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Small pelagic fish at the feed-food nexus in sub-Saharan Africa: a scoping review

Joshua Wesana[1,2,3]*, Rodrigue Yossa[4], Stuart W. Bunting[2] and Philippa J. Cohen[4]

[1]Department of Food Innovation and Nutrition, Mountains of the Moon University, Fort Portal, Uganda, [2]Natural Resources Institute, University of Greenwich, Kent, United Kingdom, [3]Department of Agricultural Economics, Ghent University, Gent, Belgium, [4]WorldFish, Penang, Malaysia

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Addis Ababa University, Ethiopia

*CORRESPONDENCE
Joshua Wesana
✉ joshua.wesana@ugent.be

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Introduction: Nourishing the growing and changing global population within sustainable limits is a pressing concern that must be addressed by 2030. To meet this challenge, it is argued food systems must transform, but a range of different food system configurations and trade-offs must be considered by national, regional and global decision-makers. Wild caught Small Pelagic Fish Species (SPFS) are a valuable source of human nutrition and are also frequently processed into fish meal and fish oil to become the principal protein and lipid sources for farmed animal feeds. The choices between the primary (i.e., for direct human consumption) and secondary (i.e., for animal feed ingredients) uses of small-pelagic freshwater and marine fish provides an illustrative example of contention and opportunity in balancing livelihood, income, consumer demand and human nutrition needs. Whilst the potential trade-offs have received much popular attention, there is a clear need to examine the evidence.

Methods: In this paper, we systematically collate peer reviewed literature and trade data from the African Great Lakes Region (AGLR) and the western coastal region of sub-Saharan Africa. A total of 201 articles met our search criteria, and of those we deemed 32 to hold sufficient and quality data for use in this review.

Results: The AGLR (76%), and specifically Kenya (64%), were best represented in the literature which covered alternative feed proteins, assessment of feed/food nutritional quality and availability of feed/food resources. We find that the use of SPFS as feed limits access for use as food. This further supports innovations to develop fish oil and fish meal alternatives to safeguard SPFS for direct human consumption, particularly in resource-poor contexts.

Discussion: Since most extracted evidence in this review was from the AGLR, there is still a need for more targeted investments for robust research that is cross-regional to better understand the magnitude, dynamics and trade-offs concerning the utilization of SPFS in SSA.

KEYWORDS

fish meal, fish oil, animal feeds, animal nutrition, aquaculture, capture fisheries, human nutrition, trade-off

1 Introduction

Nourishing the growing and changing global population within sustainable limits is one of the foundations of all the Sustainable Development Goals (SDGs) of the United Nations (United Nations, 2015). Navigating towards sustainable food systems requires decisions at global, regional and national scales weighed up against a suite of trade-offs (Mausch et al., 2020). The fisheries sector provides fish and other aquatic foods through fisheries and aquaculture, and offers an excellent case study from the points of supply and along supply chains (Tezzo et al., 2021). In low- and middle-income countries, it is capture fisheries, and particularly small-scale fisheries, that supply the majority of fish and other aquatic foods (Cohen et al., 2019; Thilsted et al., 2016). In some low- and middle-income countries, aquaculture is emerging as an important source of fish and other aquatic foods (FAO, 2020a). Despite terrestrial livestock production contributing more protein than aquaculture to consumers (Edwards et al., 2019), at a global scale aquaculture is the fastest growing food production sector. The proliferation of both aquaculture and livestock production, and projected increasing demand for animal source foods, has implications for capture fisheries – most directly where fish sourced from capture fisheries are key ingredients for farmed animal feeds (Naylor et al., 2000; Naylor et al., 2021).

The intensive production of both terrestrial and aquatic animal source foods relies on inputs of feeds. Fish meal and fish oil (FMFO) are a common ingredient of such feeds, and are a key supply of protein and lipid ingredients (Shepherd and Jackson, 2013; Tveterås and Tveterås, 2010). FMFO are mainly produced from small pelagic fish species (SPFS) that are caught from both marine and inland waters (Naylor et al., 2021). With regards to the sustainability and affordability concerns related to FMFO as a key feed ingredient, many research and development efforts seek to find alternatives and/or reduce, through breed selection, the reliance on FMFO without reducing the quality of the ultimate products (Cottrell et al., 2020; Olsen and Hasan, 2012). Although the quantity of small pelagic fish processed into FMFO is decreasing (FAO, 2020a), the current increase in aquaculture and livestock production may be explained by innovations that have led to improved efficiency (Naylor et al., 2021), including for example the use of novel plant-based ingredients in feed formulation (Turchini et al., 2019). However, weaknesses remain in alternatives (Cottrell et al., 2020) such as poor digestibility, missing essential amino acids, the presence of anti-nutritional factors and safety risks. These weaknesses limit widespread adoption of non-fish feeds (Mitra, 2020; Glencross et al., 2020).

Despite research and development investments in alternatives, FMFO often remain the key source of protein and lipid ingredients for feeds. One of the concerns raised by media, policy and research from food security perspectives is that the continued dependence on small pelagic fish for animal production diverts fish away from the diets of vulnerable populations (Thiao and Bunting, 2022; Cashion et al., 2017; Isaacs, 2016). The cost or lost opportunity for young children and women is highlighted as most severe, as their diets and health can be substantially improved by the nutrients found in high density in small pelagic fish (FAO, 2020a; Naylor et al., 2021; Cashion et al., 2017). These concerns are particularly true for populations in countries of sub-Saharan Africa where endemic nutritional deficiencies persist across the continent (Tran et al., 2019; Chan et al., 2019). In the last decade of the SDGs 2030, urgency to meet commitments made in Sustainable Development Goal 2 to end all forms of hunger intensified. Simultaneously, demographic and economic changes are driving the growing demand for animal source foods, and growth and investment in the fed animal industry follows suite. There is a pressing need to understand the opportunities and trade-offs that the fish meal and fish oil industry represents for geographies like sub-Saharan Africa (Cottrell et al., 2020; Cashion et al., 2017; Lynch et al., 2020; Fréon et al., 2014).

Literature reviews have examined the sustainability of fish oil and fish meal as a feed ingredient, and specifically on how the industry impacts on small pelagic fish stocks (Olsen and Hasan, 2012; Naylor et al., 2009). Further reviews have examined the characteristics and performance of alternative ingredients to fish oil and fish meal (Gatlin III et al., 2007; Hua et al., 2019; Shah et al., 2018; Nasopoulou and Zabetakis, 2012). Other reviews examine trade-offs between using small pelagic fish for direct human consumption relative to feed ingredients (Thilsted et al., 2016; Cashion et al., 2017; Isaacs, 2016; Tacon and Metian, 2008; Troell et al., 2014; Tacon and Metian, 2009). We build on the insights of these reviews, bringing new literature and a specific focus on the AGLR and the western coastal regions of sub-Saharan Africa. The aims of the present study are to: (i) determine the types and degree of synergy and trade-off between direct human consumption and production of fish oil and fish meal; (ii) understand trends and rationale for dominant policy and research and development recommendations provided. We further complemented the literature review with examination of data on the trade of fish oil and fish meal to (iii) understand trends in exports and imports of FMFO to estimate how this trade could affect nutritional outcomes in sub-Saharan Africa, as compared with retaining it as food for local consumption.

2 Methods

2.1 Literature search strategy

We searched Google scholar, Scopus, Too Big-To-Ignore and Web of Knowledge databases for literature published between 2000 and 2023. We used the following syntax:

> *(((fish* OR aqua* OR "small scale fish*" OR "artisanal fish*" OR "capture fish*" OR "marine fish*" OR "inland fish*" OR "small pelagic fish*" OR "fish farm*" OR animal OR poultry OR livestock) AND (feed* OR diet* OR meal* OR oil*) AND ("African great lakes region" OR "west African coast" OR "sub-Saharan Africa" OR Gambia OR Mauritania OR Senegal OR Ghana OR Nigeria OR Burundi OR "DR Congo" OR Kenya OR Malawi OR Mozambique OR Rwanda OR "South Sudan" OR Tanzania OR Uganda OR Zambia))).*

After removing duplicates, we screened titles and abstracts to determine articles to include in our review (Figure 1). Our inclusion criteria were that the article: (i) presented research from at least one country in the AGLR and or western coastal region of Africa, (ii) examined fish meal and/or fish oil production from SPFS to produce animal feeds and (iii) was written in English. We then excluded studies that examined animal feeds but did not explicitly mention FMFO as a feed ingredient. We did not impose any restriction on inclusion based on the motivation behind studies. A total of 201 articles were included in our detailed review of content and categorisation based on a full reading of the article. From here, a subset of 32 articles were found to hold data accessible and were ultimately included in the in-depth discussion of this review.

2.2 Literature data extraction

We used Endnote software (version X9) to store, manage and group articles into categories (described below). There were three data coders, and we cross-checked all selected and excluded articles among

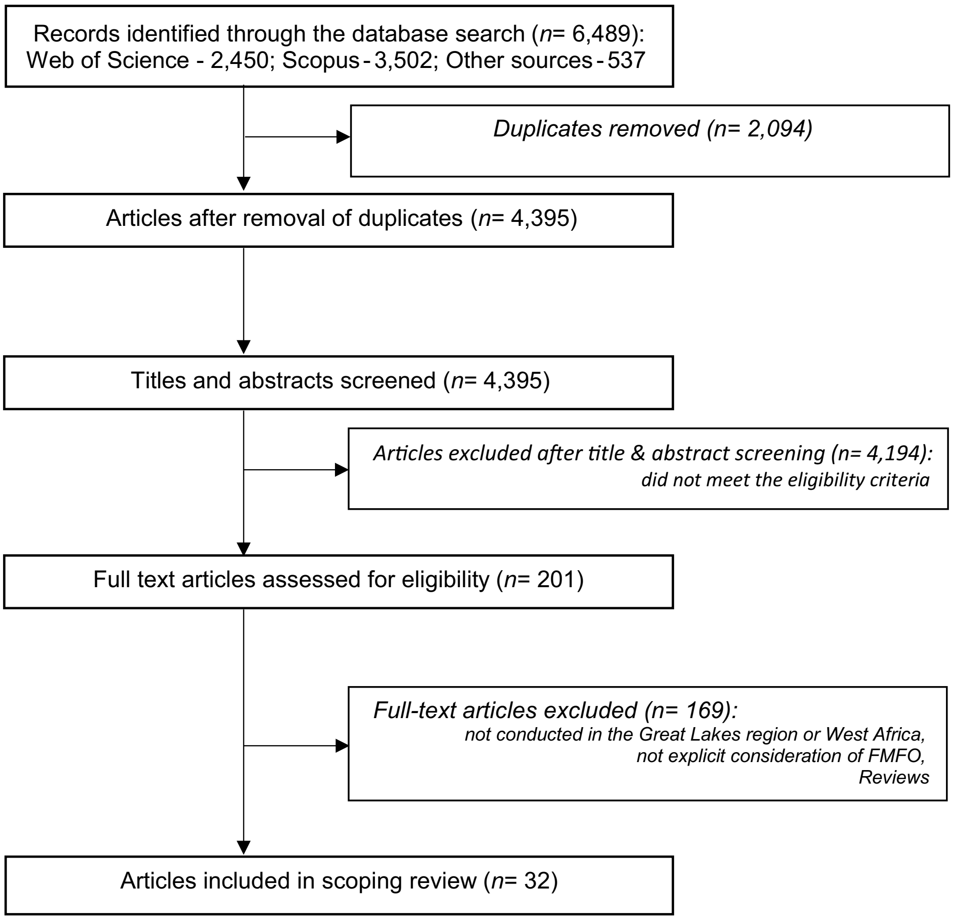

FIGURE 1
Flow chart for study search and selection.

coders to ensure studies were not incorrectly excluded or included and that categorisation decisions were consistent. If there were doubts and consensus could not be reached, an additional round of collective scrutiny of articles in question was conducted.

For the first stage of our review, we categorised the 201 studies according to basic characteristics (such as country of focus, value chain actors, study design and method of data collection), study motivation, species of small pelagic fish studied and target sector. Here, we also made a consideration and assessed whether studies discussed the trade-offs between the use of SPFS either as a feed ingredient for animals and or food for human consumption. For the second stage of our review, we also extracted findings or recommendations related to policies and future research on the use of SPFS as feed ingredients or food. A thematic assessment of extracted raw data summarized the text into manageable themes that were common across studies. This was the basis for performing a narrative synthesis of processed information into a structured presentation and discussion of review findings.

2.3 Export and import data analysis

To complement and situate the findings from the review, we examined recent trends in exports and imports of FMFO using data from the global FishstatJ database between the year of 2009–2018 (FAO, 2020b). Changes in export and import levels of FMFO during the period were calculated by subtracting the 2009 value from that reported in 2018 for each of the 15 countries. This database includes the major aquaculture and fishery commodity group and classifies "meals" and "oils" separately, where those categories aggregate 35 and 26 different products, respectively. We derived estimates of fresh fish needed to produce the reported volumes of fish meal and fish oil by using conversation ratios of 22.5% fish meal: fresh fish and 5% fish oil: fresh fish (Tacon and Metian, 2008). These are the volume (provided in metric tonnes per year) of fresh fish needed to yield the specified volume of fish meal, followed by the estimation of fish oil that would be produced. If the amount was below that required, the overall requirement of fresh fish was estimated by adjusting for the volume of fresh fish needed to yield the additional fish oil. While this approach helped to avoid double counting, the estimated amounts of fresh fish required to yield both fish meal and fish oil are assured to be adequate (Tacon and Metian, 2008).

3 Results

3.1 Characteristics of identified studies

The search of databases identified 4,395 unique articles (Figure 1). We identified 201 articles that met our inclusion criteria for categorization, with 32 having sufficient methodological description and data quality to allow uniform extraction of data. Most articles (25) with data fit for exploration reported research from the Great Lakes region. Of these, Kenya dominated with 16 studies followed by Uganda with seven studies (Table 1). Other countries in this region had at most three studies. For the western coastal region, only four studies were conducted in Nigeria while other countries in this region, like Mauritania or Senegal were least represented. We identified three multi-country studies, two from the Great Lakes Region, covering Kenya, Tanzania, Rwanda and Uganda while one included Nigeria from the western coastal region and Kenya and Zambia from the Great Lakes region. Although selected studies used a wide range of data collection approaches, feed sample collection (43%) and surveys (43%) were the most prominent.

Of the 32 articles we reviewed, 23 investigated the use of fish meal or fish oil in the aquaculture sector (Table 1), with only 5 focussed on terrestrial livestock (poultry, piggery and dairy) farming. The articles focussed on different nodes along the supply chain, but the node of focus was related to the sector studied. For example, of the 15 aquaculture studies that dealt with a single node of the supply chain, the majority ($n = 8$) were at the farmer (i.e., feed user) node and feed processor node (5). There were only two studies that focused on the feed trader node, one that examined the fishers of raw product (i.e., small pelagic fish), and one on the consumer node (i.e., consumers of the fish products fed with feeds from fish oils and fish meals). Studies of the aquaculture sector also spanned multiple nodes in the supply chain, i.e., five studies generated data from perspectives of fish farmers and feed processors, and two studies examined three nodes of the supply chain with perspectives provided by fish farmers, feed processors and feed traders. We found that the region or country of origin of the small pelagic fish destined to be feed ingredients were identified in slightly over half of studies and just over half the studies identified the specific types or species of the small pelagic fish.

3.2 Use of small pelagic fish as feed and or food

We found there to be five broad areas investigated by the articles we identified. This included research to identify feed proteins that were effective alternatives to fish oil and fish meal (25% of all 32 articles), assessment of nutritional qualities of the feed and ultimate food product (25%), and availability and sustainability of feed and food resources (22%). Few studies (12%) examined food safety (e.g., the presence of mycotoxins) or the governance of the industry or supply chains (15%).

3.2.1 Alternative sources of feed proteins

We identified eight studies that sought to examine and identify sources of feed proteins that were alternative to fish oil and fish meal. Of these, four studies solely targeted the aquaculture sector (Table 2). Two studies from Kenya noted that the digestibility and protein content of sunflower cake, fed to tilapia, was similar to that of fish meal, and only differed by the low lysine and threonine levels in the former (Maina et al., 2002; Maina et al., 2007). Furthermore, it was observed that both the protein efficiency ratio and productive protein value of sunflower cake was lower than that of fish meal when fed to tilapia. Another study from Uganda, that investigated the perception towards the use of insects as a replacement for fish meal found that fish farmers, feed traders and feed processors were positive about substituting insect biomass for expensive fish meal (Ssepuuya et al., 2019). A study from Benin that assessed available and affordable protein feed ingredients observed that use of fish meal in animal feed competed with human consumption, and its nutritional quality as a feed ingredient varied widely (Adéyèmi et al., 2020). The latter was linked to adulteration of fish meal as the main limiting factor. Fish meal was reportedly mixed with either fish offal and poultry viscera or whole garden snails and oyster shells.

There were two additional Kenyan studies targeting only one sector. The first study investigated the benefits of replacing fish meal with insects in poultry feeds and estimated that a 5–15% replacement could potentially translate into 76,000 additional jobs in the sector (Abro et al., 2020). The other study by Chia et al., (2019) on the piggery sector further indicated that insects were not only a rich source of proteins but there was high potential of converting food waste into valuable resources through the production of insects for feeds. This study further observed a complete replacement of fishmeal by insect meal had no adverse effects on pigs. Two studies from Kenya were cross-sectoral and in addition to aquaculture, they targeted the poultry and piggery sectors. Chia et al., (2019) observed a high level of awareness regarding the potential use of insects as alternative feed ingredients among fish, poultry and piggery farmers. Although another study by Nyakeri, Ogola (Nyakeri et al., 2017) targeted the aquaculture and poultry sectors, it did not explicitly discuss the use of fish meal either as feed or food.

3.2.2 Nutritional quality of feeds/food

There were six studies across the aquaculture, poultry and piggery sectors (Table 2). Three studies pointed to the low quality of local fish meal used as an ingredient in feeds. A multi-country study conducted in Kenya and Uganda among aquaculture feed processors found that nutritional quality significantly declined as sun dried fish was moved through the feed supply chain, mainly due to adulteration (Nalwanga et al., 2009). Similarly, Kasule, Katongole (Kasule et al., 2014) found that processed poultry feeds in Uganda had low levels of crude protein due to the low-quality fish meal used as a feed ingredient. While comparing fish meal produced commercially with that of artisanal producers in Senegal, Ayssiwede, Mouanda (Ayssiwede et al., 2016) observed that artisanal fish meals had lower crude protein, energy and dry matter because fish waste or poor fish co-products were used as ingredients. There were also two studies that discussed nutritional quality in relation to the availability of small fish used as ingredients. In Tanzania, a significant proportion of tilapia fish farmers reported the use of fish meal made from Lake Victoria sardine (*Rastrineobola argentea*) because it was readily available with a medium to high crude protein, fat and ash content that promotes better fish growth (Mmanda et al., 2020). In a Kenyan study, Carter, Dewey (Carter et al., 2015) also indicated that sun-dried sardines not only had the highest ash and phosphorus content but were also readily available throughout the year. While evaluating the nutritional content of processed sardines from different water bodies in Uganda, Mwanja, Nyende (Mwanja et al., 2010) found no significant difference in the type and quantity of fatty acid based on source of ingredients. Masa, Ogwok (Masa et al., 2011) further evaluated seven fish species including silver fish (*R. argentea*) from the Ugandan side of Lake Victoria and affirmed the high ratios of

TABLE 1 Summary of study characteristics; study motivations, small pelagic fish use, sectors and other characteristics.

Study motivation	Type of fish	Use	Target sector	Value chain actors	Sample size	Method of data collection	Country	Region	References
Alternative sources of feed protein	Smoked small fish	Fish meal/oil	Aquaculture	Fish farmers	10	Questionnaire survey	Benin	West Africa	Adéyèmi et al. (2020)
	Dried small fish								
	Rastrineobola argentea	Fish meal/oil	Aquaculture	Feed retailers	*ns*	Feed sample collection	Kenya	Great Lakes	Maina et al. (2002)
	Chilean anchovy								
	Rastrineobola argentea	Fish meal/oil	Aquaculture	Feed retailers	*ns*	Feed sample collection	Kenya	Great Lakes	Maina et al. (2007)
	Chilean anchovy								
	ns	Fish meal	Aquaculture	Fish farmers	241	Questionnaire survey	Kenya	Great Lakes	Chia et al. (2020)
	ns	*ns*	Aquaculture	Insect farmers	*ns*	Insect sample collection	Kenya	Great Lakes	Nyakeri et al. (2017)
				Fish farmers					
	ns	*ns*	Aquaculture	Fish farmers	207	Questionnaire survey	Uganda	Great Lakes	Ssepuuya et al. (2019)
				Feed processors	71				
				Feed traders					
	ns	Fish meal	Poultry	Poultry farmers	409	Questionnaire survey	Kenya	Great Lakes	Chia et al. (2020)
	ns	*ns*	Poultry	Insect farmers	*ns*	Insect sample collection	Kenya	Great Lakes	Nyakeri et al. (2017)
				Poultry farmers					
	Omena	Fish meal	Poultry	Poultry farmers	*ns*	Secondary data	Kenya	Great Lakes	Abro et al. (2020)
				Feed processors					
				Small fish consumers					
	ns	Fish meal	Piggery	Piggery farmers	307	Questionnaire survey	Kenya	Great Lakes	Chia et al. (2020)
	ns	Fish meal	Piggery	Piggery farmers	40	Feed sample collection	Kenya	Great Lakes	Chia et al. (2019)
Nutritional quality of feeds/ food	Lake Victoria sardines	Fish meal/oil	Aquaculture	Fish farmers	*ns*	Feed sample collection	Tanzania	Great Lakes	Mmanda et al. (2020)
				Feed processors					
	Rastrineobola argentea	Fish meal/oil	Aquaculture	Feed processors	*ns*	Feed sample collection	Uganda	Great Lakes	Mwanja et al. (2010)
	Rastrineobola agrentea	Fish meal	Aquaculture	Feed processors	*ns*	Feed sample collection	Kenya	Great Lakes	Nalwanga et al. (2009)
	Rastrineobola argentea	Fish meal	Poultry	Poultry farmers	*ns*	Feed sample collection	Uganda	Great Lakes	Kasule et al. (2014)
	Rastrineobola argentea	Fish meal	Piggery	*ns*	*ns*	Feed sample collection	Kenya	Great Lakes	Carter et al. (2015)
	Whole fish	Fish meal	*ns*	Feed processors	3	Feed sample collection	Senegal	West Africa	Ayssiwede et al. (2016)
	Silver fish/ *Rastrineobola agrentea*	Human food	Aquaculture	Fish processors	*ns*	Fish sample collection	Uganda	Great Lakes	Masa et al. (2011)

(Continued)

TABLE 1 (Continued)

Study motivation	Type of fish	Use	Target sector	Value chain actors	Sample size	Method of data collection	Country	Region	References
Mycotoxins in feed ingredients	*ns*	Fish meal	Aquaculture	Fish farmers	9	Feed sample collection	Uganda	Great Lakes	Namulawa et al. (2020)
				Feed processors	7				
	ns	Fish meal	Aquaculture	Fish farmers	52	Feed sample collection	Kenya	Great Lakes	Marijani et al. (2017)
							Tanzania		
							Rwanda		
							Uganda		
	Dried silver cyprinid	Fish meal	Aquaculture	Fish farmers	204	Feed sample collection	Kenya	Great Lakes	Mwihia et al. (2018)
	ns	Fish meal	Poultry	Feed processors	12	Feed sample collection	Nigeria	West Africa	Akinmusire et al. (2019)
Availability of feed/food resources	*ns*	Fish meal	Aquaculture	Feed processors	29	Questionnaire survey	Nigeria	West Africa	Nwabeze et al. (2017)
	Stolothrissa tanganicae	Fish meal	Aquaculture	Fish farmers	5	Observations and key informant interviews	Zambia	Great Lakes	Hasimuna et al. (2019)
				Feed processors	2				
	ns	*ns*	Aquaculture	Fish farmers	198	Questionnaire survey	Kenya	Great Lakes	Amankwah et al. (2016)
	Rastrineobola argentea	Fish meal	Piggery	Piggery farmers	164	Questionnaire survey	Kenya	Great Lakes	Mutua et al. (2011)
	Dried fish	Human food	*ns*	Consumers	1,200	Survey questionnaire	Malawi	Great Lakes	Gelli et al. (2020)
				Traders	47				
	Kapenta	Human food	*ns*	Consumers	*ns*	Records	Zambia	Great Lakes	Harris et al. (2019)
	Rastrineobola agrentea	Fish meal/oil	Aquaculture	Fisher folks	*ns*	Questionnaire survey	Kenya	Great Lakes	Isaacs (2016)
		Human food		Fish traders			Tanzania		
				Fisheries officials			Uganda		
	ns	Fish meal	Aquaculture	Feed processors	*ns*	Mixed methods	Nigeria	Cross-regional	Moehl and Halwart (2006)
							Kenya		
							Zambia		
	Bonga, Round Sardinella and Flat Sardinella	Fish meal	*ns*	Feed processors	15	Records	Mauritania	West Africa	Corten et al. (2017)

(Continued)

TABLE 1 (Continued)

Study motivation	Type of fish	Use	Target sector	Value chain actors	Sample size	Method of data collection	Country	Region	References
Governance of feed systems/ Feeds/Feeding management	*ns*	*ns*	Dairy	Dairy farmers	37	Survey questionnaire	Kenya	Great Lakes	Mutua et al. (2010)
				Feed processors	19				
	ns	Fish meal	Aquaculture	Fish farmers	177	Questionnaire survey	Ghana	West Africa	Amankwah and Quagrainie (2019)
	ns	Fish meal	Aquaculture	Fish farmers	*ns*	Farm records	Malawi	Great Lakes	Gondwe et al. (2011)
	ns	*ns*	Aquaculture	Fish farmers	*ns*	Questionnaire survey	Kenya	Great Lakes	Njiru et al. (2019)
				Feed processors					
				Fisheries officials					
				Researchers					
	Dried fish	Fish meal	Poultry	Feed processors	10	Questionnaire survey	Nigeria	West Africa	Moehl and Halwart (2006)

ns, not specified.

omega-3 to omega-6 polyunsaturated fatty acids (PUFAs) which makes silver fish a good dietary source of the former and or could readily be used in PUFA diet supplements for humans and feeds. In Zambia, feed manufacturers and seed suppliers pointed to the mixed quality of fish meal used in fish feeds (Hasimuna et al., 2019).

3.2.3 Mycotoxins in feed ingredients

A multi-country evaluation of mycotoxins in Kenya, Tanzania, Rwanda and Uganda (Table 2) found that some fish feed ingredients are highly contaminated with aflatoxins and may affect the productivity of fish and result in higher fish mortality rates (Marijani et al., 2017). In the AGLR, fish meal sold by feed suppliers and used by fish farmers in Kenya was found to have aflatoxin levels of up to 29.1 μg/kg (Mwihia et al., 2018). Similarly, aflatoxin levels at fish farms in Uganda reached 400 μg/kg in pellet and powder fish feeds made with small fish sourced from Lake Victoria (Namulawa et al., 2020). However, a West African study conducted in Nigeria, targeting the poultry sector, found the lowest level of mycotoxins in fish meal as comparted to other feed ingredients (Akinmusire et al., 2019).

3.2.4 Availability of feed/food resources

Results in Table 2 show that processed "omena," a local name for a SPFS (*R. argentea*) in Kenya was reported as the commonest feed stuff used by fish farmers (Mutua et al., 2011). Although this was attributed to the ready availability of small fish used to make fish meal, its frequent use was usually hampered by the high cost of fish meal. Although Nwabeze, Ibeun (Nwabeze et al., 2017) identified fish meal as an essential component of fish feeds in Nigeria, its cost was found to be a limiting factor of production among fish feed entrepreneurs. A regional study observed that fish meal was the most available source of protein used in animal feed formulation in Kenya, Nigeria and Zambia (Moehl and Halwart, 2006). There were three additional studies that discussed the availability of small fish in the context of human consumption. In Malawi, a seasonal decline in fish availability for consumption at a household level was noted during the hottest months of the year (Gelli et al., 2020). A similar observation was made in Zambia, where the price of dried "kapenta" (*Limnothrissa miodon*) was higher than staples such as maize hence compromising diet diversification (Harris et al., 2019). In Tanzania, "dagaa" (*R. argentea*) was described as a low-value species, traditionally available for human consumption around lakes and rural inland areas but 80% of this is now diverted to fish meal (Isaacs, 2016). Corten, Braham (Corten et al., 2017) found the amount and size of round sardinella (*Sardinella aurita*) in the coastal waters of Mauritania remained constant throughout the year, hence rejecting the hypothesis that seasonal migration potentially affects its availability for use in animal feed

3.2.5 Governance of feed systems/feeds/feeding management

We found five studies, all conducted in the AGLR on feed governance issues (Table 2). In Kenya, feed subsidies increased access for household fish farms to improved feeds and reduced farmer dependence and expenses on commercial feeds that are costly (Amankwah et al., 2016). Furthermore, the push to increase fish production by promoting cage farming in Kenya is largely unregulated and is characterized by unplanned siting of cages on Lake Victoria as well as poor fish feeding practices, likely to result in environmental concerns (Njiru et al., 2019). Similarly, it was observed that poorly managed feeding practices in Lake Malawi exacerbated the environmental impact caused by cage fish farming in Malawi (Gondwe et al., 2011). Mutua, Guliye (Mutua et al., 2010) studied the dairy sector and highlighted the varying and competing interests of farmers, feed millers and regulators towards feed formulation in Kenya. Another assessment characterized small scale feed mills in Nigeria and identified a diverse range of governance problems that not only affect profitability but also perpetuate poor management

TABLE 2 Use of small fish as animal feed or food and identified study policy implications.

Study motivation	Type of fish	Use	Findings on the use of small fish	Emerging policy issues	References
Alternative sources of feed protein	Smoked small fish Dried small fish	Fish meal/oil	Low quality fish meal in aquaculture feeds	Dependence on imported aquaculture feeds	Adéyèmi et al. (2020)
	Rastrineobola argentea Chilean Anchovy	Fish meal/oil	Potential replacement of fish meal with sunflower in aquaculture feeds	Use of local ingredients as alternatives to fish meal for aquaculture	Maina et al. (2002)
	Rastrineobola argentea Chilean Anchovy	Fish meal/oil	Potential replacement of fish meal with sunflower in aquaculture feeds	*ns*	Maina et al. (2007)
	ns	Fish meal	Potential replacement of fish meal in aquaculture, poultry and piggery feeds	Use of local ingredients as alternatives to fish meal for aquaculture, poultry and piggery	Chia et al. (2020)
	ns	*ns*	*ns*	Promotion of aquaculture feed microbiological safety	Nyakeri et al. (2017)
	ns	*ns*	Potential replacement of fish meal with insects in aquaculture feeds	Use of local ingredients as alternatives to fish meal for aquaculture	Ssepuuya et al. (2019)
	Omena	Fish meal	Potential replacement of fish meal in poultry feeds	Use of local ingredients as alternatives to fish meal for poultry	Abro et al. (2020)
	ns	Fish meal	Potential replacement of fish meal in piggery feeds	*ns*	Chan et al. (2019)
Nutritional quality of feeds/food	Lake Victoria sardines	Fish meal/oil	Availability of small fish to use as fish meal in aquaculture feeds	Establishment of standards for nutritional content of fish meal in aquaculture feeds	Mmanda et al. (2020)
	Rastrineobola argentea	Fish meal/oil	No variation in small fish composition used in aquaculture feeds	Promotion of small fish consumption for humans	Mwanja et al. (2010)
	Rastrineobola agrentea	Fish meal	Low quality fish meal in aquaculture feeds	Promotion of aquaculture feed microbiological safety	Nalwanga et al. (2009)
	Rastrineobola argentea	Fish meal	Low quality fish meal in poultry feeds	*ns*	Kasule et al. (2014)
	Rastrineobola argentea	Fish meal	Availability of small fish to use as fish meal in piggery feeds	Promotion of small fish processing and preservation	Carter et al. (2015)
	Whole fish	Fish meal	Low quality fish meal	Establishment of standards for nutritional content of fish meal	Ayssiwede et al. (2016)
	Stolothrissa tanganicae	Fish meal	Mixed quality of fish in aquaculture feeds	Establishment of standards for aquaculture feed formulation and use	Hasimuna et al. (2019)
	Silver fish/*Rastrineobola agrentea*	Human food	High omega-3 and omega-6 ratio suitable for healthy diets and supplements	Promotion of small fish as dietary sources of PUFA and for supplementation	Masa et al. (2011)
Mycotoxins in feed ingredients	*ns*	Fish meal	Fish meal as a high mycotoxin aquaculture feed ingredient	*ns*	Namulawa et al. (2020)
	ns	Fish meal	Fish meal as a high mycotoxin aquaculture feed ingredient	Promotion of poultry feed microbiological safety	Marijani et al. (2017)
	Dried silver cyprinid	Fish meal	Fish meal as a high mycotoxin aquaculture feed ingredient	Promotion of poultry feed microbiological safety	Mwihia et al. (2018)
	ns	Fish meal	Fish meal as a low mycotoxin poultry feed ingredient	Promotion of poultry feed microbiological safety	Akinmusire et al. (2019)

(Continued)

TABLE 2 (Continued)

Study motivation	Type of fish	Use	Findings on the use of small fish	Emerging policy issues	References
Availability of feed/ food resources	*ns*	Fish meal	High cost of fish meal in aquaculture feeds	Strengthened extension services to promote aquaculture feeds	Nwabeze et al. (2017)
	Rastrineobola argentea	Fish meal	Availability of small fish for fish meal in piggery feeds	Use of local ingredients as alternatives to fish meal for piggery	Mutua et al. (2011)
	Dried fish	Human food	Seasonal variability in availability of small fish	Provision of subsidies/social transfers to offset production costs to improve consumption	Gelli et al. (2020)
	Kapenta	Human food	High cost of small fish	Actions to enhance consumption of small fish	Harris et al. (2019)
	Rastrineobola agrentea	Fish meal/oil Human food	Availability of small fish for both fish meal and human consumption	Promotion of small fish processing and preservation	Isaacs (2016)
	ns	Fish meal	Availability of fish meal for feed processing	Use of local ingredients as alternatives to fish meal for aquaculture	Moehl and Halwart (2006)
	Bonga, Round Sardinella and Flat Sardinella	Fish meal	Availability of small fish for fish meal in animal feeds	Control of catch quantities of small fish used for fish meal	Corten et al. (2017)
Governance of feed systems/Feeds Feeding management	*ns*	*ns*	Consideration of competing needs of dairy chain actors	Promotion of multi-actor collaboration for improved dairy feeds	Mutua et al. (2010)
	ns	Fish meal	Access to improved feeds through subsidies	Strengthened extension services to promote aquaculture feeds	Amankwah et al. (2016)
	ns	Fish meal	Fish feeding in cage farming and environmental impact	Control on expansion of cage fish farming to enhance water quality in L. Malawi	Gondwe et al. (2011)
	ns	*ns*	Fish feeding in cage farming and environmental impact	Promotion of multi-actor collaboration for improved aquaculture feeds	Njiru et al. (2019)
	Dried fish	Fish meal	Poor management of feed mills and environmental impact	Promotion of good manufacturing practices	Adetifa and Okewole (2015)

ns, not specified.

practices that negatively impact the environment and personnel (Adetifa and Okewole, 2015).

3.3 Policy outlook on the use fish meal

3.3.1 Alternative sources of feed proteins

Four studies asserted the need to use local ingredients as alternatives to fish meal (Table 2). Although the study by Maina, Beames (Maina et al., 2002) suggested adoption of sunflower cake to replace fishmeal, it still concluded that fish meal could be produced using "omena," a local SPFS, perceived to be inexpensive compared to imported fish meals in Kenya. In Benin, it was suggested that there is a need for targeted interventions to improve the quality of a wide variety of alternatives that have potential to replace imported and costly fish meal (Adéyèmi et al., 2020). Two studies identified the emerging government interest in Kenya towards promotion of insect-based feed alternatives through policy change and programmes that could improve farmer attitudes to encourage widespread adoption of insect feeds to relieve pressure on fish meal (Abro et al., 2020; Chia et al., 2020). These assertions are supported by a Ugandan study that called for policy interventions to encourage mass production of insects (Ssepuuya et al., 2019). Biosafety concerns related to insect-based feeds in Kenya highlight the need to demonstrate the safety of these novel feed protein sources (Nyakeri et al., 2017). No policy issues were identified in two studies within this sub-category (Maina et al., 2007; Chia et al., 2019).

3.3.2 Nutritional quality of feeds/food

There were seven studies under this sub-category that made policy-relevant assertions (Table 2). The most prevalent issue was the need for standards to control the nutritional content of fish meal used in feeds, notably: consistent information for better feed related strategies in Tanzania (Mmanda et al., 2020); standardized nutritional categorization of fish meal in Senegal (Ayssiwede et al., 2016); legislation on feed formulation and use in Zambia (Hasimuna et al., 2019) and improved quality of fish meal produced and traded. In Uganda, Masa, Ogwok (Masa et al., 2011) found lower levels of PUFAs in silver fish (*R. argentea*) compared to larger species, and advocated for the use of all species, including SPFS, to produce fish oils for use

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in human dietary supplements. Another Ugandan study identified the need to change consumer attitudes towards SPFS that are perceived as undesirable to ensure that a larger proportion is consumed as food and not used in feed formulation (Mwanja et al., 2010). A study in Kenya suggested drying as a better means of preserving small fish to overcome seasonal shortages in supply and reduce competition between food for humans and feed for animals (Carter et al., 2015). Furthermore, there is interest to enhance the microbiological safety of fish by initiating and implementing quality control schemes that enable small scale producers to assure quality in Uganda (Nalwanga et al., 2009). We were unable to identify policy aspects in one study under this sub-category (Kasule et al., 2014).

3.3.3 Mycotoxins in feed ingredients

Three studies advocated for promotion of microbiological safety of fish meal in feeds. All emphasized the need for monitoring systems and procedures to control exposure to aflatoxins that could have negative health impacts on fish and people (Marijani et al., 2017; Mwihia et al., 2018; Akinmusire et al., 2019). One study under this sub-category did not identify any issue relevant to policy (Namulawa et al., 2020).

3.3.4 Availability of feed/food resources

All seven studies under this sub-category discussed policy-relevant issues. In Mauritania, Corten, Braham (Corten et al., 2017) highlighted the need to control quantities of SPFS caught for use in fish meal production in favour of human consumption by advocating that the government impose a strict ceiling on catches used for fish meal in its management plan for SPFS. A similar assertion was made by Isaacs (2016), who called for more government investment in post-harvest handling, safety and improved hygienic standards to ensure more "dagaa" is channelled towards human consumption in Tanzania. A study in Kenya acknowledged the presence of fish by-product waste and "omena" processing waste as potential sources of proteins and called for strengthened extension services to promote better use of these resources rather than risk them being discarded (Mutua et al., 2011). This aligns with similar recommendations of promoting structured extension services to fish feed producers to enhance their knowledge on effective feed formulation using available and less costly feed ingredients in Nigeria (Nwabeze et al., 2017). Promotion of extension services with information campaigns to increase acceptance of small fish has also been proposed in addition to providing subsidies to supply chain actors in Malawi (Gelli et al., 2020). In Zambia, similar efforts were targeted towards enhancing consumption of diverse nutrient-rich food, with SPFS playing a key role (Harris et al., 2019). A multi-country study in Nigeria, Kenya and Zambia called for strategies to enhance the use of local ingredients in feeds to reduce the reliance on imported fish meal (Moehl and Halwart, 2006).

3.3.5 Governance of feed systems/feeds/feeding management

There were five studies that discussed results relevant to policy. A study in Nigeria called for the promotion of good manufacturing practices to improve the state of feed mills (Adetifa and Okewole, 2015). To address low adoption of improved feeds among aquaculture farmers in Ghana, it was suggested that interventions to improve access to extension services, credit and education could be implemented (Amankwah et al., 2016). In Malawi, the proliferation of cage aquaculture and the use of fishmeal-based feeds led to the degradation of water, caused by high levels of nutrient loading and a call was made for government controls over expansion of cage farming to reduce the negative impact of algal growth and toxic cyanobacteria species (Gondwe et al., 2011). Support for multi-actor collaboration for improved quality of feeds was advocated for both the dairy (Mutua et al., 2010) and aquaculture (Njiru et al., 2019) sectors in Kenya.

3.4 Fish meal and fish oil trade assessment

We observed that Mauritania exported 125,377 t y^{-1} of fish meal and 76,521 t y^{-1} of fish oil in 2018, and this accounted for 89 and 97% of exports reported, respectively, for all countries (Table 3). Exports of fish meal increased by 101,477 t y^{-1} between 2009 and 2018, and this constituted 93% of the overall increase. Senegal and Gambia increased exports to 5,421 and 1,969 t y^{-1} over this period, respectively. These three West African coastal states accounted for 99.6% of the increase in fish meal exports from the 15 SSA countries assessed. Nigeria, Zambia and Kenya imported 9,361, 2,813 and 1,189 t y^{-1} of fish meal in 2018, respectively. This represents 91.4% of total imports reported. Fish meal imports across all countries decreased by 95,910 t y^{-1} between 2009 and 2018, with Nigeria accounting for 93.3% of the change. Other than Mauritania, only four countries (Gambia, Ghana, Mozambique and Senegal) reported fish oil exports, amounting to 2,399 t y^{-1} in 2018. Fish oil imports across all countries remained relatively low coming to a total of 525 t y^{-1} in 2018. Overall, trade in fish meal and fish oil resulted in net exports of 126,357 and 78,395 t y^{-1} from the 15 counties. Following conversion factors by Tacon and Metian (2008), it would require 561,587 t y^{-1} of fresh fish to yield 126,357 t y^{-1} of fish meal and this would also produce 28,079 t y^{-1} of fish oil. As this is 50,316 t y^{-1} below the required quantity of fish oil (78,395 t y^{-1}), it can be estimated that an additional 1,006,320 t y^{-1} of fresh fish would be needed to yield this amount. This equates to an overall requirement of 1.57 million t y^{-1} of fresh fish to produce fish meal and fish oil equivalent to the net export amounts from the 15 SSA countries assessed.

4 Discussion

This study is the systematic collation of evidence to assess the extent to which research on SPFS has addressed its use as feed and or food. Despite increasing recognition of the need for the balanced and sustainable use of SPFS for use in animal feeds, while minimizing unintended negative consequences as food for human consumption (Thilsted et al., 2016; Cashion et al., 2017; Isaacs, 2016; Tacon and Metian, 2008; Troell et al., 2014; Tacon and Metian, 2009), we found no study that clearly and sufficiently addresses this trade-off dimension. However, our literature review generally indicates a reasonable reflection on the two competing food system needs that can further shape the research landscape and narrative about the feed-food nexus of SPFS.

Considering that access and affordability to nutrient-rich foods, which constitute healthy diets, are still issues in many parts of SSA (Hirvonen et al., 2020), the review links high cost to the inability by farmers to access FMFO for use in animal feeds, particularly in the aquaculture sector. The same affordability constraint is mirrored in studies that focused on direct consumption pathways among people whose diets and food habits are traditionally based on SPFS, more so in the AGLR. Despite being abundant in its natural habitant as the most dominant fish catch in Africa (Kolding et al., 2019), collated evidence in this review point to a situation where sufficient quantities of SPFS are often inaccessible to poorer consumers. Moreover, based on FAO trade estimates, we observe a systematic increase in FMFO exports, placing pressure on local feed sources. Thereby, international trade in SPFS is leading to net exports equivalent to approximately 1.6 million tonnes annually of landed fish across the 15 SSA countries reviewed. The current situation is largely driven by the increased global demand and use of small fish as the main and premium source of essential nutrients in animal feeds (Tveterås and Tveterås, 2010; Tacon and Metian, 2008; Hardy, 2010; Oliva-Teles et al., 2015) and in human nutritional supplements (Misund et al., 2017). Hence, costs for aquaculture production in SSA, for instance, keep rising (Adeleke et al., 2020; Asiedu et al., 2017), transferring the price burden to consumers of fed-fish, most of whom have low purchasing power (Belton et al., 2018; Genschick et al., 2018). If controlled better, there could be significant contributions towards enhancing direct consumption as food or bolstering local aquaculture and livestock production to spur associated economic and social development across the region. As such, our findings reflect an endemic and worsening threat to efforts aimed at promoting healthy fish-based diets in regions with high nutritional needs, as noted in previous studies (Chan et al., 2019; Brummett et al., 2008; Beveridge et al., 2013). Nonetheless, reviewed studies that highlighted access to and affordability of SPFS as a barrier, were sensitive enough to advocate government control of FMFO-based fishing activity in favour of direct human consumption. Notably, we also observed a general drive for better post-harvest handling practices as well as a need for targeted behaviour change communication initiatives aimed to promote adoption of innovations, which ensure wise and efficient use of available SPFS, with minimal negative and unexpected impacts for food or feed uses. While the current review complements similar sentiments addressed and advocated for in previous studies (Bunting et al., 2024; Thiao and Bunting, 2022; Cashion et al., 2017), it is still not entirely clear how prescribed policy options, targeting the FMFO industry, can effectively be implemented to spur holistic, multi-sectoral and nutrition-sensitive fish food systems change in regions such as SSA (Costello et al., 2020; Golden et al., 2017).

Even so, it appears that promotion of novel animal feeds, that are less reliant on FMFO as an ingredient, is a viable pathway towards desired trade-offs for use of SPFS fish as feed or food (Naylor et al., 2009; Hua et al., 2019). Emerging evidence from our review indicate the prominence of insect-based alternatives to FMFO, not only in the aquaculture sector but also for poultry and piggery production in the AGLR. While innovative insect-based feeds are of high nutritional value, related research is largely nascent and there are still several unknowns regarding intensive insect production, processing, storage, safety, quality control and acceptability (Dobermann et al., 2017; Gasco et al., 2020). Some studies also assert that insects are low in highly unsaturated fatty acids, particularly omega-3 and omega-6,

TABLE 3 Fishmeal* exports and imports (t y^{-1}) from countries indicated and change between 2009 and 2018 with negative values in parenthesis.

Country	Fish meal						Fish oil					
	Exports			Imports			Exports			Imports		
	2009	2018	Change	2009	2018	Change	2009	2018	Change	2009	2018	Change
Burundi	–	–	–	0	8	8	–	–	–	0	0	0
DR Congo	4	0	(4)	52	0	(52)	0	0	0	0	0	0
Gambia	0	1969	1969	15	0	(15)	0	823	823	0	0	0
Ghana	0	0	0	8,103	589	(7514)	67	391	324	0	248	248
Kenya	655	0	(655)	318	1,189	871	51	0	(51)	40	7	(33)
Malawi	0	0	0	562	319	(243)	–	–	–	0	0	0
Mauritania	23,900	125,377	101,477	0	0	0	200	76,521	76,321	0	0	0
Mozambique	0	560	560	341	306	(35)	172	122	(50)	0	0	0
Nigeria	0	0	0	98,817	9,361	(89,456)	0	0	0	477	193	(284)
Rwanda	36	0	(36)	31	0	(31)	0	0	0	1	0	(1)
Senegal	6,484	11,905	5,421	1	1	0	23	1,063	1,040	9	75	66
South Sudan	–	–	–	0	4	4	–	–	–	0	0	0
Tanzania	545	989	444	0	0	0	0	0	0	1	0	(1)
Uganda	0	0	0	1	29	28	0	0	0	0	0	0
Zambia	30	176	146	2,288	2,813	525	55	0	(55)	0	2	2
Total	31,654	140,976	109,322	110,529	14,619	(95,910)	568	78,920	78,352	528	525	(3)
Net trade					(126,357)						(78,395)	

*Fishmeal includes all forms reported under the FAO major commodity group entitled "Meals" (FAO, 2020b); countries not included had no record of "Meals" exports between 1976 and 2018 in the FAO database, –, No data available. Source: FAO (2020b).

compared to SPFS (Gasco et al., 2018; Belforti et al., 2015). In addition, promoting insect-based feeds might in the long-run create the same SPFS conundrum, of diverting a low-cost protein and nutrient-rich food source away from vulnerable populations. From a food systems perspective, insects being a major food for some communities in SSA (Kim et al., 2019; Baiano, 2020), competition between the use of insects as food or feed will likely manifest gradually, now that insect acceptability in western cultures, as a healthier protein alternative, is steadily improving (Payne et al., 2019; Videbæk and Grunert, 2020; Skotnicka et al., 2021; Detilleux et al., 2021; Dupont and Fiebelkorn, 2020). Reviewed studies indicate a positive policy inclination towards promotion of insect production, safety and attitudes, hence prospects and structural conditions for success appear promising. However, it remains prudent that future research and investment priorities for insect-based ingredients in feeds learn from the example of SPFS to account for unintended disruptions to expected food system benefits, especially among populations that currently access insects as an affordable protein source. With regards to plant-based alternatives, sunflower feed ingredients were highlighted and while abundant, they have lower quality nutritional profiles compared to FMFO. Without optimized nutrient composition, complete replacement is limited, and this partly explains why the animal feed industry still heavily relies on SPFS, thereby exacerbating pressure on this finite resource, with impacts felt throughout the food system (Turchini et al., 2019; Gatlin III et al., 2007; Hardy, 2010). Continued financial support for research and innovation is needed to facilitate the development of various local feed ingredient combinations, that are cost-effective and accessible for majority including marginalised groups (Turchini et al., 2019). In addition, initiatives aiming to enhance the governance of feeding systems should be prioritised to promote the efficiency and effectiveness of feed practices among actors. This specifically calls for more investments earmarked to target better management practices among aquaculture and livestock producers for the best use possible of feeds formulated using SPFS.

We also observed that some FMFO, marketed both in the AGLR and western coastal region, are of low nutritional quality. Even if fish farmers for instance were able to access and use these available FMFO in feeds, not only productivity would negatively be affected but also the fish produced would likely lack essential nutrients, to the detriment of consumers (Bogard et al., 2017; Kwasek et al., 2020). There is also a growing food safety issue, especially in the AGLR, where contamination of fish meal with aflatoxins above recommended thresholds, was reported. Accumulation of aflatoxins in feeds often increases the risk of food intoxication, resulting in poorer health and nutritional outcomes in the general population (Oliveira and Vasconcelos, 2020; Gonçalves et al., 2020). These two issues can only compound the access and affordability challenges highlighted earlier. This further highlights the need for strengthened control measures that aim towards effective establishment and execution of nutritional and food safety standards as well as control against adulterations of FMFO, a common practice in many parts of SSA (Nalwanga et al., 2009). For this to work, the focus must be on improved surveillance, using appropriate risk assessments and assurance schemes for feed systems across SSA, to eliminate adulteration and or microbiological contamination.

With regards to governance of aquatic resources, we noticed an intensified policy push for increased cage fish farming on major lakes in the AGLR. While this increases aquaculture production and could contribute to food and nutrition security, the impact on the environment due to poor feeding practices threatens the sustainability of associated ecosystem services. Previous studies have linked excessive water eutrophication to reduced numbers of certain fish species landed in the AGLR (Njiru et al., 2019; Witte et al., 2007). As such, governments in the region have fallen short in ensuring that the positives of expanding aquaculture production through cage farming are matched with the will to conserve the environment and ensure aquaculture is sustainably intertwined with fisheries and other terrestrial food systems (Olokotum et al., 2020; Irvine et al., 2019). The reluctant policy response to this issue could be due to inconclusive evidence that clearly illustrates the environmental impact of the rapid expansion of aquaculture on freshwater lakes compared to other priorities (Naylor et al., 2021; Kashindye et al., 2015). Given that aquaculture on major lakes in the region is poised to grow further to fill the deficiency created by declining fisheries for certain species (Chan et al., 2019), there is a need to execute rigorous foresight studies, using updated scenario data, to better understand the impact of uncontrolled nutrient build-up on aquatic food species thriving in these water environments. Such predictive and illustrative information could be used in the development and design of policies to protect the ecosystems of the major African lakes. This could also facilitate the process of setting up acceptable thresholds to ensure aquaculture expansion into natural water bodies is sustainable.

5 Conclusion

This scoping review affirms that evidence on the combined assessment of the use of SPFS as feed and food is still largely nascent. However, collated evidence in our review shows that aquaculture is the main destination for FMFO to satisfy the growing demand for animal protein at the expense of direct human consumption of SPFS. Studies have indicated that the continued global dependence on SPFS as inputs for the animal feed industry limits local access not only among fish and livestock farmers but also populations that traditionally depend on these fish species as food for direct consumption. To overcome this trade-off challenge, studies have demonstrated the technical viability and potential to produce insect feeds and or use plant proteins as alternatives to FMFO. However, research targeting cost–benefit analysis, feasibility assessments, safety assessments, acceptability and accompanying policy development are needed to guide and foster commercial-scale production of promising alternatives to FMFO. This could relieve pressure and create opportunities for SPFS stocks to be managed sustainably to maximise their economic and social benefits. Considering that SPFS has traditionally been labelled a "poor-persons" food in sub-Saharan Africa, actions to transform food environments (De Bruyn et al., 2021) and devise more diverse product concepts that include for instance SPFS dust/powder, could increase their appeal to wider segments of consumers, notably women and children susceptible to multiple nutrient deficiencies. This could make a significant contribution towards bolstering regional food security and better nutritional outcomes. In this study, the combination of literature and trade estimates for 15 countries indicates that the extent of trade activity does not necessarily translate into scientific literature and or vice versa. Thereby, despite West African states, particularly Mauritania, being the largest exporter of FMFO, there were few studies extracted and so assertions made in this review are mainly based on the AGLR. Future investments in development research on the magnitude, dynamics and trade-offs concerning the utilization of SPFS could generate the greatest benefits if more integrated and cross-regional perspectives that encompass multiple SSA regions are adopted.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JW: Visualization, Conceptualization, Software, Investigation, Resources, Funding acquisition, Supervision, Data curation, Project administration, Writing – review & editing, Validation, Formal analysis, Writing – original draft, Methodology. RY: Data curation, Writing – review & editing, Supervision, Formal analysis, Investigation, Resources, Funding acquisition, Conceptualization, Project administration. SB: Writing – review & editing, Formal analysis, Methodology, Visualization, Software, Validation, Conceptualization, Data curation, Investigation. PC: Data curation, Validation, Conceptualization, Supervision, Funding acquisition, Writing – review & editing, Project administration, Methodology.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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