



Smallholder pig production in Boma (Democratic Republic of the Congo): Techno-economic constraints, local feed resources and opportunities for sustainable intensification

[Production porcine à petite échelle à Boma (République Démocratique du Congo) : contraintes technico-économiques, ressources fourragères locales et opportunités d'intensification durable]

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Abstract

Smallholder pig production plays an important role in food security and rural livelihoods in the Democratic Republic of the Congo (DRC). However, productivity remains constrained by persistent technical, economic and animal health challenges that limit the sector's sustainability, particularly in peri-urban areas such as Boma. This review synthesizes current evidence on pig production systems in Boma, with emphasis on production constraints, the potential of locally available feed resources and strategies for sustainable intensification. A structured literature review was conducted using peer-reviewed publications, institutional reports and technical documents published between 2000 and 2026. The available evidence was critically analyzed to assess production systems, feeding practices, animal health, biosecurity, economic performance and opportunities for resource valorization. The literature indicates that pig production in Boma is dominated by traditional and semi-intensive smallholder systems characterized by inadequate feeding practices, limited veterinary support, weak biosecurity and restricted access to credit and extension services. Feed represents the largest production cost, accounting for approximately 60–75% of total production expenses. Locally available resources, including cassava products, brewery by-products, plantain residues, legume biomass and insect-derived proteins, offer considerable potential to reduce feeding costs and improve resource-use efficiency within circular bioeconomy frameworks. Overall, improving feeding strategies, strengthening animal health services, promoting farmer training and supporting evidence-based policies are key priorities for enhancing the productivity, resilience and sustainability of pig production in Boma. Future research should prioritize integrated techno-economic evaluations and field validation of locally adapted feeding systems.

Keywords: pig production; techno-economic constraints; local feed resources; sustainability; Boma; Democratic Republic of the Congo.

Résumé

L'élevage porcin à petite échelle joue un rôle important dans la sécurité alimentaire et les moyens de subsistance ruraux en République démocratique du Congo (RDC). Cependant, la productivité reste limitée par des difficultés techniques, économiques et sanitaires persistants qui freinent la pérennité du secteur, notamment dans les zones périurbaines comme Boma. Cette étude synthétise les données actuelles sur les systèmes de production porcine à Boma, en mettant l'accent sur les contraintes de production, le potentiel des ressources fourragères locales et les stratégies d'intensification durable. Une analyse documentaire structurée a été menée à partir de publications à comité de lecture, de rapports institutionnels et de documents techniques publiés entre 2000 et 2026. Les données disponibles ont été analysées de manière critique afin d'évaluer les systèmes de production, les pratiques d'alimentation, la santé animale, la biosécurité, la performance économique et les possibilités de valorisation des ressources. La littérature indique que la production porcine à Boma est dominée par des systèmes traditionnels et semi-intensifs à petite échelle, caractérisés par des pratiques d'alimentation inadéquates, un soutien vétérinaire limité, une biosécurité insuffisante et un accès restreint au crédit et aux services de vulgarisation. L'alimentation représente le principal poste de dépenses, soit environ 60 à 75 % des coûts totaux de production. Les ressources locales disponibles, telles que les produits du manioc, les sous-produits de brasserie, les résidus de plantain, la biomasse de légumineuses et les protéines d'insectes, offrent un potentiel considérable pour réduire les coûts d'alimentation et améliorer l'efficacité de l'utilisation des ressources dans le cadre d'une bioéconomie circulaire. De manière générale, l'amélioration des stratégies d'alimentation, le renforcement des services de santé animale, la promotion de la formation des éleveurs et le soutien de politiques fondées sur des données probantes constituent des priorités essentielles pour améliorer la productivité, la résilience et la durabilité de la production porcine à Boma. Les recherches futures devraient privilégier les évaluations technico-économiques intégrées et la validation sur le terrain des systèmes d'alimentation adaptés localement.

Mots-clés : production porcine ; contraintes technico-économiques ; ressources fourragères locales ; durabilité ; Boma ; République démocratique du Congo.

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1. Introduction

Pig production is among the fastest-growing livestock sectors worldwide and plays an essential role in improving food security, nutrition and household incomes, particularly in low- and middle-income countries. In sub-Saharan Africa (SSA), rapid urbanization, population growth and increasing demand for animal-source foods have stimulated the expansion of smallholder pig farming, making it an important source of employment and livelihood diversification (Dio et al., 2020; Adesehinwa et al., 2024; Mathobela et al., 2024).

Despite its socio-economic importance, pig production in SSA remains constrained by several interconnected challenges. Feed accounts for approximately 60–75% of production costs, while recurrent outbreaks of African swine fever (ASF), inadequate biosecurity, limited genetic improvement, weak veterinary services and insufficient extension support continue to reduce productivity and profitability (Dione et al., 2020; Adesehinwa et al., 2024). These constraints are further aggravated by climate variability, unstable feed markets and limited access to agricultural credit, particularly among smallholder farmers.

In the Democratic Republic of the Congo (DRC), pig farming is predominantly practiced under traditional and semi-intensive systems characterized by small herd sizes, low-input management and a strong dependence on locally available feed resources (Kambashi et al., 2014). Although the sector contributes substantially to food security and rural livelihoods, productivity remains low because of poor feeding practices, inadequate housing, limited disease control and insufficient technical support.

Boma, one of the major urban centres of Kongo Central Province, illustrates both the challenges and opportunities facing pig production in the DRC. The region benefits from abundant agricultural and agro-industrial by-products, including cassava products, plantain residues, brewery by-products and legume biomass, which could reduce feed costs and support more sustainable production systems. However, these resources remain poorly characterized and are rarely incorporated into scientifically formulated feeding strategies. At the same time, disease pressure, weak veterinary infrastructure, limited access to finance and fragmented market organization continue to constrain sector development.

Although numerous studies have examined pig production systems in sub-Saharan Africa,

comprehensive reviews integrating technical, economic and nutritional aspects specific to Boma remain scarce. Existing publications generally address production practices, animal health or feeding separately, providing limited guidance for the development of integrated and locally adapted improvement strategies.

Unlike previous reviews that have generally examined pig production in sub-Saharan Africa from isolated technical, nutritional or animal health perspectives, the present review adopts an integrated systems approach specifically focused on Boma, Democratic Republic of the Congo. It combines evidence on production systems, techno-economic constraints, local feed resource valorization, biosecurity, circular bioeconomy and sustainable intensification within a single analytical framework. Furthermore, this review critically compares the situation in Boma with experiences from other African countries, including Uganda, Kenya, Nigeria, Cameroon, Ghana and South Africa, in order to identify transferable practices and context-specific constraints. By integrating technical, economic, environmental and policy dimensions, this review provides a comprehensive evidence base to support future research priorities, decision-making and sustainable development strategies for the pig sector in the Democratic Republic of the Congo.

Therefore, this review aims to provide a comprehensive and critical synthesis of current knowledge on smallholder pig production systems in Boma, Democratic Republic of the Congo. Specifically, it seeks to (i) characterize existing production systems and their performance, (ii) identify the major nutritional, technical, economic and animal health constraints limiting productivity, (iii) evaluate the potential of locally available feed resources within circular bioeconomy frameworks, (iv) compare the situation in Boma with similar production systems across sub-Saharan Africa, and (v) identify research gaps, policy implications and future priorities for achieving sustainable and resilient pig production.

2. Literature review

2.1. Literature Search Strategy

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, 2020) guidelines to ensure a transparent and reproducible literature selection process. Although designed as a narrative review, a structured search strategy was adopted to minimize selection bias.

The literature search was performed between January and April 2026 using five electronic databases: Scopus, Web of Science, CAB Abstracts, PubMed and Google Scholar. Additional references were identified from the reference lists of relevant articles and reports published by international organizations (FAO, WOA and ILRI). The search covered publications published between 2000 and 2026, with particular emphasis on studies published from 2020 onwards.

The search strategy combined keywords and Boolean operators, including: ("pig production" OR "smallholder pig farming") AND ("Democratic Republic of the Congo" OR "sub-Saharan Africa") AND ("feed resources" OR "African swine fever" OR biosecurity OR sustainability). Equivalent search strings were adapted for each database.

addressing pig production systems, feeding, animal health, biosecurity or farm economics in the Democratic Republic of the Congo or comparable sub-Saharan African countries. Duplicate records, publications lacking sufficient scientific information and studies unrelated to the review objectives were excluded.

A total of 217 records were initially identified. After removing 39 duplicates, 178 records were screened based on titles and abstracts. Eighty-one full-text articles were assessed for eligibility, and 42 studies meeting the inclusion criteria were retained for qualitative synthesis (figure 1). The methodological quality of the selected studies was assessed according to their scientific relevance, methodological transparency and contribution to the review objectives.

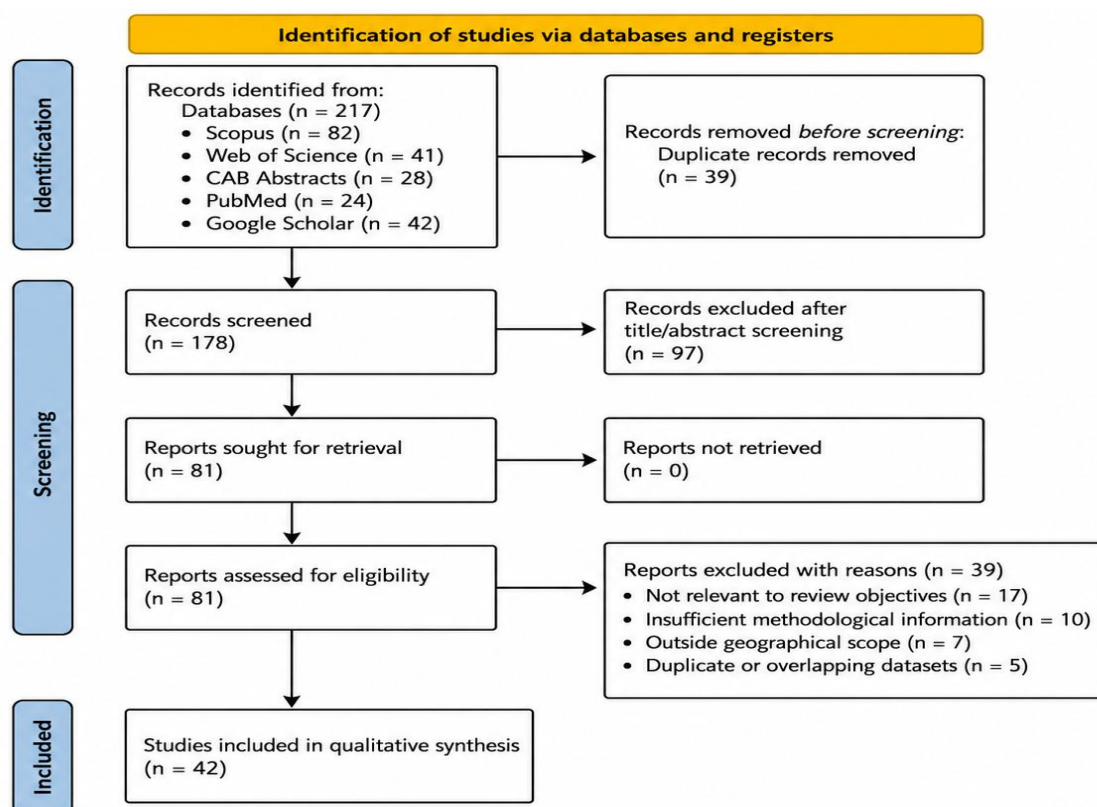


Figure 1. PRISMA 2020 flow diagram illustrating the identification, screening, eligibility assessment and inclusion of studies considered in this review

3. Results

3.1. Pig production systems in Boma

3.1.1. Production systems and farm characteristics

Pig production in Boma is predominantly based on smallholder farming systems, where pigs are generally integrated into household livelihood

strategies rather than managed as specialized commercial enterprises. These systems are characterized by limited external inputs, small herd sizes, low levels of investment and strong dependence on locally available resources. Similar production patterns have been reported in other regions of the

Democratic Republic of the Congo, where peri-urban and rural pig farmers operate along a gradient from extensive to semi-intensive systems depending on market access, availability of feed resources and proximity to urban centres (Kambashi et al., 2014).

In Boma, pig farming contributes to household income generation, food security and financial resilience, particularly through the sale of live animals during periods of economic need. However, productivity remains constrained by limited access to improved genetic resources, veterinary services, technical training and organized markets. These constraints are not unique to Boma but reflect broader challenges affecting smallholder pig systems across sub-Saharan Africa (Ouma et al., 2015; Dione et al., 2018).

Compared with Uganda, where smallholder pig production has benefited from participatory training programmes and improved farmer awareness of biosecurity practices, pig producers in Boma generally have fewer opportunities for extension support and structured interventions (Dione et al., 2018; Dione et al., 2020). Similarly, studies from Kenya and Ghana indicate that improved organization of producer groups and stronger integration into value chains can contribute to increased productivity and market participation among smallholder farmers (Ouma et al., 2015; Kilelu et al., 2017).

3.2. Breeds and genetic resources

Pig populations in Boma are mainly composed of local breeds and crossbred animals adapted to local environmental conditions. Indigenous pigs generally show valuable adaptive traits, including tolerance to local climatic conditions, ability to survive under low-input management and capacity to utilize fibrous feed resources. However, their productive performance is often limited by slow growth rates, low reproductive efficiency and variable carcass characteristics.

Recent studies have emphasized the importance of conserving African local pig genetic resources while improving productivity through sustainable breeding strategies adapted to local conditions. Pius et al. (2024) highlighted that indigenous pig populations represent important genetic reservoirs for climate adaptation, particularly in regions facing increasing environmental stress.

In comparison, some African countries such as Uganda and Kenya have implemented more structured approaches combining local genetic resources with improved exotic breeds. Nevertheless, uncontrolled crossbreeding remains a challenge because it may

reduce adaptation traits if introduced without appropriate management strategies.

3.3. Housing and management practices

Housing systems in Boma are generally characterized by simple structures constructed with locally available materials. These systems provide limited protection against climatic stress, injuries and disease transmission. Similar observations have been reported among smallholder pig farmers in Uganda and South Africa, where inadequate housing and limited biosecurity measures contribute to increased disease risks and reduced animal performance (Dione et al., 2018; Simbizi et al., 2025).

The limited adoption of improved management practices is associated with several factors, including insufficient technical knowledge, restricted financial capacity and weak access to advisory services. Recent evidence indicates that farmer training and participatory extension approaches can significantly improve husbandry practices and disease prevention strategies in smallholder pig systems (Dione et al., 2020).

3.4. Role of pig production in household livelihoods

Beyond meat production, pigs play multiple socioeconomic roles in Boma. They represent a form of savings, provide rapid financial returns compared with larger livestock species and contribute to household resilience during periods of economic uncertainty.

Similar multifunctional roles have been documented throughout sub-Saharan Africa. In Uganda, pig value chains have become important sources of income for rural households, although productivity remains affected by disease pressure, feed costs and weak market coordination (Ouma et al., 2015). In this context, improving pig production in Boma requires not only technical interventions but also strengthening of market organization, access to services and farmer networks.

Overall, pig production systems in Boma share many characteristics with smallholder systems observed elsewhere in sub-Saharan Africa, including low external inputs, dependence on local resources and vulnerability to disease and market constraints. However, the limited availability of institutional support, technical services and organized value chains appears to represent a particularly important limitation in the Congolese context. Understanding these production characteristics provides the basis for analysing the nutritional, health and economic constraints affecting the sustainability of pig farming in Boma.

Table I. Characteristics of smallholder pig production systems in Boma.

Component	Characteristics in Boma	Main implications
Production system	Extensive to semi-intensive smallholder systems	Low productivity but high adaptability
Herd size	Small household-based herds	Limited economies of scale
Genetic resources	Local breeds and crossbreds	Adaptation but moderate performance
Feeding system	Dependence on local resources and crop residues	Low feed cost but nutritional limitations
Housing	Simple local structures	Increased exposure to diseases
Health management	Limited veterinary intervention	High vulnerability to outbreaks
Marketing	Informal local markets	Weak bargaining power
Main constraints	Feed availability, diseases, technical support	Reduced productivity

3.5. Production Constraints Affecting Pig Production in Boma

The productivity and sustainability of pig production in Boma are constrained by multiple interconnected factors encompassing nutrition, animal health, management practices, socioeconomic conditions and institutional limitations. These constraints rarely occur in isolation; instead, they interact to reduce production efficiency, farm profitability and the resilience of smallholder production systems. Similar multifactorial challenges have been reported across sub-Saharan Africa, although their magnitude and relative importance vary according to local production conditions (Adesehinwa et al., 2024; Herrero et al., 2023).

3.6. Nutritional constraints and feed resources

Feed represents the largest production cost in pig farming and remains the principal factor limiting

productivity in Boma. Smallholder farmers depend largely on cassava products, household food residues, plantain wastes and seasonal agro-industrial by-products whose nutritional quality is often variable. Consequently, pigs frequently receive unbalanced diets deficient in protein, essential amino acids and minerals, leading to reduced growth performance and reproductive efficiency.

Similar nutritional challenges have been reported in Uganda, Kenya and Cameroon, where dependence on locally available feed resources and fluctuations in feed availability contribute to poor animal performance (Ouma et al., 2015; Dione et al., 2018; Adesehinwa et al., 2024). Nevertheless, recent studies indicate that strategic use of agro-industrial by-products and locally formulated diets can substantially reduce feeding costs while maintaining acceptable productive performance (table II).

Table II. Major locally available feed resources for pig production in Boma

Feed resource	Main nutritional contribution	Availability	Main limitation
Cassava peels	Energy	High	Low protein, cyanogenic compounds
Cassava leaves	Protein	Seasonal	Fibre content
Plantain peels	Energy	Moderate	Seasonal availability
Brewery by-products	Protein and energy	Moderate	Variable supply
Household food waste	Energy	High	Variable composition

3.7. Animal health and biosecurity constraints

Animal diseases remain among the major causes of economic losses in pig production systems throughout sub-Saharan Africa. In Boma, inadequate veterinary coverage, limited diagnostic capacity and weak implementation of biosecurity measures increase the risk of infectious disease outbreaks. African swine fever (ASF) is particularly important because of its high mortality, absence of an effective commercial vaccine and severe economic consequences for smallholder farmers.

Comparable situations have been described in Uganda, Kenya and South Africa, where improvements in farm biosecurity, farmer awareness and surveillance systems have significantly reduced disease risks (Chenais et al., 2019; Mutua & Dione, 2021; Simbizi et al., 2025). These experiences suggest that strengthening preventive health management may offer greater long-term benefits than relying primarily on curative interventions.

Animal diseases remain a major constraint to pig production in Boma. African swine fever (ASF)

represents the most serious threat because of its high mortality rate and devastating socioeconomic consequences for smallholder farmers. Gastrointestinal parasitism is also highly prevalent and significantly impairs growth performance through reduced feed efficiency and poor nutrient utilization. In addition, respiratory diseases contribute to moderate production losses by decreasing growth rates and overall animal performance, while bacterial infections increase mortality and treatment costs, thereby reducing farm profitability. Collectively, these health challenges underscore the importance of strengthening disease surveillance, preventive healthcare and farm biosecurity to improve the productivity and sustainability of pig production systems in Boma (Chenais et al., 2019; Penrith et al., 2019; Dione et al., 2020).

3.8. Management and technical constraints

Management practices in Boma are predominantly traditional, with limited adoption of improved housing, reproductive management and herd health programmes. Low levels of technical knowledge, insufficient extension services and inadequate farmer training reduce the implementation of recommended husbandry practices.

Participatory training programmes implemented in Uganda have demonstrated that improving farmers' knowledge of nutrition, hygiene and biosecurity can substantially enhance production performance and disease prevention (Dione et al., 2020). Similar capacity-building initiatives could be adapted to the context of Boma.

3.9. Economic and market constraints

The profitability of pig production in Boma is limited by high feed costs, restricted access to credit, fluctuating market prices and weak organization of value chains. Most farmers market live pigs individually through informal channels, limiting their bargaining power and reducing income stability.

Evidence from Kenya and Uganda indicates that strengthening producer organizations, improving market coordination and facilitating access to financial services can substantially improve the economic sustainability of smallholder pig farming (Kilelu et al., 2017; Ouma et al., 2015).

Economic constraints constitute a major barrier to the development of smallholder pig production systems in sub-Saharan Africa. High feed costs, limited access to financial services, weak market integration and inadequate veterinary support collectively reduce farm profitability and discourage investment in improved production practices. Table

III summarizes the principal economic constraints affecting smallholder pig production and their implications for farm performance.

Economic constraints represent another major barrier to the sustainability of smallholder pig production in Boma. High feed costs substantially reduce farm profitability because feed accounts for the largest share of production expenses. At the same time, limited access to credit restricts farmers' ability to invest in improved housing, quality breeding stock, veterinary care and balanced feeding strategies. Weak market organization further reduces producers' bargaining power, often resulting in low farm-gate prices and unstable incomes. In addition, limited access to veterinary services contributes to higher disease incidence and mortality, thereby increasing production losses and compromising overall farm performance. Addressing these interconnected economic constraints will require improved access to financial services, strengthened producer organizations, better market integration and expanded veterinary and extension support to enhance the profitability and resilience of smallholder pig production systems (Ouma et al., 2015; Kilelu et al., 2017; Dione et al., 2020; Adesehinwa et al., 2024).

3.10. Environmental and institutional constraints

Pig production in Boma is also influenced by environmental and institutional factors. Limited waste management practices may contribute to environmental pollution, while inadequate regulatory support and insufficient veterinary infrastructure reduce the effectiveness of disease control programmes. Climate variability may further affect the seasonal availability of feed resources, increasing production costs and reducing farm resilience.

Recent studies emphasize that sustainable pig production requires integrated policies combining nutrition, animal health, environmental management and market development within broader livestock development strategies (Herrero et al., 2023; Mathobela et al., 2024).

3.11. Interactions among production constraints

Smallholder pig production in Boma is constrained by a complex interplay of nutritional, sanitary, economic and institutional factors that should not be considered independently. The literature consistently demonstrates that these constraints interact to create a self-reinforcing cycle of low productivity, poor profitability and limited farm resilience (Adesehinwa et al., 2024). Poor nutrition compromises immune function, increases susceptibility to infectious diseases and reduces

growth and reproductive performance. In turn, disease outbreaks—particularly African swine fever (ASF)—result in high mortality, reduced herd productivity and substantial economic losses, thereby limiting farmers' capacity to reinvest in improved feeding, housing and veterinary care (Chenais et al., 2019; Penrith et al., 2019).

This situation is further exacerbated by limited access to extension services, veterinary support, credit facilities and improved production technologies, all of which constrain the adoption of better husbandry and biosecurity practices. Consequently, low productivity reduces farm income, restricting investment in animal health, nutrition and infrastructure, and perpetuating the cycle of poor performance (Ouma et al., 2021; Mathobela et al., 2024; Simbizi et al., 2025).

Similar interactions among nutritional, health, economic and institutional constraints have been widely reported in smallholder pig production systems across sub-Saharan Africa, where sustainable improvements have generally been achieved through integrated interventions rather than isolated technical solutions (Dione et al., 2018a; Dione et al., 2020; Adesehinwa et al., 2024).

Therefore, improving pig production in Boma will require coordinated strategies that combine balanced nutrition, strengthened animal health and biosecurity, farmer capacity building, improved access to veterinary and financial services, and stronger market integration.

3.12. Economic profitability and pig value chains

Pig production constitutes an important livelihood activity in Boma, providing income, employment and animal-source food for rural and peri-urban households. Nevertheless, the economic performance of smallholder pig farming remains constrained by high production costs, low productivity and inefficient marketing systems. Feed expenditures generally represent the largest component of production costs, often accounting for more than 60–70% of the total cost of pig production

in sub-Saharan Africa (Adesehinwa et al., 2024). Consequently, fluctuations in feed prices have a direct impact on farm profitability and producers' capacity to expand their operations.

Beyond production costs, the profitability of pig farming depends on access to veterinary services, availability of quality breeding stock, market infrastructure and price stability. In Boma, most pigs are marketed through informal channels involving local traders, live-animal markets and direct sales to consumers. While these marketing systems provide immediate cash income, they often limit producers' bargaining power and reduce the value captured along the value chain.

Experiences from Uganda and Kenya demonstrate that better organization of producer associations, improved market information systems and stronger integration of farmers into formal value chains can substantially enhance household income and market competitiveness (Ouma et al., 2015; Kilelu et al., 2017). Similarly, strengthening slaughterhouse infrastructure, meat inspection services and producer cooperatives would improve market efficiency while enhancing food safety and consumer confidence.

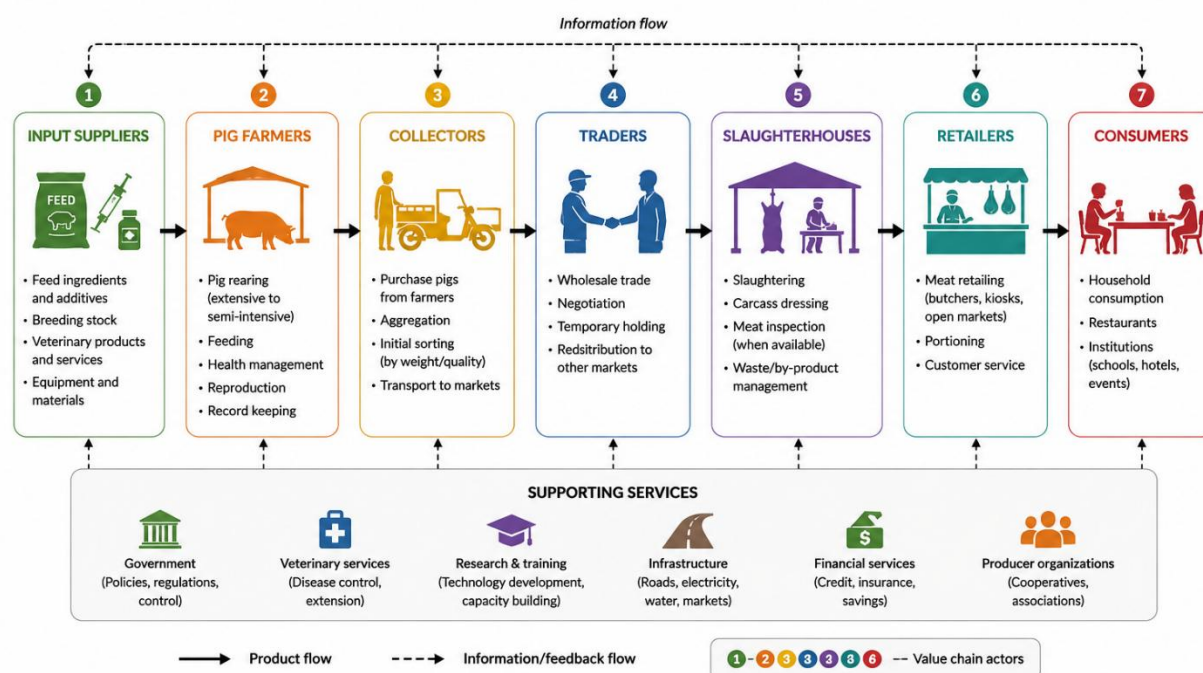
Economic sustainability also depends on reducing production costs through greater utilization of locally available feed resources, improved feed formulation and better herd management. Recent studies suggest that integrating agro-industrial by-products into pig diets may significantly improve profitability while contributing to circular bioeconomy objectives (Mathobela et al., 2024).

Therefore, future development strategies for pig production in Boma should combine technical innovations with institutional support aimed at strengthening value chains, improving market access and increasing farmers' economic resilience (table III and figure 2).

Table III. Main factors influencing the economic performance of smallholder pig production

Factor	Effect on profitability	Possible intervention
Feed cost	High production costs	Use of locally available feed resources
Animal diseases	Mortality and treatment costs	Improved biosecurity and veterinary services
Market access	Low selling prices	Producer organizations and market linkages
Credit availability	Limited investment	Microfinance and agricultural credit
Technical knowledge	Low productivity	Farmer training and extension services

Actors, main activities, flows and support services



Source: Adapted from Ouma et al. (2015), Kilelu et al. (2017), Adesehinwa et al. (2024) and field information from Boma.

Figure 2. Simplified pig value chain in Boma.

3.13. Valorization of Local Feed Resources:

Opportunities for Sustainable Pig Production

Feed accounts for the largest proportion of pig production costs in sub-Saharan Africa, making the identification of affordable and nutritionally adequate alternative feed resources a major research priority (Adesehinwa et al., 2024; Yuan et al., 2025; Kililu et al., 2023). In Boma, the abundance of locally available agricultural by-products and agro-industrial residues offers significant opportunities to reduce dependence on imported feed ingredients while promoting environmentally sustainable livestock production.

3.14. Cassava-based feed resources

Cassava (*Manihot esculenta*) is one of the most widely cultivated crops in the Democratic Republic of the Congo and represents a strategic energy source for pig feeding. Cassava roots are rich in digestible carbohydrates, whereas cassava leaves provide valuable protein, vitamins and minerals. Several studies have demonstrated that appropriately processed cassava products can partially replace maize in pig diets without compromising animal performance, provided that cyanogenic compounds are adequately reduced through drying, fermentation or other detoxification methods (Randolph et al., 2007; Hetero et al., 2023).

Despite these advantages, the nutritional composition of cassava products varies considerably

according to cultivar, agronomic practices and processing techniques. Consequently, locally adapted feeding recommendations remain necessary before large-scale adoption in smallholder production systems.

3.15. Agro-industrial by-products

The growing agro-processing sector in and around Boma generates substantial quantities of brewery residues, plantain wastes and legume by-products that remain underutilized. Brewery spent grains constitute an important source of digestible protein and fibre, whereas residues from plantain processing provide inexpensive sources of dietary energy (McDermott et al., 2010). Similarly, groundnut, soybean and cowpea residues can improve dietary protein content while reducing reliance on imported soybean meal.

The integration of these by-products into pig diets contributes not only to lowering feed costs but also to reducing environmental pollution through the recycling of organic residues, thereby supporting the development of circular livestock production systems (Randolph et al., 2007; Hetero et al., 2023; Tatemoto et al., 2025).

3.16. Insect-derived proteins as sustainable alternatives

The use of insect-derived proteins has emerged as one of the most promising innovations in animal nutrition. Black soldier fly (*Hermetia illucens*) larvae

and termites possess high concentrations of digestible protein, essential amino acids and lipids, making them attractive alternatives to conventional protein sources such as fishmeal and soybean meal (Mathobela et al., 2024).

In addition to their nutritional value, insects can be produced using locally available organic wastes, transforming low-value biomass into high-quality animal feed while simultaneously reducing environmental pollution. Nevertheless, further research is required to optimize production systems, evaluate economic feasibility and establish appropriate inclusion levels under Congolese farming conditions.

3.17. Toward circular bioeconomy-based pig production

The efficient utilization of local feed resources extends beyond reducing production costs. It represents an important component of the circular bioeconomy, where agricultural residues are converted into valuable livestock products while minimizing waste generation and dependence on imported inputs. Such integrated systems have gained

increasing attention as sustainable strategies for livestock development in sub-Saharan Africa (Mathobela et al., 2024).

For Boma, combining cassava products, brewery by-products, plantain residues and insect-derived proteins with improved feed formulation practices could substantially enhance feed self-sufficiency, reduce production costs and strengthen the resilience of smallholder pig farming. However, successful implementation will require nutritional characterization of local feed resources, farmer training, quality control measures and supportive public policies.

Overall, the available literature demonstrates that local feed resources constitute one of the most promising pathways toward economically viable and environmentally sustainable pig production in the Democratic Republic of the Congo. Future studies should focus on optimizing feed formulations, evaluating long-term animal performance and assessing the economic and environmental impacts of these alternative feeding strategies under field conditions.

Table IV. Nutritional characteristics, advantages, limitations and research priorities of locally available feed resources for sustainable pig production in the Democratic Republic of the Congo.

Feed resource	Nutritional contribution	Main advantages	Major limitations	Research priority
Cassava roots	Energy	High availability	Cyanogenic compounds	Processing optimization
Cassava leaves	Protein	Rich in amino acids	Anti-nutritional factors	Detoxification
Brewery spent grain	Protein + fibre	Low cost	Seasonal availability	Conservation methods
Plantain residues	Energy	Readily available	Low protein	Diet balancing
Legume residues	Protein	Local production	Variable composition	Nutrient characterization
Black soldier fly larvae	High-quality protein	Circular bioeconomy	Production scalability	Economic feasibility
Termites	Protein and lipids	Traditional resource	Seasonal availability	Standardization and safety

3.18. One Health Perspective for Sustainable Pig Production

The One Health concept recognizes the close interdependence between animal health, human health and environmental sustainability. In pig production systems, this integrated approach is particularly relevant because disease emergence, food safety, antimicrobial use and waste management have direct implications for both public health and livestock productivity. Incorporating a One Health perspective is therefore essential for developing resilient and sustainable pig production systems in Boma.

3.19. Animal health and disease prevention

Animal health remains one of the major determinants of productivity in smallholder pig farming. In Boma, infectious diseases, parasitic

infestations and inadequate biosecurity contribute to reduced growth performance, reproductive losses and increased mortality. African swine fever (ASF) is particularly devastating because of its rapid transmission, high case fatality rate and severe socio-economic consequences for smallholder farmers (Chenais et al., 2019; Penrith et al., 2019).

Experiences from Uganda, Kenya and South Africa demonstrate that improved farm biosecurity, early disease detection, farmer awareness and coordinated surveillance systems can substantially reduce disease risks and improve herd resilience (Dione et al., 2020; Simbizi et al., 2025). Strengthening veterinary services and community-based disease surveillance should therefore be considered priorities for pig sector development in Boma.

3.20. Public health and food safety

Although pork is an important source of high-quality animal protein, inadequate slaughter practices, poor meat inspection and poor hygiene throughout the pork value chain may increase the risk of food-borne diseases and compromise public health. Informal slaughter and marketing systems remain common in many sub-Saharan African countries, where limited veterinary inspection and inadequate sanitary infrastructure increase the likelihood of microbial contamination during slaughter, carcass handling and meat distribution (Grace, 2015; Fèvre et al., 2017; Thomas et al., 2021). Food-borne pathogens such as *Salmonella enterica*, *Campylobacter* spp. and pathogenic *Escherichia coli* have been repeatedly associated with pork production systems operating under inadequate hygienic conditions (Grace, 2015; Thomas et al., 2021). Strengthening meat inspection, improving slaughter hygiene and enhancing farmer and butcher training would therefore contribute to both food safety and consumer confidence.

3.21. Environmental sustainability

Environmental sustainability is closely linked to pig production because manure management, nutrient recycling and water quality directly influence ecosystem health. In smallholder production systems, inadequate disposal of pig manure may contribute to nutrient losses, water contamination and pathogen dissemination (Herrero et al., 2023; Ran et al., 2022). Conversely, improved manure management through composting, anaerobic digestion and integrated crop–livestock systems enhances nutrient recycling, reduces environmental pollution and improves farm sustainability (Herrero et al., 2023; Ran et al., 2022; Mathobela et al., 2024). Such approaches are particularly relevant for Boma, where crop and livestock production are closely interconnected and where agricultural by-products can be efficiently recycled within circular production systems.

3.22. Integrating One Health into pig production systems

The implementation of a One Health approach requires coordinated action among farmers, veterinarians, public health professionals and environmental specialists. Evidence from African smallholder pig systems indicates that integrated interventions combining farmer training, strengthened biosecurity, participatory disease surveillance and improved veterinary services are more effective than isolated technical measures in reducing disease occurrence and improving farm productivity (Dione et al., 2020; Chenais et al., 2021;

Simbizi et al., 2025). Beyond disease control, integrated management also contributes to safer pork production, improved environmental stewardship and greater resilience of smallholder farming systems. Consequently, adopting a One Health framework would provide a robust basis for enhancing the sustainability and competitiveness of pig production in Boma.

3.23. Circular Bioeconomy and Sustainable Feed Resources

3.23.1. Circular bioeconomy as a pathway for sustainable pig production

The circular bioeconomy has emerged as a promising strategy for improving the sustainability of livestock production by maximizing resource-use efficiency and minimizing waste generation. In pig production, this approach promotes the recovery and valorization of agricultural and agro-industrial by-products as alternative feed ingredients while recycling livestock waste into valuable agricultural inputs (Stegmann et al., 2020; Van Zanten et al., 2019).

For smallholder pig production systems in Boma, the adoption of circular bioeconomy principles offers an opportunity to reduce feed costs, improve resource efficiency and decrease the environmental footprint of production. Because feed represents the largest component of production costs, replacing conventional feed ingredients with locally available by-products could substantially improve farm profitability while reducing competition between human food and animal feed (Mottet et al., 2017; Van Zanten et al., 2019).

3.24. Valorization of locally available agricultural by-products

Boma possesses a wide range of agricultural and agro-industrial residues that could be more efficiently incorporated into pig feeding systems. Cassava peels and leaves, plantain peels, maize bran, palm kernel cake and brewery by-products are produced in significant quantities but remain underutilized despite their nutritional potential. Several studies have demonstrated that, when properly processed and incorporated into balanced diets, these by-products can partially replace conventional feed ingredients without adversely affecting animal performance (Okai et al., 2015; Adeshinwa et al., 2024).

Cassava residues are particularly attractive because of their widespread availability in the Democratic Republic of the Congo. Although cassava peels are rich in digestible carbohydrates, appropriate drying or fermentation is necessary to reduce

cyanogenic compounds before inclusion in pig diets (Morgan and Choct, 2016). Likewise, brewery spent grain represents an important source of protein and

fibre that can improve diet quality while lowering feeding costs when used at appropriate inclusion levels (Mussatto, 2014).

Table V. Potential agricultural by-products for sustainable pig feeding in Boma

By-product	Nutritional value	Potential use	Main limitation
Cassava peels	Energy	Partial maize replacement	Cyanogenic compounds
Cassava leaves	Protein	Protein supplement	High fibre
Plantain peels	Energy	Energy source	Seasonal availability
Brewery spent grain	Protein and fibre	Protein ingredient	Variable moisture content
Palm kernel cake	Fibre and residual oil	Energy supplement	Limited digestibility
Maize bran	Energy	Feed ingredient	Variable nutrient composition

3.25. Black soldier fly larvae as an alternative protein source

Among emerging circular bioeconomy technologies, the production of black soldier fly (*Hermetia illucens*) larvae has attracted considerable attention as a sustainable source of protein for livestock feeding. Black soldier fly larvae efficiently convert organic waste into high-quality biomass rich in protein and lipids, making them a promising alternative to soybean meal and fishmeal (Barragán-Fonseca et al., 2017; van Huis, 2020).

Recent feeding trials have shown that partial replacement of conventional protein sources with *Hermetia illucens* meal can maintain pig growth performance while reducing feed costs and improving the environmental sustainability of production systems (Biasato et al., 2019; Gasco et al., 2020). Considering the abundance of organic waste generated in Boma, insect farming could represent an innovative opportunity for developing locally produced feed ingredients within a circular production system.

3.26. Recycling livestock waste within integrated farming systems

Circular bioeconomy principles extend beyond feed production to include efficient recycling of livestock waste. Pig manure represents a valuable source of organic matter and plant nutrients that can be recycled through composting or anaerobic digestion. These practices improve soil fertility, reduce dependence on mineral fertilizers and contribute to climate-smart agriculture (Herrero et al., 2023; Ran et al., 2022).

Integrated crop-livestock systems, where agricultural residues are used to feed pigs and manure is subsequently returned to crop fields, create closed nutrient cycles that improve both environmental sustainability and farm profitability. Such systems are

particularly well suited to the mixed farming conditions commonly found in Boma.

3.27. Opportunities and challenges for implementation in Boma

Despite the considerable potential of circular bioeconomy approaches, several barriers remain. These include limited technical knowledge, inadequate processing facilities for agricultural by-products, insufficient quality control of alternative feed ingredients and weak extension services. In addition, economic feasibility and farmer acceptance should be evaluated before large-scale implementation.

Nevertheless, growing evidence from sub-Saharan Africa indicates that combining locally available feed resources, improved feed formulation and integrated waste management can simultaneously reduce production costs, improve environmental sustainability and strengthen the resilience of smallholder pig production systems (Adesehinwa et al., 2024; Mathobela et al., 2024). Consequently, promoting circular bioeconomy practices should become an integral component of future pig development strategies in Boma.

4. Discussion

4.1. Main findings of the review

This review highlights that pig production in Boma is predominantly characterized by smallholder, low-input production systems that contribute substantially to household livelihoods but remain constrained by multiple interconnected nutritional, health, technical and socioeconomic challenges. Feed scarcity, recurrent disease outbreaks, limited veterinary services and weak market integration collectively reduce productivity and farm profitability. These findings are consistent with the broader body of evidence describing smallholder pig production systems across sub-Saharan Africa (Dione

et al., 2018a; Ouma et al., 2015; Adesehinwa et al., 2024).

However, the present review also demonstrates that many of these constraints are mutually reinforcing rather than independent. Poor nutrition increases disease susceptibility, disease outbreaks

reduce productivity and household income, and limited financial resources prevent investment in improved feeding, housing and biosecurity. This self-reinforcing cycle represents one of the principal barriers to sustainable pig production in Boma (table V).

Table VI. Comparative characteristics of smallholder pig production systems in selected sub-Saharan African countries

Country	Production system	Major constraints	Main opportunities	Representative references
Democratic Republic of the Congo	Extensive to semi-intensive	Feed scarcity, ASF, weak veterinary services	Local feed resources, growing urban demand	Present review; Kambashi et al. (2014)
Uganda	Semi-intensive smallholder	ASF, feed costs	Biosecurity training, producer organizations	Dione et al. (2018a); Dione et al. (2020)
Kenya	Mixed smallholder systems	Disease outbreaks, marketing constraints	Value chain development	Ouma et al. (2015)
Cameroon	Family-based production	Feed availability, limited genetics	Agro-industrial by-products	Niba et al. (2022)
Ghana	Smallholder systems	High feed costs, limited investment	Expanding pork demand	Osei-Amponsah et al. (2023)
Nigeria	Extensive and semi-intensive	Biosecurity, feed costs	Feed innovation	Adesehinwa et al. (2024)
South Africa	Commercial and emerging smallholders	Biosecurity compliance	Advanced market integration	Simbizi et al. (2025)

4.2. Comparison with other African pig production systems

The production systems observed in Boma share many characteristics with those reported in Uganda, Kenya, Cameroon, Ghana and Nigeria, particularly the predominance of smallholder farms, dependence on locally available feed resources and vulnerability to infectious diseases. Nevertheless, important differences also emerge.

Compared with Uganda, where participatory farmer training and improved biosecurity programmes have strengthened disease prevention (Dione et al., 2020), producers in Boma continue to face limited access to veterinary extension services. Similarly, Kenya has made notable progress in organizing pig value chains and improving market linkages (Ouma et al., 2015), whereas marketing in Boma remains largely informal. In Nigeria, recent research has focused on optimizing alternative feed resources and reducing production costs (Adesehinwa et al., 2024), while South Africa has demonstrated the benefits of stronger regulatory frameworks and farm-level biosecurity for disease control (Simbizi et al., 2025).

These comparisons indicate that the challenges affecting Boma are not unique but reflect broader structural constraints across sub-Saharan Africa. However, the relatively limited institutional support available to pig producers in the Democratic Republic

of the Congo appears to exacerbate the impact of these constraints.

4.3. Implications for sustainable pig production

The findings suggest that improving pig production in Boma requires integrated interventions rather than isolated technical solutions. Increasing feed availability without strengthening animal health services is unlikely to generate sustained productivity gains. Likewise, improving biosecurity alone will have limited impact if farmers remain constrained by inadequate nutrition, poor market access and limited financial resources.

Experiences from several African countries indicate that combining improved feeding strategies, strengthened veterinary services, farmer training and better market integration can substantially enhance both productivity and household income (Dione et al., 2020; Adesehinwa et al., 2024). Incorporating circular bioeconomy principles, including the use of agro-industrial by-products and integrated crop–livestock systems, could further improve production efficiency while reducing environmental impacts.

4.4. Knowledge gaps and future research priorities

Despite the growing literature on pig production in sub-Saharan Africa, important knowledge gaps remain for the Democratic Republic of the Congo. Most available studies are localized, cross-sectional and descriptive, limiting the understanding of long-term production dynamics. Quantitative information on

zootechnical performance, feed conversion efficiency, economic profitability and the prevalence of major pig diseases remains scarce, particularly for Boma.

Future research should prioritize longitudinal studies assessing production performance under different management systems, nutritional evaluation of locally available feed resources, epidemiological surveillance of African swine fever and other priority diseases, and economic analyses of alternative feeding strategies. Additional research is also required to evaluate the potential of insect-based proteins, integrated crop–livestock systems and circular bioeconomy approaches under Congolese production conditions.

4.5. Policy implications

The evidence synthesized in this review highlights the need for coordinated policies supporting sustainable pig sector development in the Democratic Republic of the Congo. Priority actions should include strengthening veterinary and extension services, improving farmer access to quality breeding stock and locally adapted feed resources, promoting producer organizations, expanding market infrastructure and encouraging investment in sustainable livestock production technologies.

Furthermore, integrating One Health and circular bioeconomy principles into national livestock development strategies could simultaneously improve animal health, food safety, environmental sustainability and rural livelihoods. Such integrated policies would contribute not only to increased pig productivity but also to broader objectives related to food security, poverty reduction and sustainable agricultural development.

5. Conclusions

Pig production in Boma plays an important role in food security, income generation and rural livelihoods but remains constrained by interconnected nutritional, health, technical and economic challenges. This review demonstrates that improving productivity requires integrated interventions combining balanced nutrition, strengthened animal health and biosecurity, improved farmer training, better market integration and enhanced institutional support. Experiences from other sub-Saharan African countries indicate that such coordinated approaches can substantially improve the sustainability and resilience of smallholder pig production systems.

Future efforts should focus on strengthening veterinary and extension services, promoting the use of

locally available feed resources, improving value chain organization and integrating One Health and circular bioeconomy principles into pig production systems. In addition, further research is needed to generate quantitative data on production performance, economic profitability, disease epidemiology and alternative feeding strategies under the specific conditions of the Democratic Republic of the Congo. Collectively, these actions would contribute to the sustainable development of the pig sector and its role in enhancing food security and rural economic development.

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Authors' Contributions

J.M. K. contributed to study conception, data collection, and drafting of the manuscript.

A.K.A. contributed to data analysis, interpretation of results, and critical revision of the manuscript.

A.T.T. contributed to critical revision of the intellectual content.

G.B.K. supervised the study and approved the final version of the manuscript.

Ethical Considerations

Not applicable

Consent for Publication

The authors declare that this manuscript does not contain any identifiable personal data, images, or videos requiring consent for publication.

Conflict of Interest

The authors declare that they have no competing financial or non-financial interests related to this study.

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References

- Adeshinwa, A. O. K., Boladuro, B. A., Dunmade, A. S., Idowu, A. B., Moreki, J. C., & Wachira, A. M. (2024). Pig production in Africa: Current status, challenges, prospects and opportunities. *Animal Bioscience*, 37(4), 730–741. <https://www.doi.org/10.5713/ab.23.0342>
- Alarcón, L. V., Allepuz, A., & Mateu, E. (2021). Biosecurity in pig farms: a review. *Porcine health management*, 7(1), 5. <https://doi.org/10.1186/s40813-020-00181-z>
- Arvidsson, A. (2023). *Smallholders and pigs in northern Uganda: an ethnographic study of pig rearing, disease management and local knowledges*. Swedish University of Agricultural Sciences. <https://doi.org/10.54612/a.3k6m0t3sru>
- Bai, X., & Plastow, G. S. (2022). Breeding for disease resilience: opportunities to manage polymicrobial challenge and improve commercial performance in the pig industry. *CABI Agriculture and Bioscience*, 3(1), 6. <https://doi.org/10.1186/s43170-022-00073-y>
- Chenais, E., Boqvist, S., Sternberg-Lewerin, S., Emanuelson, U., Ouma, E., Dione, M., Aliro, T., Crafoord, F., Masembe, C., & Ståhl, K. (2019). Knowledge, attitudes and practices related to African swine fever within smallholder pig production in northern Uganda. *Transboundary and Emerging Diseases*, 66(1), 259–273. <https://doi.org/10.1111/tbed.12347>
- Dione, M. M., Ouma, E. A., Roesel, K., Kungu, J., Lule, P., & Pezo, D. (2018a). Participatory assessment of animal health constraints and their impact on pig production in Uganda. *Preventive Veterinary Medicine*, 155, 95–105.
- Dione, M., Masembe, C., Akol, J., Amia, W., Kungu, J., Lee, H. S., & Wieland, B. (2018b). The importance of on-farm biosecurity: Sero-prevalence and risk factors of bacterial and viral pathogens in smallholder pig systems in Uganda. *Acta tropica*, 187, 214–221.
- Dione, M. M., Dohoo, I., Ndiwa, N., Poole, J., Ouma, E., Amia, W. C., & Wieland, B. (2020). Impact of participatory training of smallholder pig farmers on knowledge, attitudes and practices regarding biosecurity for the control of African swine fever in Uganda. *Transboundary and emerging diseases*, 67(6), 2482–2493.
- Dixon, L. K., Stahl, K., Jori, F., Vial, L., & Pfeiffer, D. U. (2020). African swine fever epidemiology and control. *Annual review of animal biosciences*, 8(1), 221–246.
- Gwaka, L., & Dubihlela, J. (2020). The resilience of smallholder livestock farmers in sub-saharan Africa and the risks imbedded in rural livestock systems. *Agriculture*, 10(7), 270.
- Herrero, M., Mason-D'Croz, D., Thornton, P. K., Fanzo, J., Rushton, J., Godde, C., & Gill, M. (2023). Livestock and sustainable food systems: status, trends, and priority actions. *Science and innovations for food systems transformation*, 375–399.
- Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H., & Bindelle, J. (2014). Smallholder pig production systems along a peri-urban–rural gradient in the western provinces of the Democratic Republic of the Congo. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 115(1), 9–22.
- Kilelu, C. W., Klerkx, L., & Leeuwis, C. (2017). Supporting smallholder commercialisation by enhancing integrated coordination in agrifood value chains: Experiences with dairy hubs in Kenya. *Experimental Agriculture*, 53(2), 269–287.
- Leslie, E. E., Geong, M., Abdurrahman, M., Ward, M. P., & Toribio, J. A. L. (2015). A description of smallholder pig production systems in eastern Indonesia. *Preventive veterinary medicine*, 118(4), 319–327.
- Makungo, P., Fasina, F. O., Mbajjorgu, C. A., & Oguttu, J. W. (2025). Husbandry practices among peri-urban free-roaming pigs in Gert Sibande District Municipality, Mpumalanga, South Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 126(2), 171–179.
- Mathobela, R. M., Molotsi, A. H., Marufu, M. C., Strydom, P. E., & Mapiye, C. (2024). Transitioning opportunities for sub-Saharan Africa's small-scale urban pig farming towards a sustainable circular bioeconomy. *International journal of agricultural sustainability*, 22(1), 2315918.
- Mutua, F., & Dione, M. (2021). The context of application of biosecurity for control of African swine fever in smallholder pig systems: current

- gaps and recommendations. *Frontiers in veterinary science*, 8, 689811.
- McDermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., & Van de Steeg, J. A. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock science*, 130(1-3), 95-109.
- Nantima, N., Davies, J., Dione, M., Ocaido, M., Okoth, E., Mugisha, A., & Bishop, R. (2016). Enhancing knowledge and awareness of biosecurity practices for control of African swine fever among smallholder pig farmers in four districts along the Kenya-Uganda border. *Tropical animal health and production*, 48(4), 727-734.
- Ng'ang'a, K. G., & Cramer, L. K. (2024). Contributions of the CGIAR Livestock and Climate Initiative to Kenya's Third National Climate Change Action Plan (2023–2027) (NCCAP III).
- Ouma, E., Dione, M., Mtimet, N., Lule, P., Colston, A., Adediran, S., & Grace, D. (2021). Demand for *Taenia solium* cysticercosis vaccine: lessons and insights from the pig production and trading nodes of the uganda pig value chain. *Frontiers in veterinary science*, 8, 611166.
- Ouma, E. A., Dione, M. M., Lule, P. M., Pezo, D. A., Marshall, K., Roesel, K., & Jagwe, J. (2015). Smallholder pig value chain assessment in Uganda: Results from producer focus group discussions and key informant interviews.
- Penrith, M. L., Bastos, A. D., Etter, E. M., & Beltrán-Alcrudo, D. (2019). Epidemiology of African swine fever in Africa today: Sylvatic cycle versus socio-economic imperatives. *Transboundary and Emerging Diseases*, 66(2), 672-686.
- Pius L, Huang S, Wanjala G, Bagi Z, & Kusza S. (2024). African Local Pig Genetic Resources in the Context of Climate Change Adaptation. *Animals* (Basel). Aug 19;14(16):2407. doi: 10.3390/ani14162407. PMID: 39199941; PMCID: PMC11350805.
- Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., & Ruel, M. (2007). Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of animal science*, 85(11), 2788-2800.
- Simbizi, V., Moerane, R., & Gummow, B. (2025). The Role of Smallholder Pig Farmers in the Biosecurity of Pig Diseases in the Eastern Cape Province of South Africa. *Veterinary Medicine International*, 2025(1), 4755096.
- Singh, M., Pongenere, N., Mollier, R. T., Patton, R. N., Yadav, R., Katiyar, R., & Mishra, V. K. (2023). Participatory assessment of management and biosecurity practices of smallholder pig farms in North East India. *Frontiers in Veterinary Science*, 10, 1196955.
- Tatemoto, P., Vieira, F., & Broom, D. M. (2025). Pig farming practices compromising biosecurity and causing poor welfare of pigs. *Frontiers in Veterinary Science*, 12, 1558734. <https://doi.org/10.3389/fvets.2025.1558734>
- Yuan M, Cui Z, Sun Y, Li J, Xiaoxiao L, Hong X, & Yan P. (2025). Comparison of Meat Quality and fibre Characteristics in Pigs Breeding in Cement Floor and Deep Litter Floor. *Vet Med Sci. Sep*;11(5): e70590. doi: 10.1002/vms3.70590. PMID: 40884308; PMCID: PMC12397947.