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Transitioning opportunities for sub-Saharan Africa's small-scale urban pig farming towards a sustainable circular bioeconomy

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ABSTRACT

Small-scale urban pig farming (SUPF) in sub-Saharan Africa (SSA) contributes to food, nutrition, income and social security of indigent urbanites but is associated with animal, human and environmental health risks. In this context, it is critical to identify key strategies to optimize the benefits and minimize the risks of SUPF in SSA. The current review identifies a set of existing management practices that synchronously enhance sustainability and circularity of SUPF and explore factors influencing the capacity of farmers to adopt such practices. The review demonstrates that there is a multitude of opportunities for enhancing the sustainability and circularity of SUPF in SSA through application of sustainable and circular economy practices (SCEPs) in housing, feeding, breeding, health, marketing and waste management. However, these opportunities can only be fully realized if appropriate urban planning, by-laws, and policies are implemented, and socio-economic, psychological and institutional factors, private-public partnerships and international corporations that promote widespread application of SCEPs are holistically integrated into decision-making processes of the relevant stakeholders. Research should continuously focus on identifying SCEPs adopted by farmers and incorporating their adoption predictors in decision-making. This has the potential to transition SUPF in SSA towards a more sustainable and circular food system.

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1. Introduction

Escalating urbanization and rising of per capita income in Sub-Saharan Africa (SSA) triggered dietary transition towards consumption of animal-source foods (Milford et al., 2019; Regmi & Meade, 2013; Sangwan & Tasciotti, 2023). This has created a niche for livestock farming within cities to enhance the food, nutrition, income and social security of the poor urbanites (Crush et al., 2011; Lindahl et al., 2019). Small-scale urban livestock farming is emerging as a more suitable strategy to satisfy the growing demand for animal-source foods in SSA's urban areas (Lindahl et al., 2019; Mugumaarhahama et al., 2020). Species such as poultry and pigs are preferred because they are early maturing, and have high growth and reproductive efficiencies, and quick economic returns (Lindahl et al., 2019; Mugumaarhahama et al., 2020).

Small-scale urban pig farming (SUPF) offers opportunities to improve the quality of life of poor urban residents through enhanced access to nutritious and healthy meat, and increased cash income from sales (Jacobson et al., 2014; Wilson, 2018). Currently, the world's pig population stands at 752.54 million pigs with the African continent holding only 3.1% of the global herd (Statista, 2021). Pig farming in Africa is

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concentrated in the SSA region, which has over 40 million pigs raised mostly on small-scale farms (Kambashi et al., 2014; Weka et al., 2021). Despite its contribution to the livelihoods of poor urbanites in SSA, pig farming in urban areas is hotly contested largely because of the growing concerns about transmission of zoonotic diseases and environmental pollution related to inappropriate management of pig waste (Makita et al., 2011; Wilson, 2018). As a result, several SSA cities such as Nairobi and Kambala discourage pig farming and most farmers operate without legitimate acknowledgement and support of their key livelihood activity (Alarcon et al., 2017; Jacobson et al., 2014).

Interestingly, the demand for pork in SSA metropolises is consistently growing owing to increasing consumer purchasing power, health-consciousness and prices for competing meats (Latino et al., 2020; Mugumaarhahama et al., 2020). The ability of pigs to valorize bio-wastes abundant in cities, better transport system, proximity to value addition infrastructure and high-value markets in urban areas (Ouma et al., 2017; Twine & Njehu, 2020; Zijlstra & Beltranena, 2013) present small-scale urban pig farmers with opportunities to supply high value-added products. Optimization of these opportunities could enhance economic, environmental, and social security, and transitioning of SUPF towards a sustainable circular bioeconomy. However, this will also entail moving beyond the traditional farming paradigm and integrating sustainable and circular economy practices (SCEPs) and their adoption predictors, which will give insights into the basis for farmers' decision-making process. The current review, therefore, evaluated and identified management practices that can concurrently improve sustainability and circularity of SUPF in SSA, and explore factors influencing the capacity of farmers to adopt SCEPs.

2. Review methodology

All the eligible scholarly articles used in the current review were sourced systematically (Rethlefsen et al., 2021) by searching large bibliographic electronic databases of scientific, technical and livestock research including AGRICOLA, AGRIS, AJOL, Google scholar, PubMed, Sabinet, Sci-Hub, ScienceDirect, SciELO, SCOPUS, SpringerLink and Web of Science. Firstly, a broad Boolean search string 'small-scale urban pig farming' AND 'sub-Saharan Africa' was used. Multiple combination of terms or phrases such as 'factors influencing adoption of sustainable management practices by livestock farmers', 'importance of pigs', 'pig production systems', 'pig management practices', 'pig housing', 'pig breeding', 'pig feeding and water supply', 'pig health and biosecurity', 'pig and pork marketing', 'pig waste management', 'sustainable and circular economy practices', 'urban planning', 'urban by-laws' and 'urban agriculture/livestock policy' were then used. Google search engine was largely used to search published articles, official reports and documents that were not retrieved from the first search activity whereas ResearchGate and Research Square repositories were used to access pre-print where necessary. Sources of information used were from searched literature published in English between the periods 1990 and 2023. Titles and abstracts identified in other languages were translated to English using Google Translate, and any of it that appeared to be relevant, the full documents were then translated and considered for inclusion in the review. Following the comprehensive search for all available potentially relevant literature, the documents were first filtered for relevance and then for risk of bias (Figure 1). Structured approaches were used to describe and critique the relevant literature.

3. Importance of urban pig farming in sub-saharan Africa

It is important to first note that pig farming is well suited to urban areas because of its minimum space, labour, capital and investment requirements (Lindahl et al., 2019; Mugumaarhahama et al., 2020). Urban pig farming in SSA contributes directly to household food and nutrition security through provision of pork meat and its by-products (Jacobson et al., 2014). Pork is a source of excellent quality proteins, energy, fatty acids (e.g. oleic acid, n-3 and n-6 fatty acids), minerals (i.e. selenium, zinc, phosphorus and iron) and vitamin B (i.e. thiamine and cobalamin) important for human nutrition and health (Dugan et al., 2015; Yi et al., 2023). In addition, pork contains bioactive compounds including creatine, taurine, glutathione and choline that have human health benefits (Prasow et al., 2019).

Pig farming in SSA's urban areas is an important source of cash income through sales of breeding and finisher pigs, pork, and manure (Gebregziabhear, 2022; Kimbi et al., 2016; Ouma et al., 2017). The cash income is used to buy food and essential household

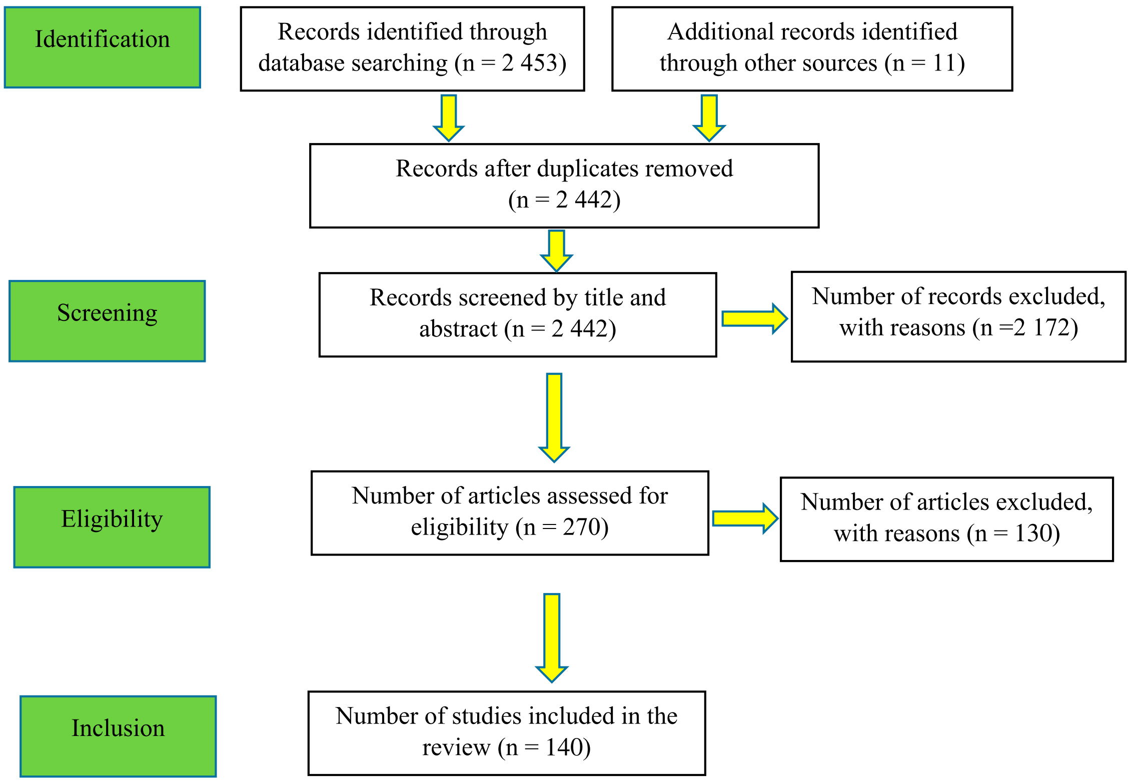

Figure 1. PRISMA flow diagram.

items, pay hired labour, settle education fees, medical bills and debts, and provide financial capital for other agricultural inputs and investments (Herrero et al., 2013). In addition, urban pig farming creates employment opportunities for the urban poor mostly women and youth through production and marketing of breeding and finisher pigs, slaughtering of pigs, management of wastes, selling of fresh, processed and value-added pork products (Jacobson et al., 2014; Mugonya et al., 2018; Nyapendi et al., 2010). It also presents employment and entrepreneurship opportunities to input suppliers, distributors, processors, traders and marketers among other service providers along the pig value chain (Nyapendi et al., 2010; Twine & Njehu, 2020). Moreover, it can increase household economic stability by acting as a cash buffer, capital reserve, insurance, bartering tool and deterrent against inflation, and reduce the risks associated with job losses and low-paying jobs (Herrero et al., 2013; Kimbi et al., 2016).

Urban dwellers raise pigs as a hobby, for dowry, prestige, status and traditional ceremonies (Alarcon et al., 2017; Jacobson et al., 2014). Urban pig farming can also easily be combined with childcare and domestic work, presenting an opportunity for women empowerment (de Zeeuw & Drechsel, 2015; Ström et al., 2017). Furthermore, pig dung is used as a source of organic fertilizer and clean energy (Fenández et al., 2023; Herrero et al., 2013). Interestingly, pigs efficiently valorize animal, plant, food wastes and low-quality feeds into pork with low human health and environmental effects compared to ruminants (Olsen et al., 2023; Zijlstra & Beltranena, 2013). In comparison with ruminants, pigs provide higher and quicker monetary returns owing to their unique inherent attributes like fast growth rates, excellent feed conversion efficiency, high carcass yield, early maturity, high prolificacy and short generation interval (Carter et al., 2013; Lindahl et al., 2019). These pig attributes lead to significant and timely returns on investment and satisfy high urban consumer demand for pork. Figure 2 demonstrates the bioeconomy circularity flow in small-scale urban pig farming.

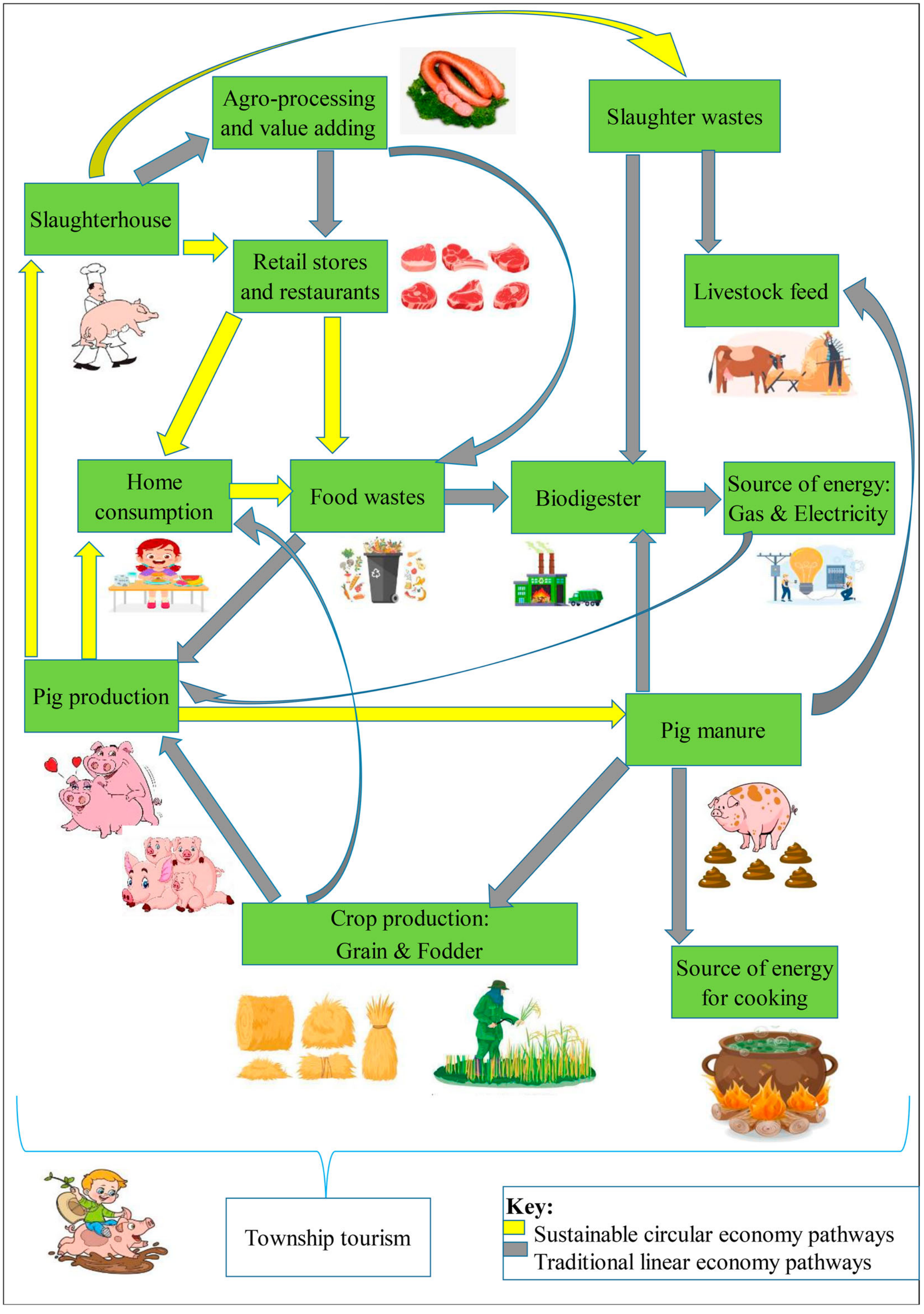

Figure 2. Bioeconomic circularity flow diagram in the small-scale urban pig farming.

4. Urban pig production systems in sub-Saharan Africa

Urban pig farming involves rearing of pigs within a town, city or metropolis boundary (Jacobson et al., 2014; Jagganath, 2022). Pigs in the SSA's urban areas are raised under complex and diverse production systems largely classified based on location, degree of commercialization, land tenure, intensity of inputs and scale of production. Based on location, urban pig production systems may occur on the owner's homestead (on-plot) or land away from the residence (off-plot) (Jagganath, 2022; Thys, 2006). From land tenure's viewpoint, urban pig farming in SSA is practiced on either private (owned or leased) or public land (Jagganath, 2022; Thys, 2006). According to the degree of commercialization, pig production systems can be classified as subsistence or commercial. Subsistence pig production system is a non-commercial system where more than half of the value of produce is consumed at home and surplus is sold (Jagganath, 2022; Thys, 2006). In a commercial system, more than half of the value of produce is sold but small amounts of produce may occasionally be used for home consumption (Smith & Olaloku, 1998; Thys, 2006). In SSA's urban areas, the majority of farmers are commercially-oriented (Kagira & Kanyari, 2010; Nyapendi et al., 2010).

Regarding intensity of inputs, urban pig farming is categorized into intensive, semi-intensive and extensive (Jacobson et al., 2014; Thys, 2006). Intensive (feedlot) farming is a high-input system where pigs are kept in confined housing at high densities and completely rely on humans for the provision of healthcare, water and feed. In contrast, extensive (backyard) farming is a low-input system where pigs freely roam outdoors (free-range) with little or no health care and autonomy over shelter, water and feed. Under semi-extensive production systems, pigs are exposed to a combination of both intensive and extensive conditions, either simultaneously, or varied in accordance with changes in climatic conditions, animal physiological status or type of market. Intensive pig farming is the most common system in SSA's urban areas (Dione et al., 2014; Herrero et al., 2013; Twine & Njehu, 2020).

Pig production systems in SSA's urban areas are further classed into small-, medium- and large-scale based on scale of production (Jacobson et al., 2014; Thys, 2006). Large-scale production system involves rearing of large number of pigs on a large piece of land with huge capital investments, large labour force and advanced technologies. On the contrary, in a small-scale system a small number of pigs are raised on small a piece of land and other factors of production are also small in quantities (capital, labour and technology). In medium-scale, factors of production are intermediate in quantities. Small-scale urban pig production systems predominate within the cities in SSA whereas medium- and or large-scale production systems are rare due to space restrictions (FAO et al., 2017; Kambashi et al., 2014). The choice of type of production system is to some extent a lifestyle preference but is also influenced by economic, social and environmental factors that affect farmers' decisions and shape the production system through modification of management practices (Sassenrath et al., 2010). Therefore, to maintain or enhance sustainability and circularity, a chosen production system should apply appropriate management practices.

5. Urban pig farming management practices

The sustainability and circularity of a livestock farming business is largely determined by a farmer's management practices (Dagevos & de Lauwere, 2021). Broadly, management practices are the methods, initiatives and innovations a manager (i.e. farmer) implements to improve the efficiency of a business (van Assen et al., 2009). Depending on management practices followed by the farmer, pig farming can result in several negative and positive impacts, creating both risks and opportunities for economic, social and environmental security (Foguesatto et al., 2020). To minimize the risks and exploit the opportunities, it is important to identify a set of management practices that simultaneously promote sustainability and circularity for adoption by farmers.

5.1. Opportunities for improving pig housing management practices

In SSA's urban areas, small-scale farmers commonly raise pigs in traditional housing systems largely comprised of enclosed sub-standard structures (Ibrahim et al., 2021; Molotsi et al., 2021). Pig house walls are often built with wood, mud bricks, stones, fence and cement blocks (Bawa et al., 2004; Muhanguzi et al., 2012). Roofs are either left open, closed with traditional (e.g. grass, reeds, straws, or bamboo sticks) or modern (i.e. iron, zinc, asbestos, or polycarbonate sheets) materials (Bawa et al., 2004; Twine & Njehu, 2020). Concrete, wooden, stones and earthen floors are the most common flooring materials (Kambashi et al., 2014; Molotsi et al., 2021). The floors are either bare or insufficiently covered with grass, sawdust, wood shavings, crop residues or leaves (Jacobson et al., 2014; Twine & Njehu, 2020). The type of building materials used and housing structure built are largely determined by affordability, availability, durability, farmer's knowledge, and preferences, pig numbers and production stage (Molotsi et al., 2021; Nath et al., 2013).

Some small-scale urban farmers often clean the pig houses once a day (Ibrahim et al., 2021; Molotsi et al., 2021). However, cleaning frequency is largely influenced by flooring material with earthen floors being the most difficult to clean especially in the wet season (FAO, 2010; Molotsi et al., 2021). Pig houses owned by small-scale urban pig farmers are often poorly sited and lack effluent channels (Jacobson et al., 2014). Most pig houses are not partitioned for pigs of different ages, which largely increases piglet mortality incidences through maternal overlay and hypothermia (Lekule & Kyvsgaard, 2003; Weka et al., 2021). The pig housing capacity varies from one to ten pigs per pen, each pig occupying a floor space of 2–6 m^2 (Ndou, 2010).

High costs of building materials and lack of pig housing design and construction expertise are the major reasons why small-scale farmers in urban areas use sub-standard housing (Bawa et al., 2004; Kouam et al., 2020; Nwachukwu & Udegbunam, 2020). Sub-standard housing adversely affects the growth, health and welfare of pigs (Ludwiczak et al., 2021; Thys, 2006). Insufficiently covered side walls, roofs and floors provide limited protection against precipitation, wind, hot and cold temperatures, pathogens, and predators (Kimbi et al., 2016; Muhanguzi et al., 2012). Such conditions also allow pigs to potentially escape, causing pollution and traffic accidents (Jacobson et al., 2014; Thys, 2006). Sustainable pig housing management practices should include the provision of adequate materials for housing and bedding, sufficient space and good ventilation, protection against climatic extremes, partitioning of the house to cater for different pig classes, routine cleaning and hygiene maintenance, humane handling and movement of animals and appropriate management of wastes (Kyriazakis & Whittemore, 2006; Lekule & Kyvsgaard, 2003). Educating small-scale urban pig farmers on empirical pig housing and husbandry by extension officers and relevant stakeholders through mass media approach to adopt sustainable pig housing management practice will play a significant role in transitioning SUPF towards a sustainable circular bioeconomy.

5.2. Opportunities for improving urban pig feeding management practices

Feeds and feeding practices are key components of a pig enterprise (Guendel, 2002). Diets of confined pigs in SSA's urban areas are primarily comprised of abundantly available crop residues and by-products generated from agro-industrial processes including production of alcohol and biofuel, and the processing of industrial crops, tubers, sugarcane, herbs, spices and multipurpose trees (Katongole et al., 2011; Mugumaarhahama et al., 2020; Okello et al., 2021). Other common pig feed sources are food leftovers including bakery by-products and former food products collected from homesteads, hospitals, schools, restaurants, hotels, food processing plants, waste dumpsites, formal and informal markets (Jacobson et al., 2014; Mutua & Dione, 2021). In addition, pigs consume weeds and grass cut from public lands in urban areas (Ibrahim et al., 2021; Katongole et al., 2012). Slaughterhouse and dairy processing by-products (e.g. meat meals, rumen digesta and whey) are used as pig feed by some farmers (Alao et al., 2017; Lumu et al., 2013; Muhanguzi et al., 2012). All these feeds are either fed separately, simultaneously, or as total mixed diets (Ibrahim et al., 2021). In most cases, pigs are offered the same feed twice a day, in the morning and evening (Abah et al., 2019; Alfredo, 2014). The nutrient composition of some local feed resources for pigs was presented in Table 1, and Table 2 showed the requirements of major nutrients such as the protein, energy, calcium and phosphorus of pigs at different ages and physiological stages. Table 3 presented estimates of daily feed consumption of pigs at different stages and age.

Ad libitum feeding and the use of conventional cereal-legume based total mixed diets and supplements rich in proteins, amino acids, vitamins and or minerals are common among the wealthier small-scale farmers (Ibrahim et al., 2021; Mutua & Dione, 2021). Piglets are supplemented with iron within two weeks of birth, and this is done at the same

Table 1. Nutrient composition of various local feed resources for pigs.

Feed resources	DM (%)	CP (%)	EE (%)	CF (%)	ME (kcal/kg)	References
Swill	25.4	8.9	5.4	5.8	–	Muthui et al., 2019
	11.9	11.9	2.9	3.1	–	
Home-made diets	–	15.8	11.7	–	2688	Muthui et al., 2019
	–	14.5	3.25	–	2102	
	–	21.4	3.23	–	2832	
Bakery by-product	90.8	12.3	5.39	–	3856	NRC, 2012
Brewers grain	92.0	26.5	4.7	–	1920	NRC, 2012
Fish meal	–	63.3	5.9	0.2	–	NRC, 2012
Maize bran	88.5	11.0	6.3	10	2584	Liu, Song, et al., 2014; Noblet & Perez, 1993; NRC, 2012
	87.8	10.8	3.6	12.8	2018	
	89.9	9.9	3.1	–	–	
	89	10.1	2.7	10.6	–	
Maize	89.0	11.0	4.0	–	–	Ocampo et al., 2005
Rice bran	91.1	14.0	16.0	13	2997	Noblet & Perez, 1993; NRC, 2012
	90.1	13.8	16.4	7.8	2970	
Rice	92.0	15.0	17.0	–	–	
Wheat pollard	87.9	19	5.3	8	2871	Noblet & Perez, 1993; NRC, 2012
	87.9	14.9	3.5	4.9	2937	
	90	16.3	4.9	8.8	–	
Wheat bran	87.4	15.1	4.7	11	1833	González et al., 2015; Noblet & Perez, 1993; NRC, 2012
	87.1	14.8	3.5	9.2	2199	
	88.6	15.8	–	–	2547	
	89.1	13.8	3.3	4.6	–	
Cabbage	6.9	1.8	6.4	–	–	Tayyeb et al., 2017
Banana	33.0	4.0	1.0	–	–	Ocampo et al., 2005
Sweet potatoes	33.0	4.5	1.0	–	–	Ocampo et al., 2005
Cassava tuber	30.0	3.0	1.0	–	–	Ocampo et al., 2005
Cassava leaves	16.0	21.0	5.0	–	–	Ocampo et al., 2005

DM: dry matter, CP: crude protein, EE: ether extract, NDF: neutral detergent fibre, ADF: acid detergent fibre, CF: crude fibre, ME: metabolisable energy.

Table 2. Nutrient requirements of pigs at different growth stages.

Weight of pigs (kg and phase)	Digestible protein (%)	Digestible energy (Kcal/day)	Calcium (%)	Phosphorus (g/kg)
0–3	17.0	3400	0.9–1.0	0.75
3–6	16.0	3350	0.8–1.0	0.75
6–10	16.0	3300	0.8–1.0	0.65
10–16	14.0	3300	0.7–0.85	0.60
16-Slaughter	13.0	3300	0.6–0.75	0.50
Gestating sow	11.0	3050	0.60–0.70	0.55
Lactating sow	13.0	3200	0.9–1.10	0.60

Source: Beyihayo et al. (2015) and NRC (1998)

Table 3. Estimated daily feed consumption by different stage and age of pigs.

Categories	Age (months and phase)	Feed (kg/day)
Weaner pigs	2–4	0.25–0.75
Grower pigs	5–6	0.75–1.50
Adults	7–10	1.50–2.50
Sow	Pregnant/lactating	2.50–3.50

Source: Beyihayo et al. (2015)

time with teeth clipping, tail docking, castration, and ear notching or tagging (Abah et al., 2019; Ouma et al., 2014). Though rare in urban areas, extensively raised pigs rely on the natural scavenging feed resource base and are sometimes supplemented with locally available feed resources including crop residues and food leftovers (Kagira & Kanyari, 2010; Katongole et al., 2012).

Scarcity of feed and low feed quality coupled with high feed prices and substantial price fluctuations for conventional feeds have been identified as key challenges for small-scale urban pig farmers (Ajala, 2007; Okello et al., 2021). This is because production of conventional feedstuffs is limited in urban areas (Twine & Njehu, 2020) and roughage is expensive to transport from the countryside (Thys, 2006). More importantly, the use of conventional feedstuffs for pigs competes with food and fuel uses for humans (Sandström et al., 2022). As a result, the majority of small-scale urban pig farmers opt for non-conventional feed resources owing to their local abundance, cost-effectiveness and non-food-competing attributes (Lumu et al., 2013; Ouma et al., 2015). The use of non-conventional feed resources by small-scale farmers is, however, limited by the shortage of affordable and energy-efficient processing and preservation technologies, lack of data on animal production and product quality responses, existence of microbial, chemical and physical contaminants in feed and meat (Pinotti et al., 2021). This is compounded by lack of farmer's awareness and knowledge of these feed resources and their low levels of public acceptance (Pinotti et al., 2021).

The diversity and nutritional composition of non-conventional feed resources for pigs in SSA largely vary with source of feed, season and location (Beyihayo et al., 2015; Carter et al., 2013; Okello et al., 2021). In most cases, locally available, and low-cost non-conventional feed resources do not meet pigs' nutritional requirements for either maintenance and/ or production (Jacobson et al., 2014; Ouma et al., 2015). This often results in inadequate feeding practices (i.e. feeding of imbalanced diets, under- and over-feeding), which adversely affects pig health, growth, reproduction, pork yield and quality (Beyihayo et al., 2015; Okello et al., 2021; Wabacha et al., 2004b). It is, therefore, indispensable to evaluate the nutritional and bioactive profiles of locally available feedstuffs, and their effects on animal production and quality. The integration of mixed crop-pig farming, and pigs' ability to valorize crop residues, plant and animal agro-industrial by-products and food leftovers (UN-DESA, 2021; Zijlstra & Beltranena, 2013) are key SCEPs for pig feeding management in SSA's SUPF areas as highlighted on Figure 2.

5.3. Opportunities for improving urban pig water supply management practices

The major source of drinking water for urban pigs is municipal water obtained from public or private taps (Ibrahim et al., 2021; Ouma et al., 2015). Other sources include boreholes and wells, rivers, streams, dams, lakes, harvested rainwater, recycled water and wastewater (Kagira & Kanyari, 2010; Muhanguzi et al., 2012). On average, confined pigs are offered water twice a day depending on the accessibility of the water and season (Ouma et al., 2015). Besides drinking, water on small-scale urban pig farms is used for cleaning the pens, feed and water troughs and bathing the pigs (Komlatsky et al., 2022; Mfewou & Lendzele, 2018).

Scarcity of drinking water is one of the critical challenges to small-scale pig farming in SSA's urban settlements (Kagira & Kanyari, 2010; Muhanguzi et al., 2012). During periods of water scarcity, farmers in SSA's small-scale urban pig farms are compelled to engage in inappropriate water supply practices including provision of insufficient amounts of water (e.g. water restriction and water deprivation practices) and/or use of poor-quality water resources (Jacobson et al., 2014; Muhanguzi et al., 2012). Poor-quality pig drinking water sources include contaminated conventional resources and non-conventional water resources such as untreated domestic and industrial wastewater, polluted rainwater, saline and drainage waters (Ouma et al., 2015; Wabacha et al., 2004b). These inappropriate water supply practices adversely influence health and growth of pigs by compromising their ability to feed, regulate metabolic heat and maintain normal body functions (Beyihayo et al., 2015). Most small-scale farmers are vulnerable to water scarcity as they often lack infrastructure investments to harvest, decontaminate and store water (Roelofse et al., 2013). Inadequate information on the amount and quality of water consumed by pigs raised on small-scale urban farms in SSA merit investigation. Owing to their role in reducing pollution and conserve water, harvested rainwater, recycled water and wastewater are important SCEPs for water management in SUPF areas in SSA. Research on microbial and chemical quality as well as the portability of these water resources is important.

5.4. Opportunities for improving urban pig breeding and reproductive management practices

Small-scale urban pig farming is predominated by exotic breeds and non-descript crossbreds of unknown genetic characterization (Gebregziabhear, 2022; Kambashi et al., 2014). The non-descript breeds are a result of indiscriminate and unregulated crossing of different exotic breeds (i.e. Landrace, Large White, Hampshire and Duroc), and replacement of indigenous pigs with exotic breeds (Jacobson et al., 2014; Okello et al., 2015). Though non-descript crossbreds have potential to produce high meat yields, they present an economic risk for small-scale farmers because of higher input requirements (Jacobson et al., 2014; Kagira & Kanyari, 2010). On the contrary, indigenous pig breeds are often unaccompanied by high-performance traits but have low feed requirements and high thermal tolerance, disease, and parasite resistance (Halimani et al., 2020; Lekule & Kyvsgaard, 2003). In addition, slow-growing indigenous breeds often yield lean pork with unique flavours, which can be presented as a special dish at premium prices in niche markets (Lemke et al., 2008; Zhao et al., 2017). A catalogue of common pig breeds in various sub-Saharan countries was presented in Table 4.

Breeding practices are not consistent across small-scale pig farms in the SSA's urban areas (Okello et al., 2015; Twine & Njehu, 2020). Under this system, pig breeding is largely informal and characterized by natural mating with a boar to sow ratio of up to 1:15 (Okello et al., 2015; Roelofse et al., 2013). The mating system can either be controlled or random with use of boars from farmers' own herd or neighbourhood, which promotes inbreeding and transmission of diseases (Kambashi et al., 2014). Key

Table 4. Catalogue of common pig breeds in sub-Saharan countries.

Pig breeds	sub-Saharan countries
Exotic breeds	
Large White	South Africa, Angola, Benin, Botswana, Burkina Faso, Burundi, Central African Republic, Congo, Gabon, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritius, Namibia, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo, Uganda, Zambia, Zimbabwe
Landrace	South Africa, Angola, Benin, Botswana, Burundi, Central African Republic, Gabon, Ghana, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Sierra Leone, Togo, Uganda, Zambia, Zimbabwe
Hampshire	South Africa, Botswana, Kenya, Seychelles
Duroc	South Africa, Angola, Botswana, Central African Republic, Gabon, Guinea-Bissau, Lesotho, Seychelles, Sierra Leone, Zimbabwe
Large Black	South Africa, Rwanda
Yorkshire	Ghana, Mali, Rwanda
Berkshire	Rwanda, Sierra Leone
Indigenous breeds	
Windsnyer	South Africa
Tswana	Botswana
Mukota	Zimbabwe
Kolbroek	South Africa
Warthogs	Botswana
Ganda	Angola
Porco	Angola
Local Pig of Benin	Benin
Meishan	Benin
Korogho	Burkina Faso, Côte d'Ivoire, Mali
Bamiléké	Cameroon
Kousseri	Cameroon
Mankon Long Nose	Cameroon
Bakosi	Cameroon
Porc local africain	Burkina Faso, Burundi, Central African Republic, Congo, Gabon, Niger
Porc local tchadien	Chad
Ashanti Dwarf	Ghana
Hampen	Ghana
Porc local	Guinea-Bissau, Madagascar
Basotho	Lesotho
Malawi	Malawi
Race chinoise	Mali
Mongoose	Mauritius, Seychelles
Landim	Mozambique
West African dwarf	Nigeria
Indigène	Rwanda
Alentejano	Sao Tome and Principe
Porc De Dapaong	Togo
Wessex Saddleback	Uganda
Lusitu	Zambia
Nsenga	Zambia
Dalland	Zimbabwe

FAO website: https://www.fao.org/dad-is/browse-by-country-and-species/en/

sustainable breeding management practices such as record keeping, systematic breeding, controlled cross-breeding, selective breeding and artificial insemination, which can minimize inbreeding, and transmission of diseases are not followed or well understood by small-scale urban pig farmers in SSA (Mohakud et al., 2020; Mugonya et al., 2018). In addition, most small-scale urban pig farmers in SSA lack access to superior breeding stock and information services (Gebregziabhear, 2022; Lekule & Kyvsgaard, 2003).

Reproductive performance and management practices of small-scale urban farms in SSA is variable (Table 5). The wide variation can be explained by the heterogeneity in prevalence of diseases and parasites, nutrition, breeds, climatic conditions, farmers' production objectives and management practices (Gebregziabhear, 2022). However, the variation presents a huge opportunity to improve reproduction performance of pigs in the SSA region. It is important to note that the bulk of the existing publication presents one or few reproductive performance attributes at a given time. To this end, comprehensive evaluation of sustainable breeding and reproductive management practices is critical in improving the sustainability and circularity of SSA's SUPF.

Table 5. Reproductive performance of sows under small-scale intensive urban production system in Sub-Saharan Africa.

Attribute	Values range	References	Benchmark indices	References
Fertility index	0.79–1.47	Kouamo et al., 2015		
Fecundity	100	Kouamo et al., 2015		
Age at first puberty (Ages at first estrus)	9–10 months	Goraga et al., 2017		
Age at first service	4–13 months	Berihu & Tamir, 2015; Goraga et al., 2017; Kambashi et al., 2014; Kouamo et al., 2015; Okello et al., 2015	6–8 months	Koketsu & Iida, 2020
Service per conception	1–2	Berihu & Tamir, 2015		
Gestation period	3–4 months	Berihu & Tamir, 2015; Goraga et al., 2017	114–116 days	Koketsu & Iida, 2020
Age at first farrowing	11–123months	Kouamo et al., 2015		
Sow longevity /Lifespan	5–8 years	Okello et al., 2015		
Weaning-to-service interval	2–4 months	Abah et al., 2019; Berihu & Tamir, 2015; Okello et al., 2015; Wabacha et al., 2004b	<7 days	Althouse, 2011
Farrowing interval	5–8 months	Abah et al., 2019; Berihu & Tamir, 2015; Okello et al., 2015; Wabacha et al., 2004b	5months	Althouse, 2011
Farrowing to conception interval	1.9–2.2 months	Goraga et al., 2017		
Litter size at birth	6–13	Berihu & Tamir, 2015; Goraga et al., 2017; Kouamo et al., 2015; Okello et al., 2015	>11.5	Althouse, 2011
Number of piglets born alive per sow per litter	4–19	Abah et al., 2019; Goraga et al., 2017; Kambashi et al., 2014; Okello et al., 2015; Wabacha et al., 2004b	11–12	Althouse, 2011
Number of piglets born dead per sow per litter	0.7–3.0	Berihu & Tamir, 2015; Goraga et al., 2017; Okello et al., 2015	<0.2	Althouse, 2011
Litter size at weaning	2–5	Berihu & Tamir, 2015		
Number of piglets weaned per litter	3–14	Abah et al., 2019; Berihu & Tamir, 2015; Kambashi et al., 2014; Okello et al., 2015; Wabacha et al., 2004b	>9.5	Althouse, 2011
Preweaning mortality per litter per sow	1.0–4.0	Berihu & Tamir, 2015; Okello et al., 2015	<1.4	Althouse, 2011
Preweaning piglet mortality per litter	12–36%	Abah et al., 2019; Berihu & Tamir, 2015; Okello et al., 2015; Wabacha et al., 2004b	<14%	
Litters per sow per year	1–2	Berihu & Tamir, 2015; Wabacha et al., 2004b	2.4	Althouse, 2011
Number of farrowing's per sow per year	1.0–2.0	Berihu & Tamir, 2015; Goraga et al., 2017; Okello et al., 2015		
Lactation period	25–31 days	Kouamo et al., 2015	25–28 days	Koketsu & Iida, 2020
Age at weaning	1–4 months	Abah et al., 2019; Goraga et al., 2017; Kambashi et al., 2014; Kouamo et al., 2015; Okello et al., 2015	18–23 days	Althouse, 2011
Number of piglets weaned per sow per year	4–16	Abah et al., 2019; Goraga et al., 2017		
Boar age at first service	6–18 months	Kambashi et al., 2014		
Boar longevity lifespan	1–4 years	Okello et al., 2015		

5.5. Opportunities for improving urban pig health management practices

Sub-Saharan Africa's SUPF is dominated by non-adapted exotic and non-descript crossbreds often mated randomly and kept in dilapidated, crowded, and dirty houses and fed untreated food and agro-industrial wastes (Gebregziabhear, 2022; Mutua & Dione, 2021). Dilapidated housing allows pigs to escape and roam freely exposing them to human excreta and domestic wastewater which they consume owing to their non-selective feeding behaviour (Gebregziabhear, 2022). This is more prevalent in low-income, high-density suburbs and squatter settlements (i.e. slums) characterized by extremely high human population density, sub-standard housing, informal pig slaughter and pork sales, and lack of electricity, water, sewerage, and refuse removal services (Mtimet et al., 2018). Common health management practices in the pig value chain include unregulated movement of animals, humans, and motor vehicle traffic, as well as sharing of farming equipment (Kouam et al., 2020; Mutua & Dione, 2021). Inadequate sanitation supplies and infrastructure, along with the panic sale of sick pigs and contaminated pork, further confound the problem. Irregular inspection of pork and inappropriate management of animal, human and domestic wastes are also major impediments (Kouam et al., 2020; Mutua & Dione, 2021). All these malpractices often result in increased contact rates and pathogen transmission within and between pig populations, build-up of pig- and pork-associated zoonotic pathogens in the environment and in carrier animals and the emergence of new serotypes or mutations (Kayano et al., 2023).

Common microbial diseases in SSA's SUPF include Africa Swine Fever (ASF) and zoonotic diseases such as anthrax and brucellosis (Ajala, 2007; FAO et al., 2017; Mutua & Dione, 2021). Zoonotic endo (e.g. *Ascaris suum*, *Taenia solium*, *Trichinella spiralis*) and ecto (e.g. *Sarcoptic scabei var suis* and *Haematopinus suis*) parasites are also prevalent (Ajala, 2007; Ouma et al., 2018; Wabacha et al., 2004b). Apart from being public health risks, diseases and parasites adversely impact production and welfare of pigs if left untreated, quality and safety of pork, trade of pigs and pork, consumer demand, and enterprise sustainability (Carter et al., 2013; Kagira et al., 2012). Information on the impact of disease and parasite on SUPF value chain is either insufficient or missing in many SSA countries (FAO et al., 2017) and merit further research.

When disease and parasites occur, small-scale urban pig farmers respond by either doing nothing, seeking veterinary assistance, treating with commercial drugs or traditional remedies, slaughtering for home consumption or sale (Ajala, 2007; Mutua & Dione, 2021; Wabacha et al., 2004b). Sustainable biosecurity practices such as complete confinement of pigs, use of protective clothing and foot baths, isolation of sick pigs, quarantine of newly acquired pigs, culling of disease or parasite carriers, maintenance of adequate distances between farms, active disease surveillance through symptoms and reporting to veterinary officials, purchase of pigs from reputable non-diseased sources, inspection of carcasses, appropriate disposal of carcasses and proper cooking of pork are either ignored, rarely or incorrectly performed (Mutua & Dione, 2021; Wabacha et al., 2004a). Other sustainable biosecurity practices such as vaccination, spraying and deworming of pigs, cleaning and disinfection of pigs are neither done routinely nor appropriately (Abah et al., 2019; Guendel, 2002). In most cases, diseases are neither monitored, diagnosed nor reported timeously and accurately resulting in inadequate or inappropriate treatment of animals (Mutua & Dione, 2021).

Lack of adoption of sustainable biosecurity practices in SSA's SUPF sector is largely attributed to high costs of veterinary vaccines, drugs and biosecurity essentials, complexities of application of biosecurity and absence of tenure security to invest in biosecurity facilities (Dione et al., 2014). Another key challenge is farmers' lack of knowledge and information on pig health management due to limited veterinary extension services (Mutua & Dione, 2021; Thys, 2006). To minimise this challenge, use of community-based animal health workers, privatization of extension and veterinary services, education, and training of value chain actors on sustainable animal health management practices have been recommended (Maake & Antwi, 2022; Smith & Olaloku, 1998). To this end, research should be conducted to determine SSA's pig farmers' willingness to adopt sustainable biosecurity practices, invest in biosecurity infrastructure, and pay for veterinary extension services.

5.6. Opportunities for improving urban pig marketing management practices

In the majority of SSA's urban areas, pig marketing is often informal and uncoordinated (Mugonya et al., 2018; Shyaka et al., 2022). Marketing is done by individual small-scale farmers who sell breeding stock to other farmers and live pigs through auctions to a variety of intermediaries mostly locally-based pig assemblers, traders, brokers, and slaughter slabs (Ajala & Adesehinwa, 2008; Alarcon et al., 2017). Live pigs are mostly marketed on a per-head basis and price agreement reached by one-on-one bargaining between a seller and a buyer based on visual appraisal of the animal (Berihu & Tamir, 2015; Ouma et al., 2018). This could result in farmers not obtaining the true economic value for their pigs and in turn have a negative influence on their financial income. Weighing of pigs, classification/ grading of pig carcasses is rare (Berihu & Tamir, 2015). This could be mitigated by training farmers to use tape measures to assess the girth and height of pigs in order to estimate their weight, especially before slaughter or sale, as access to weighing scales is a limiting constraint. In cases where farmers slaughter at home, they often consume the offals and sell carcasses directly to butchers, restaurants, vendors, informal wet markets, and individual consumers (Antwi & Seahlodi, 2011; Nyapendi et al., 2010). Only a few small-scale farmers sell pigs to commercial abattoirs, pork-processing factories, supermarkets, and export markets (Atherstone et al., 2019; Shyaka et al., 2022).

The SUPF sector in SSA encounter many market-related challenges including barriers to contact buyers, unstable and poorly integrated marketing channels, high transaction costs, lack of price harmonization and inadequate marketing advisory services (Antwi & Seahlodi, 2011; Muhanguzi et al., 2012; Twine & Njehu, 2020). Sustainable and circular economy practices such as processing, value-addition of pig and pork products are either rare or non-existent in the SUPF sector largely due to exorbitant cost of equipment, infrastructure and energy (Ndwandwe & Weng, 2018; Twine & Njehu, 2020). Processing of pig carcasses into different pork cuts (i.e. chops, ribs, belly, roast and shoulders), and value addition of low-quality cuts into mince, sausages, bacon, polony, ham, biltong, cooked salted ears, hot dogs, bologna, nuggets, patties, sand luncheon meat-type products could improve the profitability and sustainability of the SUPF enterprise (Lemke et al., 2008). Residual pork attached to bones and trimmings that are usually discarded after deboning and meat trimming processes can respectively be mechanically recovered and restructured using simple technology into different products for human consumption (Sun, 2009). A shift from selling fresh pork in the local informal markets to sell of processed and value-added products in formal markets and speciality pork products in niche markets can advance transition of SUPF in SSA towards a sustainable food system.

In SSA, small-scale urban pig farmers go through tedious procedures to secure legal protection against existing marketing regulations and lack the scale of operations to secure better prices from traders (Berihu & Tamir, 2015; Roelofse et al., 2013). In this context, urban planning, by-laws, and policies should recognize the embeddedness of SUPF within SSA urban food systems, in which both formal and informal play an integral role. Marketing cooperative can be forged to enhance farmers' bargaining power for better terms of trade and increase access to high-value markets (Antwi & Seahlodi, 2011; Ouma et al., 2018). Small-scale urban pig farmers should also take advantage of the existing high demand for live pigs, pork and by-products, proximity to input suppliers and high-value markets, low transport costs and better access to price information and financial services (Ajala & Adesehinwa, 2008; Twine & Njehu, 2020). The growing demand for pork in SSA's urban areas calls for the continuous assessment of quantities, quality and value of pigs, pork and by-products traded and SCEPs for pig marketing management. It also calls for creation of a niche organic urban pig farming enterprise that may resonate with health and welfare-conscious urban consumers. Such information is critical in formulating marketing strategies that optimize producer prices and satisfy shifting consumers' preferences.

5.7. Opportunities for improving urban pig waste management practices

In SSA, SUPF produces waste in liquid, solid and/ or semi-liquid forms including dung, urine, wastewater, dead animals, slaughter wastes, bedding material and feed residues (Ibrahim et al., 2021; Komakech et al., 2014; Lupindu et al., 2012). The quantities of SUPF wastes produced per farm largely varies with herd size, farm size and production objectives (Gbenou et al., 2022; Omowumi et al., 2021). In most

SSA's urban areas, SUPF wastes are often left to decompose or illegally discarded into landfills, dumpsites, streams, drainage channels, public open spaces or along roadsides (Ibrahim et al., 2021; Lupindu et al., 2012). This is largely driven by lack of demand and markets for wastes coupled with knowledge deficit about the value of wastes, inadequate transport services and waste management regulations (Gbenou et al., 2022; Ibrahim et al., 2021; Komakech et al., 2014). In addition, it is caused by absence of waste management facilities and shortage of field space, labour, capacity and technologies for waste treatment, storage, and application (Gbenou et al., 2022; Ibrahim et al., 2021; Komakech et al., 2014). In some cases, pig wastes are incinerated, buried, and utilized raw or partially processed as manure, energy, animal feed and insecticide against weevils, sold or given free of charge to farmers (Ibrahim et al., 2021; Thys, 2006).

Inappropriate handling, transportation, treatment, storage, and utilization and/ or disposal of SUPF wastes present several animal, human and environmental health challenges (Ibrahim & Sonja, 2019). These problems include air, water and land pollution, transmission of zoonotic and non-zoonotic disease and parasites from pig waste to humans and other livestock (Ibrahim et al., 2021; Ogbuewu et al., 2012; Otte et al., 2007). Moreover, misuse and/ or overuse of antibiotics in SUPF increases risk of emergence of antimicrobial-resistant pathogens, which can be spread to humans, livestock, and the environment through improper waste management (Ibrahim et al., 2021).

Some small-scale urban pig farmers compost wastes in open-air pits, trenches or heaps without adequate aeration and protection from rainfall and sunlight, which increases spread of pathogens by insects and rodents, loss of nutrients through leaching and run-off, and emission of greenhouse gases (Ibrahim et al., 2021; Komakech et al., 2014; Lupindu et al., 2012). Apart from impairing air quality, malodorous emissions, hydrogen sulphide and ammonia from decomposition of pig wastes can result in acidification of rainwater and eutrophication of water bodies (Ibrahim et al., 2021). Unfortunately, the malodorous emissions can also initiate tensions and conflicts between pig farmers and neighbouring residents (Mfewou & Lendzele, 2018; Omowumi et al., 2021). Additionally, decomposition of huge piles of wastes can generate excessive heat that can easily catch fire and damage the environment by emission of toxic pollutants into air, water and soil (Gbenou et al., 2022; Omowumi et al., 2021). Besides that, pig waste may produce allergens that cause occupational and proximity diseases to farmers and neighbours, respectively (Thys, 2006).

Interestingly, appropriate waste management practices can simultaneously reduce environmental, animal and human health risks, whilst producing clean energy, organic fertilizers and animal feeds (Franke-Whittle & Insam, 2013). For example, pig wastes can be used to generate biogas, which can be transformed into thermal, electrical, or mechanical energy (Ibrahim et al., 2021; Limeneh et al., 2022). In integrated pig-fish production systems, pig dung can be used as fishpond fertilizer and supplementary feed for fish (Efole Ewoukem et al., 2012). Some farmers in SSA use pig wastes as bio-substrates for the vermicomposting process to produce microbiologically safe organic fertilizers and insect-based animal feed (Ibrahim et al., 2021). Dead animals and abattoir waste can be used to produce bristles for brush making, animal feed and lard for making grease, soap, candles, lubricants, chemicals, paints, and biodiesel (Chakraborty et al., 2014; Franke-Whittle & Insam, 2013). Low-cost, robust and simple technologies adapted to the specific circumstances of the small-scale farmers can be developed to treat wastewater for crop and livestock water supply (Bryant et al., 2017). These opportunities of utilising pig waste to produce high-value marketable products could make SUPF a sustainable circular bioeconomy (Nath et al., 2023).

Lack of information and effective extension services on animal waste management is an important challenge for the SUPF sector in SSA (Ibrahim & Sonja, 2019; Ogbuewu et al., 2012). Hence, small-scale urban pig farmers in SSA should be trained on sustainable and circular economy practices for managing waste. Further research should determine the quantities of different types of pig wastes produced by the SUPF sector, identify SCEPs used in waste management and evaluate their health, environmental and financial impacts in various SSA's cities. Such information could enhance adoption of SCEPs by small-scale urban pig farmers (Ibrahim & Sonja, 2019).

5.8. Opportunities for improving urban planning, legislative and policy practices

In most SSA's countries, SUPF commonly utilizes marginal or unwanted land with legal status ranging from illegal to tolerated (Mfewou & Lendzele, 2018; Smith & Olaloku, 1998; Thys, 2006). The majority of small-scale-urban pig farmers are either unaware of the existing legal frameworks or consider them to be excessive, inappropriate and or inexecutable (Jacobson et al., 2014; Thys, 2006). In most cases, urban planners and policymakers neglect small-scale pig farming considering it as unproductive, informal, archaic, a nuisance and potential public health and environmental hazard (Crush et al., 2011; Mfewou & Lendzele, 2018; Thys, 2006). It has, however, been argued that food, nutrition, and income benefits of SUPF can outweigh animal, human and environmental health risks if it becomes more productive, and proper urban planning, by-laws, and policies are put in place (David et al., 2010; Latino et al., 2020). For example, government in some sub-Saharan Africa countries plays a role in assisting farmers with grants and loans for procuring farming equipment and production inputs as part of the food security initiative programmes to alleviate poverty and improve livelihoods of farmers (Langyintuo, 2020). The role of urban planning, by-laws, and policy in unmasking the potential of SUPF to enhance food, nutrition and income security while maintaining animal, human and environmental health in SSA's cities has, however, not been investigated. There is also potential revenue for urban councils if the sector is properly regulated and productive, and optimization of land use with potentially derelict structures being converted into productive SUPF thereby contributing to the circular economy.

6. Opportunities for the adoption of sustainable and circular economy practices

Generally, adoption rates of SCEPs among small-scale farmers in SSA countries is low (El Fartassi et al., 2023; Garzón Delvaux et al., 2020). This is caused by limited understanding of the factors that influence adoption of SCEPs (Foguesatto et al., 2020; Liu et al., 2018). Apart from agro-ecological factors, SCEPs are largely influenced by the personal attributes of the farmer, perceptions, and attitudes (i.e. psychological factors), farm attributes, institutional factors, public-private partnerships and international corporations (Foguesatto et al., 2020; Liu et al., 2018). In this regard, understanding the factors that influence SCEPs is of paramount importance in determining small-scale farmers' adaption capacity and willingness to create innovative practices.

Among farmers' personal attributes, gender is one of the main factors influencing adoption of SCEPs in SSA's SUPF (Carter et al., 2017; Quisumbing et al., 2015). In SSA's small-scale urban pig farms, women predominate most of the activities along the pork value chain (Carter et al., 2017; Dione et al., 2020). However, women face more restrictions than men in accessing, using, and controlling productive resources, inputs and services, technology, financial assets and market information (Mutua & Dione, 2021; USAID, 2021). These disparities largely emanate from socio-cultural barriers, family roles and responsibilities (Dione et al., 2020; Mutua & Dione, 2021). However, adoption of SCEPs' contribution to economic, social and environmental security by small-scale urban pig farmers is not well known and merit research.

Age of the farmer can positively or negatively affect the adoption of SCEPs. On one hand, older farmers often have pig farming knowledge, resources, experience and authority, which may promote adoption of SCEPs relative to young farmers (Mafimisebi & Oguntade, 2011; Mwangi & Kariuki, 2015). On the other hand, older farmers are more risk averse, have less energy and interest in long-term planning, investment, and adoption of SCEPs compared to young farmers (Mafimisebi et al., 2012; Mwangi & Kariuki, 2015). Regarding religion, Islam and Judaism prohibit pig farming and pork consumption, hence, adoption of SCEPs is discouraged in areas where these religions are practiced as farmers experience stigmatization, discrimination and social rejection (Weka et al., 2021; Wilson, 2018). However, most Christian denominations promote humane farming of pigs among other animals, which they equate with righteousness (Adam et al., 2019; Szucs et al., 2012) and such communities could adopt SCEPs. Most African traditional religion, encourage production and consumption of pork and are also expected to adopt SCEPs.

Another factor that affects the adoption of SCEPs is family size, which is often used as a proxy for the availability of family labour (Foguesatto et al., 2020). Small-scale urban pig farmers in SSA usually exhaust family labour prior to employing hired labour, which might improve farm profitability and positively influence adoption of SCEPs (Motsa'a et al., 2018; Ume et al., 2020). Farmers' urban pig farming experience and access to education, training, and extension have been positively associated with adoption of SCEPs (Alfredo, 2014; Mutua & Dione, 2021; Wang & Hu, 2023). These factors influence farmers' perceptions and attitudes, which in turn affect their sincerity, rationality and capacity to acquire, synthesise and apply technical knowledge, skills and information relevant adoption of SCEPs (Foguesatto et al., 2020; T. Liu et al., 2018).

Types of livestock kept, source of income, and farm size and herd size, which are often used as a proxy for economic status positively influence adoption of SCEPs (Kouam & Moussala, 2018; Liu et al., 2018). For example, multi-species livestock farming enhances adoption of SCEPs by ensuring livelihood diversifications, and multiple income streams for the farmers compared to monoculture (i.e. mono-species) farming (Martin et al., 2020; Mosnier et al., 2022). Regarding source of income, secondary income increases spending and investment on farming inputs (Kouam & Moussala, 2018; Mwangi & Kariuki, 2015) and enhances farmers' capacity to take risks, access credit and widen information sources relative to having one source of income (Foguesatto et al., 2020; Liu et al., 2018). With respect to herd size, small as opposed to large herds are expected to generate less income from sales which may negatively influence adoption of SCEPs (Koketsu & Iida, 2020; Kouam & Moussala, 2018). In the same context, small farms limit the herd size that can be kept, and space required to apply SCEPs, and lack economics of scale to invest in the adoption of SCEPs (Liu et al., 2018; Marinus et al., 2022; Mwangi & Kariuki, 2015).

When access to land is limited and tenure is insecure as it is in most SUPF in SSA, production objectives are short term and adoption of SCEPs that require high capital investments is limited or non-existent (Jacobson et al., 2014; Thys, 2006). Ultimately, this affects the ability of households to produce, sell, and access food. City authorities and policymakers in SSA' should seek alternative ways of providing land and securing its tenure for small-scale urban pig farmers and explore opportunities of combining it with tourism and recreational land uses. Adoption of SCEPs can also be encouraged by institutional support, which can solve farmers' technical and financial challenges through provision of extension and veterinary support, input supply and distribution, information, subsides, incentives, credit, and insurance services (Garzón Delvaux et al., 2020; Piñeiro et al., 2020). Further studies should investigate how socio-economic, psychological, institutional factors simultaneously influence adoption SCEPs by small-scale urban pig farmers in SSA. To this end, private-public partnerships and international corporations should be forged to broaden access to skills, information, and technology that could enhance adoption of SCEPs by small-scale pig farmers in SSA (Raidimi & Kabiti, 2017; UN-DESA, 2021).

7. Conclusions

In spite of being a potential public health and environmental hazard, SUPF in the SSA region provides a multitude of economic, environmental and social benefits including food, nutrition, income, organic fertilizer, clean energy, waste valorization, social inclusivity and socio-cultural benefits. These benefits could offset hazards if SCEPs are adopted to improve the sustainability and circularity of the SUPF enterprise. However, SCEPs would become more effective if enabling urban plans, by-laws and policies are enacted and implemented in the SSA's. Beyond this, the importance of integrating socioeconomic, psychological and institutional factors, public-private partnerships and international corporations in enhancing farmers capacity to adopt SCEPs should be emphasized. All this could transform SUPF in SSA into a sustainable circular bioeconomy.

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