a daily weight gain of 0.473 kg was recorded, 0.129 kg less than the control diet. Intake was lower with the moringa diet (1.5 kg MS d^{-1}) in comparison with the control (2 kg MS d^{-1}); however, feed conversion was better (3.1) in contrast to the control diet (3.4) (Rivero *et al*., 2020). Mulberry improves digestibility in pigs when stems are removed and only the leaves with petioles are provided (Rodríguez-Molano *et al*., 2019).

Along with the benefits mentioned earlier, producing some of the ingredients for animal feed reduces dependence on inputs and the carbon footprint of livestock farming. The further the distance covered to supply the ingredients to produce the balanced pig feed, the greater the carbon footprint (Ottosen *et al*., 2021).

Soil conditions in free-range pig farming systems

The flow of rainwater from mountains to oceans has increased in speed because soil and plant-covered surfaces that can retain water have reduced. This decrease is due to the soil degradation caused by urbanization and farming malpractices, giving way to drought and flood periods (Suárez-Castillo, 2018). On the other hand, the oxidation of organic matter generated in conventional farming releases CO_2 and CH_4 from the soil to the atmosphere, warming the planet and reducing the soil's productive capacity (Ottosen *et al*., 2021).

Animal production through regenerative livestock farming can improve soil conditions when integrated with soil fauna, increasing porosity, organic matter, carbon sequestration, and water retention at low costs (Suárez-Castillo, 2018). Pigs are inefficient in the assimilation of nutrients, so they release between 40 and 50 % of nutrients in their excretions, which contain nitrogen, phosphorous, potassium, calcium, magnesium, organic matter, and micronutrients not available in commercial soil-improving products. These nutrients can be deposited in the soil when grazing and incorporated by microorganisms as they are decomposed into humic substances, contributing to soil fertility (Rivero *et al*., 2013).

Grazing techniques in cattle, such as Voisin Rational Grazing (VRG), have been demonstrated to regenerate soils damaged by intensive production, improving soil bulk density. With these techniques, nutrients are reincorporated, and the amount and variety of soil fauna species increase (Bautista-García *et al*., 2022). Additionally, adequate pasture management through VRG helps produce higher-quality forage for the animals and increase the available biomass in comparison with conventional grazing (Suárez-Castillo, 2018). These benefits are obtained without chemical fertilizers, since the organic matter produced by the animals is evenly distributed in the pastures (Trinidad-Santos and Velasco-Velasco, 2016). A high stocking rate over short periods on healthy and biodiverse soils improves nutrient availability and creates a virtuous cycle that benefits both the soil and production (Figure 1).

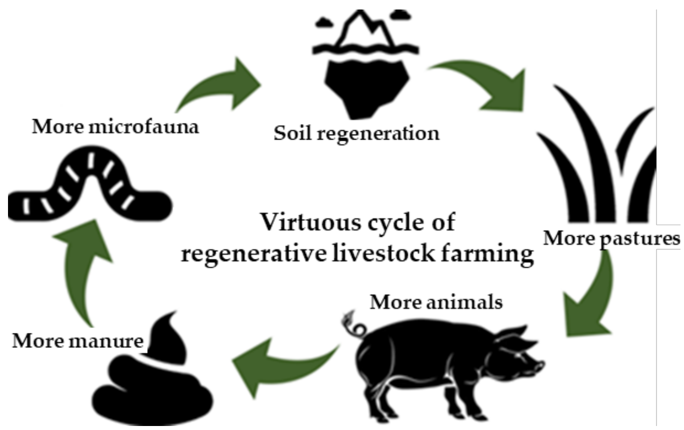

Figure 1: Virtuous cycle of regenerative livestock farming in soil improvement and production efficiency.

To adapt these grazing techniques to pig farming, it is recommended to consider factors such as the division of plots to give pastures a longer resting time and avoid soil erosion while maintaining plant coverage (Milera-Rodríguez, 2022). When three methods for housing pigs on pasture were compared, it was discovered that rotating the animals increased weight gain by 8.5 % and feed efficiency by 8 %. In the field, nutrients such as nitrate, potassium, phosphorous, manganese, zinc, and copper were better distributed when plots were rotated or animals were moved in strips, which favored plant recovery by 22 %, while the externalities of conventional systems were not generated (Pietrosemoli *et al*., 2020).

It is also important to consider the natural behavior of pigs. Rooting, which is the habit of pigs to stir the soil with their snouts, often affects pastures and exposes the soil (Milera-Rodríguez, 2022). A poorly planned outdoor pig farming system can degrade the vegetative cover, exposing the soil to erosion, runoff, and compaction (Bautista-García *et al*., 2022). In a 174 d experiment, at a density of 6 kg m^{-2} of pigs in a continuous grazing system, the amount of total available organic carbon in the soil ranged from 3.2 to 4.3 mg g^{-1} in the first 5 cm of depth; total phosphorous increased from 100.1 to 168.6 mg kg^{-1} at the same depth; the carbon content in humic acids increased from 0.7 to 0.8 mg g^{-1} from 5 to 10 cm depth; and the carbon content in fulvic acid increased from 0.029 mg g^{-1} to 0.34 mg g^{-1} (Rivero *et al*., 2013).

Pig manure is commonly used in agriculture for having a more nitrogen-rich chemical composition (3–5 %) than cattle manure (1–3 %). In general, Mexican soils are degraded and low in organic matter, with only about 1 %. This type of soil is estimated to provide 17.4 kg of N ha^{-1}, in contrast to a fertile soil (4 % of organic matter), which can provide 69.6 kg of N ha^{-1}. Therefore, pig excretions have a great potential to regenerate organic matter in the soil (Rivero *et al*., 2013; Trinidad-Santos and Velasco-Velasco, 2016).

The possibility of using fertilized grazing pens is suggested for agricultural production during the resting period of the plot, since grain yield, number of ears, specific grain weight, and final plant height have been proven to be similar between chemical and organic manure-based fertilizers on maize crops, leading to savings on agricultural inputs for farmers and favoring the resilience of the small-scale agricultural and livestock activities (Couoh-Moo *et al*., 2022). Along with this is the benefit of the work of the animals in plowing as a result of rooting, which mixes the nutrients, loosens the soil, and prepares it for sowing (Milera-Rodríguez, 2022).

Meat quality in free-range pig farming systems

The use of chemical additives in pig feed, such as ractopamine hydrochloride, antibiotics, hormonal implants, and β-agonists, has raised concerns among the health sector and consumers in Mexico (Almaguel *et al*., 2021). On the other hand, FRPFS is a more natural way of producing meat without additives, which leads to a greater innocuity of the final product (Velasco *et al*., 2019).

Pork is nutritious and high in cholesterol, zinc, iron, and vitamin B12. Pork may improve its properties depending on the diet of the animal. A study conducted with people that ate 100 g of pork fed with 10 % avocado meal for six weeks showed a reduction in body fat (1.3 %), body mass index (BMI) (1.3 %), visceral fat (0.4 %), waist circumference (4.4 %), and blood glucose (18.5 %) (González-Jiménez *et al*., 2021). Pork from pasture-fed animals contains high levels of unsaturated fatty acids, such as oleic acid (Velasco *et al*., 2019). However, these nutritional advantages will depend on environmental conditions and the quality of the animals' diet.

Pigs that finish fattening in winter exhibit a higher fat thickness and a more basic hydrogen potential (pH) in the meat, which allows for a longer shelf life after processing (Lebret *et al*., 2021). Meat under this production system dehydrates more slowly, which favors its industrialization and makes it possible to produce different cured products such as cold meats. Product transformation is key to competing with conventional production, which is preferred by butchers due to its higher carcass yield and low-fat content (Ramos-Canché *et al*., 2020). Small-scale farmer associations can help broaden the productive area in which an FRPFS can be implemented and collectively increase livestock benefits.

Challenges of the system

The FRPFS presents challenges that may reduce farmers' interest in its use. To establish these systems, a greater extension of land is required, unlike the conventional system, since the animal load is low (Pietrosemoli *et al*., 2020). In Mexico, small-scale pig farmers usually have plots smaller than 1 ha (Solís-Tejeda *et al*., 2024). Likewise, weight gain in these systems tends to be lower, so it is necessary to provide varied diets with adequate energy and protein levels to reduce the fattening period (Soledad-Carballo *et al*., 2010; Lebret *et al*., 2021).

Despite this, disease reduction must be taken into consideration, since management with less stress improves profitability (Milera-Rodríguez, 2022), and the integration with other subsystems such as maize favors the acceptance by agricultural farmers, who require reductions in fertilization costs (Couoh-Moo *et al*., 2022). On the other hand, animals that have been adapted to conventional systems can undergo stress and diseases when placed in the outdoors. It is important to integrate rustic animals, such as Creole pigs, or to consider a generational adaptation of the herd to the system (Ramos-Canché *et al*., 2020).

CONCLUSIONS

The free-range pork production systems are viable for small-scale farmers, since they reduce dependence on external inputs, increase the resilience of the production units, and favor animal well-being by allowing natural behaviors. In these systems, pigs produce fewer negative externalities, and grazing can be managed to ensure their excretions benefit the regeneration of organic matter in the soil. Commercialization requires different channels than those for conventional pork, but the benefits must be comprehensively quantified, and the interaction with other agricultural and forestry systems should be leveraged. Research on how to increase daily weight gain, adjust stocking rates, and optimize rotation to improve soil management is recommended.

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