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ORIGINAL ARTICLE

Fish seed and feed value chains analysis and their critical factors for aquaculture development in Tanzania

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Abstract

Seeds and feeds are among the most important inputs required for sustainable aquaculture industry development in any country worldwide. However, the value chain analysis of seeds and feeds in most developing countries including Tanzania has not been mapped, and the key actors are not identified and characterized. To address this knowledge gap, we mapped the fish seed and feed value chains in Morogoro, Dar es Salaam, Coast and Lindi regions in Tanzania, evaluated their performances, analyzed their contributions to aquaculture growth and finally assessed the critical factors impending aquaculture development before proposing appropriate strategies for upgrading. We found that the fish seed value chain comprised broodstock suppliers, seed producers, seed marketers, traders and fish farmers. Tilapia (*Oreochromis* sp.) and African sharptooth catfish (*Clarias gariepinus*) seeds produced were primarily sold to farmers at an advanced fry stage (1 to 5 g) at a price ranging from USD 0.09 to 0.13 and USD 0.22 to 0.27, respectively. The feed value chain consisted of suppliers, producers, importers, traders and fish farmers. The feeds produced were powdered, compressed and extruded pellets and granules sold at an average price of USD 2.50/kg. The seed and feed value chains in the four regions drive the aquaculture development and employ 137 and 109 people, respectively. The fish farming was mainly affected by insufficient seeds and feeds; inadequate extension services, inadequate technical skills in seed and feed production; limited farming equipment; insufficient capital and limited access to market. We propose increasing seed and feed production through collaborative research between researchers and the private sector, enhancing delivery of extension services to all fish farmers, providing fiscal incentives to hatchery and feed investors, organizing hatchery owners into associations, and undertaking marketing awareness campaign for aquaculture growth in the country for food, income and employment generation.

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KEYWORDS
aquaculture growth, aquaculture seed and feed, sustainable aquaculture, Tanzania aquaculture development, value chain analysis

1 | INTRODUCTION

Many developing countries such as Tanzania are mainly dependent on capture fisheries as the main source of protein, income and employment for several decades. However, capture fisheries production has shown a declining trend in major fishing grounds (FAO, 2018). In recent years, capture fisheries recorded a worldwide decrease of 4% compared to 2019 (FAO, 2022). Indeed, the capture fisheries in Tanzania have experienced a decrease in fish production by 14% (from 483,756 to 415,881 metric tonnes) between the year 2020/2021 and 2021/2022, respectively (URT, 2021/2022). However, the demand for fish in Tanzania is high as reflected by a low annual per capita fish consumption of 8.5 kg compared to an average of 20.2 kg globally (FAO, 2022). The country intends to increase the fish per capita consumption to 10.5 kg, which translates into an additional demand of about 100,000 metric tonnes of fish (Ministry of Finance and Planning (MoFP), 2021). The required fish to fill the demand is expected to come from aquaculture production because fish supply from capture can no longer keep pace with demand due to the fast-growing population (Mzula et al., 2021).

Fish farming operations in Tanzania started in the 1950s, maintaining a slow growth until in the 1980s due to poor farming methods and technology (Balarin, 1985). The fish farming activities have increased recently due to conserted efforts by the government to promote and develop aquaculture. Currently, Tanzania has 31,998 fish farmers scattered in different parts of the country (URT, 2021/2022), which has increased the fish production from aquaculture (Mzula et al., 2021). In fact, the aquaculture production increased by 27% (from 22,793 metric tons in 2020/2021 to 28,856.87 metric tons) by May 2022 (URT, 2021/2022). The aquaculture production is mainly contributed by finfish 25,286.46 tons (88%), majority of which are tilapia (URT, 2021/2022). To meet the envisioned fish supply, Tanzania has set short-term sector growth goals, which include, (i) improve quantity and quality of seed produced by the private hatcheries, (ii) enhance the availability of quality and affordable locally produced fish feeds, (iii) improve aquaculture extension services and (iv) transform aquaculture value chain to increase efficiency and productivity. Information on the value chains for aquaculture seed and feed is urgently needed to realize these objectives.

A value chain entails a sequence of activities and services required to convey a product or service from its invention to final consumers and disposal after use (Hellin & Meijer, 2006; Kaplinsky & Morris, 2000). It involves input suppliers, producers, processors and buyers, which are supported by a range of technical, business and financial service providers. The various players in the value chain can be established by conducting a diagnostic tool called value chain analysis (VCA). The VCA assesses the multidimensional performance of value chains, including the analysis of product and information flows and their management and control (Islam & Hasan, 2020). The analysis makes different stakeholders aware of the available opportunities for improving specific value chain stages. Thus, VCA is a useful approach for assessing factors affecting the value chain, its costs and earnings (El-Sayed et al., 2015; Macfadyen et al., 2012; Rubin et al., 2009). The VCA is also helpful in identifying and analyzing gaps and weaknesses in value chain performance for suggesting appropriate strategies for upgrading, management and development strategies to improve it. These actions are more likely to increase the aquaculture industry productivity. Accordingly, the importance of using VCA as a tool for analyzing fisheries and aquaculture activities and services has been increasing in recent years in different Asian countries such as India (Belton et al., 2017), Vietnam (Pham et al., 2018) and Bangladesh (Hernandez et al., 2018). Moreover, VCA has been conducted in African countries such as Zambia (Kaminski et al., 2018) and Egypt (El-Sayed et al., 2015; Macfadyen et al., 2012; Nasr-Allah et al., 2014b). Most of these countries have improved notably aquaculture production (FAO, 2022), probably attributed to the VCA conducted, which suggests the need for specific VCA for each country. The diversity of African aquaculture systems and variations in domestic quantity and quality of inputs and services required further necessitates the aquaculture value chains (Kaminski et al., 2018).

The aquaculture production in Tanzania has increased from 4790 to 28,857 tons between 2015/2016 and 2021/2022, respectively, which is equivalent to 502% growth (URT, 2021/2022). However, the country has currently limited knowledge on VCA for aquaculture seed and feed. The available study (Mwaijande & Lugendo, 2015) analyzed the fish farming value chain with a view of formulating policy actions rather than improved production. Consequently, the contributions of seed and feed value chains to aquaculture development in Tanzania have not been mapped and key players have not been identified, described and characterized. Thus, the value chain performance of the aquaculture sector in Tanzania is not well understood, which hampers the achievement of the sector growth goals. To achieve the sectorial goals for growth, analysis of the aquaculture value chain in Tanzania is critical.

Therefore, the present study aimed to fill this knowledge gap by undertaking a VCA of fish seed and feed production and assessing their contributions to aquaculture development in Tanzania. Specifically, we mapped the fish seed and feed value chains by describing the main actors and stakeholders and determined their performance with regard to employment. We further assessed the contributions of seed and feed value chains to aquaculture development in Tanzania and identified and synthesized the critical factors hindering each value chain and overall aquaculture development. We finally suggest appropriate strategies for upgrading the aquaculture industry. The information generated serves as a baseline for the aquaculture

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industry growth in Tanzania and elsewhere with similar conditions by bringing awareness to various stakeholders on the opportunities for future improvement at various stages of the value chains.

2 | MATERIALS AND METHODS

2.1 | Data collection

During the present study, a research tool that was used to analyze feed value chain in Egypt was adopted, with minor modifications to suit a Tanzanian aquaculture environment (El-Sayed et al., 2015). Two checklists for seed and feed producers, and one open-ended questionnaire for fish farmers were drafted following El-Sayed et al. (2015) (Appendix A1). The checklists were translated into the Kiswahili language. Pilot sampling was done by administering the questionnaires to a sample of 15 respondents to assess strengths and weaknesses of the developed study tools. Following the piloting, study experts discussed the checklists and the questionnaire. The checklists and the questionnaire were modified and improved to accommodate the observations encountered during the pilot survey.

To save time, money and avoid administering the questionnaires to unwilling respondents, fish seed and feed producers were approached by phone calls to obtain their willingness to participate in the study and make appointments. Local link-persons were used to guide the research team to fish farming regions during data collection. Upon arrival, the research team introduced briefly about the study mission and enquired the farmer willingness to participate in the interview. The appropriate questionnaire was then administered and completed by a research team member to the willing participants.

The sampling frame was designed to capture the seed and feed value chains, their links and factors influencing them. All aquaculture seed (10) and feed (5) producers available in the selected areas of Morogoro, Dar es Salaam and Coast regions (Eastern zone), and Lindi region (Southern zone) were visited (Figure 1). In addition, a total of 67 small-scale fish farmers were interviewed in order to understand the contributions of seed and feed value chains to fish farming development in the country (Table S1). To understand the challenges facing aquaculture in the country, the farmers were allowed to nominate all critical factors impending development depending on their activities (seed, feed and fish farming). Focus group discussions with the fish farmers were also conducted in order to obtain more information that could not be captured by using the questionnaire (Nasr-Allah et al., 2014a). We aimed to collect financial information from each fish farmer. We further obtained secondary information from the Division of Aquaculture (DAq) in the Ministry of Livestock and Fisheries, fisheries research and training institutions, higher learning institutions, district fisheries officers, aquaculture staff and policy makers. More information was also obtained from the Food and Agriculture Organization of the United Nations (FAO).

2.2 | Data validation

The responses from individual fish farmers had little variations. Hence, no data cleaning was conducted.

2.3 | Data analysis

The data on seed, feed, and fish farmers were analyzed separately. The information obtained from the present survey was coded and their frequencies and percentages were computed by using IBM SPSS Statistics for Windows Version 20.0 (IBM Corp, Armonk, NY, USA).

3 | RESULTS

3.1 | Seed value chain mapping, description, characteristics and performance

The fish seed value chain in the studied regions comprised mainly five stakeholder groups categorized as input suppliers, seed producers, fish farmers, seed producers who were also fish farmers, and agents (Figure 2). The majority (60%) of African sharptooth catfish seed producers obtained broodstock from the wild, whereas 20% purchased from formal sources and 20% sources were not known. Likewise, 40% of the tilapia seed producers obtained their broodstock from the wild, while 30% were from formal stations. The remaining 30% acquired their brooders from other farmers or self-produced. The majority of hatcheries (73%) were private owned, while the remaining (27%) were operated by the government (Table 1).

Most of the surveyed hatcheries produced both tilapia and African sharptooth catfish seeds (50%), with the latter species contributed 30% of the production compared to 20% of tilapia seed. Eighty percent of the tilapia hatcheries produced mixed-sex compared to 20% monosex (all male) seed producers. The majority (40%) of African sharptooth catfish seed operators produced between 1,000,000 and 2,000,000 seeds yearly, whereas 20% produced between 2,000,000 and 3,000,000 seeds yearly (Table 1). The remaining African sharptooth catfish seed producers had no records of the seed produced. Half of the tilapia seed producers (50%) produced between 2,000,000 and 5,000,000 seeds yearly. Only 20% of tilapia seed producers produced between 10,000,000 and 25,000,000 seeds per annum, and 30% of the producers did not have any records. The produced African sharptooth catfish seeds were sold directly to fish farmers (99%) at an advanced stage from 1 to 5 g. The price of seeds ranged from USD 0.09 to 0.13 and USD 0.22 to 0.27 for tilapia and African sharptooth catfish, respectively. The 10 hatcheries visited employed 137 employees, 60% of whom were youth, with males occupying a higher percentage (70%) than females (30%). Most of the workers (70%) were part-timers, whereas only 30% were permanent employees.

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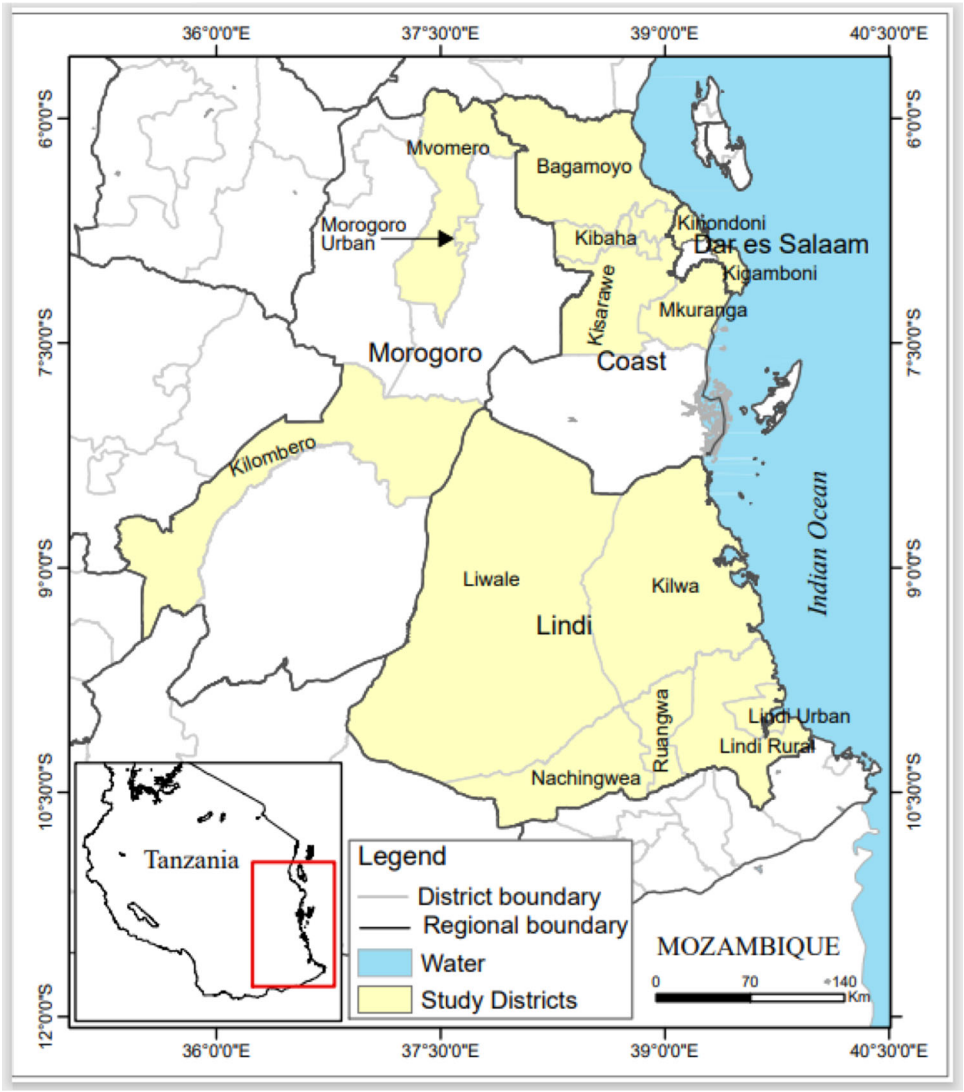


FIGURE 1 Map showing the studied districts in the four regions

3.2 | Feed value chain mapping description, characteristics and performance

The feed value chain comprised six stakeholders designated as input suppliers, local commercial feed producers, feed importers, marketers/traders, fish farmers and on-farm local feed producers (Figure 3). The five private aquaculture feed investors visited during the study, two were based in Dar es Salaam, one in Morogoro and two in the Coast region. Four of them were local feed producers, while one was an importer (Table 2). The feed producers had a production capacity of 986.4 tons per annum. The common types of fish feed produced or imported were floating (extruded) pellets and sinking (compressed and powdered) feeds. Imported feeds accounted for 74%, while 26% were locally made (Table 2). Extruded pellets and granules accounted for 80% of all pelleted feeds with compressed pellets contributing 20% (Table 2).

About 76% of all imported and locally made feeds were sold directly to fish farmers, while 18% and 6% were supplied by retailers and agents, respectively (Table 2). Nearly all feed ingredients used to make local feeds were locally available (Table 3). The farmers perceived the quality of feeds as good (42%), moderate (13%) and poor quality (45%) (Table 4). Most fish farmers (79%) admitted that industrial feed had better quality than on-farm feeds (Table 4) and thus mixed feeding was a common practice among them. The feed price ranged from USD 1.50 to 3.50/kg for brooder and fingerling feeds, with an average price of USD 1.34/kg. Eighty percent of the fish farmers fertilized their ponds with manures from different animals and poultry. The five feed producers visited employed 109 employees with more part-timers (70%) than permanent workers (30%). Permanent employees were men representing 63%, and the remaining (37%) were women. Similarly, 55% and 45% of the temporary employees were men and women, respectively.

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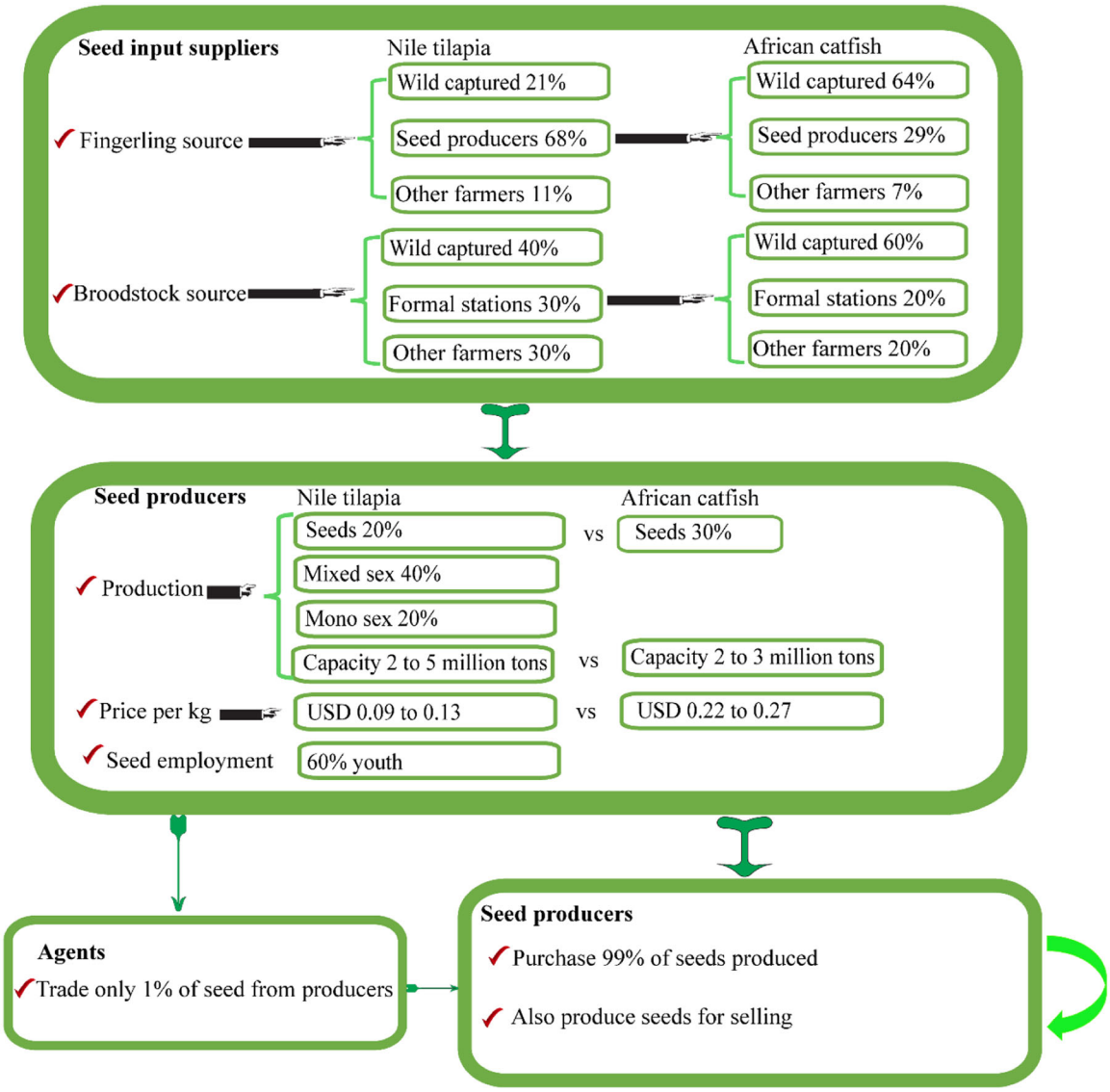


FIGURE 2 Fish seed value chain in Tanzania. The width of the arrows reflects the percentage of stakeholders involved in a particular activity

3.3 | The contribution of seed and feed value chains to the development of aquaculture in Tanzania

The fish farming value chain in the studied regions comprised four stakeholders classified as input suppliers of seeds and feeds, fish farmers, marketers/traders and consumers (Figure 4). The fish farming actors were mainly men (87%) aged between 36 and 55 years (48%) with primary education (52%), while youth contributed 29% (Table 5). Fish famers exclusively stocked the tilapia and African catfish seeds produced into ponds (100%) either in earthen (57%) or concrete (40%) or both (3%) and fed with the various feeds. The tilapia and African sharptooth catfish in the ponds were reared as monoculture (40% and 21%) or polyculture (39%). The tilapia stocked were harvested after 6 to 7 months and 6 to 12 months for African catfish weighing 500 g and 500 to 4000 g, respectively. The fish were sold as fresh (93%) or after processing (7%) by frying (25%), smoking (25%) or both (50%). The produced fish were sold at a price ranging from USD 1.35 to 4.50 (Table 6). We found an increasing trend in fish farming activities from 1990 to 2020 (Figure 5).

3.4 | Critical factors affecting aquaculture value chains development in Tanzania

We identified issues with more than 17% of responses as critical factors affecting the aquaculture value chain performance in the studied regions. We found that aquaculture performance was mainly limited by lack of education (67%), lack of capital (49%), higher price of feed raw materials (45%), absence of quality seed (40%), absence of quality feed (37%) and insufficient water or too expensive water (27%), as most operators (70%) had no reliable source of good quality water. Moreover, fish predators (22%), lack of reliable access to fish market (20%) and inadequate extension officers (18%) were all reported as critical factors for aquaculture development. Indeed, only 58% of the fish

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TABLE 1 Type and capacity of fish seed producers and their geographical location

Region	Seed producer	Ownership	Type of seeds produced	Capacity of seed production per year
Morogoro	Kingolwira Aquaculture Centre	Public	Tilapia	2,000,000
Morogoro	Kingolwira Aquaculture Centre	Public	African catfish	30,000
Morogoro	Sokoine University of Agriculture	Public	Tilapia	2,900,000
Morogoro	Sokoine University of Agriculture	Public	African catfish	80,000
Dar es Salaam	Righa's Safina Ltd.	Private	Tilapia	1,200,000
Dar es Salaam	Righa's Safina Ltd.	Private	African catfish	1,800,000
Dar es Salaam	Green Fish Ltd.	Private	African catfish	216,000
Dar es Salaam	Eden Agri-Aqua Ltd.	Private	Tilapia	15,360,000
Dar es Salaam	Eden Agri-Aqua Ltd.	Private	African catfish	1,000,000
Dar es Salaam	Faith Aqua Ltd.	Private	Tilapia	900,000
Dar es Salaam	Faith Aqua Ltd.	Private	African catfish	1,800,000
Coastal region	Polopolo Farm Ltd.	Private	Tilapia	1,800,000
Coastal region	Mr Sobo	Private	African catfish	120,000
Coastal region	Ruvu Fish Farm Ltd.	Private	Tilapia	24,000,000
Coastal region	Mr Machui	Private	African catfish	250,000

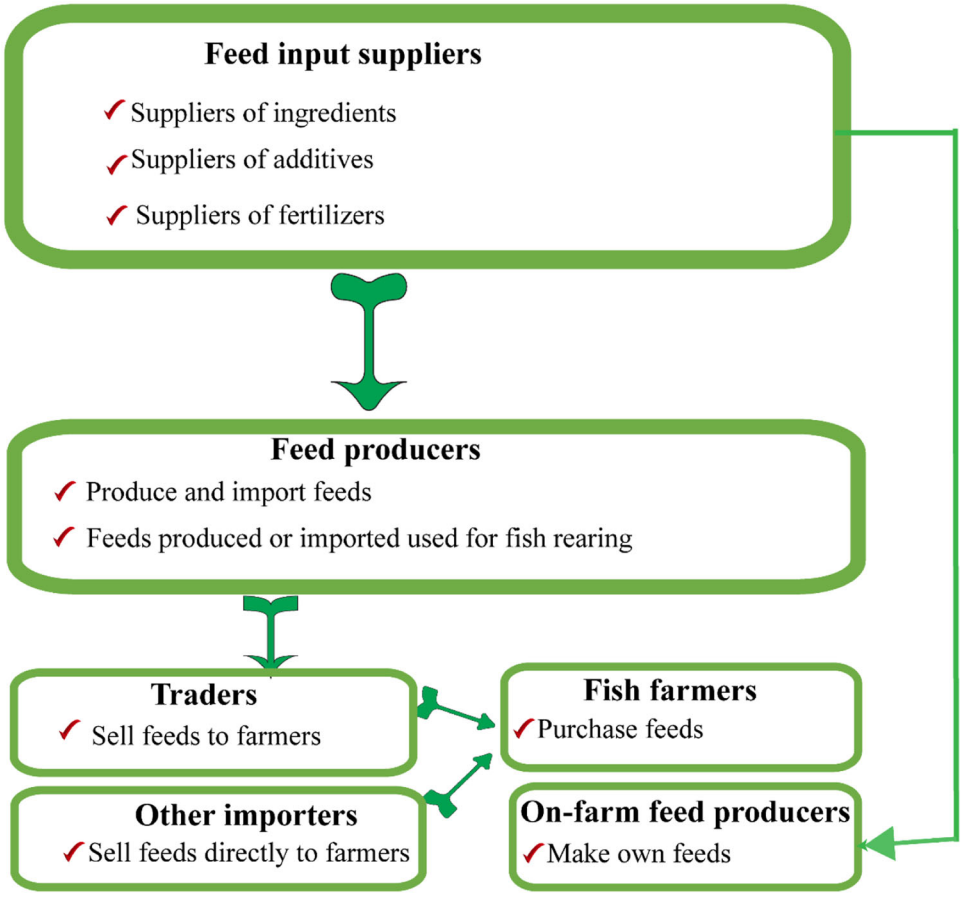


FIGURE 3 Fish feeds value chain in Tanzania. The width of the arrows reflects the percentage of stakeholders involved in a particular activity

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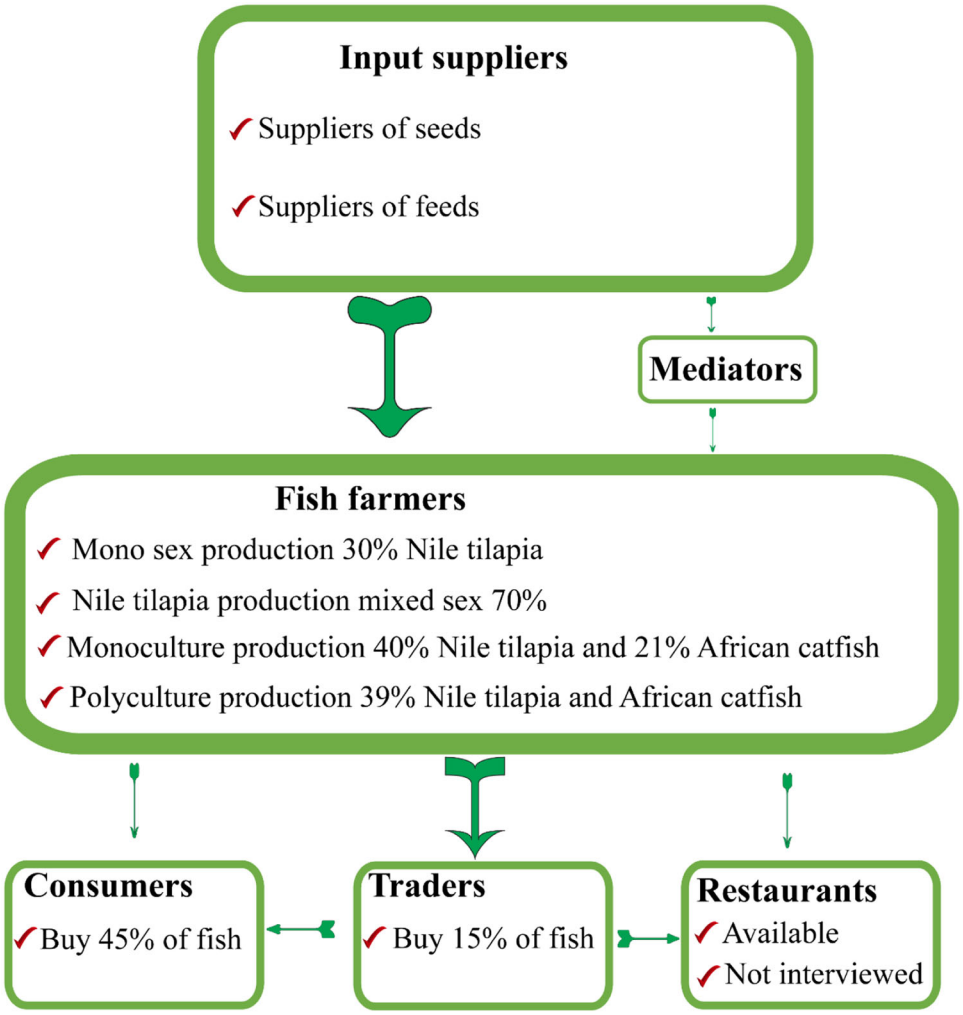


FIGURE 4 Fish farming value chain in Tanzania. The width of the arrows reflects the percentage of fish farmers involved in a particular activity

farmers received extension services and most of them (95%) reported improved fish farming activities, while 70% did not receive any formal fish farming training. The fish farmers also reported the absence of equipment for fish farming (18%) as an obstacle (Table 7).

4 | DISCUSSION

4.1 | The available production opportunities in seed and feed value chains for different stakeholders

The present study reported five fish seed value chain actors in the studied regions reflecting the low aquaculture industry development in the country. However, the industry offers a remunerative opportunity for the private sector to act as input suppliers of fish seeds. Evidently, fish seeds in the studied areas were produced mainly by private hatcheries (80%), similar to Egypt where tilapia seed production was entirely done by private hatchery operators (Nasr-Allah et al., 2014c). Accordingly, recent data from the government officials show that the seven hatcheries existing in Tanzania produced 3,389,240 fish seeds (only 11%) compared to 27 private hatcheries, which produced 26,943,288 seeds (89%) (URT, 2021/2022). More seed production is required if the country is to meet the target of 10.5 kg per capita consumption as stipulated in the National Five Year Development Plan 2021/2022 to 2025/2026 (MoFP, 2021). It is estimated that an additional 100,000 metric tonnes of fish will be required, which in turn demand extra 500,000,000 fish seeds. The dominance of the private sector in aquaculture seed production sector in Tanzania reflects the lucrative nature of the business.

Moreover, our study found that 60% and 40% of African sharptooth and tilapia brooders, respectively, were obtained from wild. This, further offers an opportunity for the private sector to engange in hatchery development in the country to produce hatchery-reared brooders for quality seeds production. The produced tilapia and African sharptooth catfish seeds are currently sold at a size of 1 to 5 g, fetching a price range of USD 0.09 to 0.13 and USD 0.22 to 0.27, respectively. This size has a high market demand as in Egypt (Nasr-Allah et al. 2014c) due to easy transportation (Nasr-Allah et al., 2014b) and thus can be sold directly to fish farmers countrywide as was shown by 99% of the fish seed producers in this study. The opportunity in fish seed production

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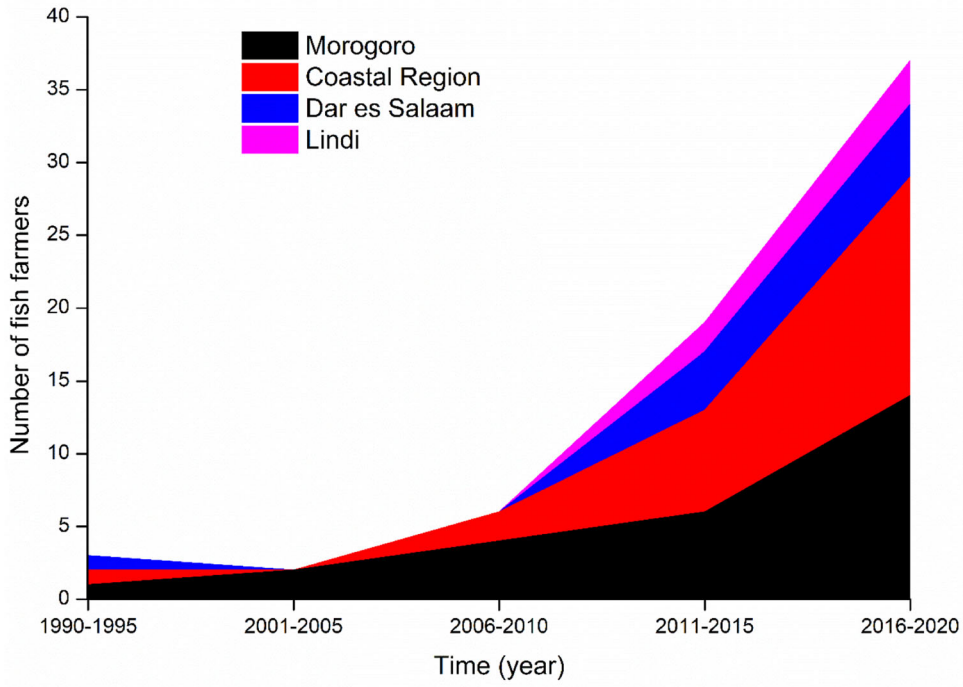


FIGURE 5 Trends in fish farming adoption in Tanzania from 1990 to 2020

also offers a chance to a few traders who acted as middlemen by buying fish seeds and selling them to farmers as reported in this study, similar to other African countries (Nasr-Allah et al., 2014b). These results indicate that fish seed production offers opportunities for the private sector to enter into the supply chain due to demand for fish seed, availability of hapa-based technology and favourable climatic conditions for production.

Like the fish seed value chain, the key players in feed value chain in the studied regions were six, relatively similar to four reported by El-Sayed et al. (2015). The fish feed value chain also offers the private sector in Tanzania an opportunity to produce fish feeds due to high market demand. The private sector plays a major role in fish feed production in Tanzania because no public sector-/state-owned holding companies exist contrary to Egypt, where fish feeds are produced by both the private sector and public sector-/state-owned holding companies (El-Sayed et al., 2015). Indeed, reports from the government of the United Republic of Tanzania indicated that the country had six private fish feed factories, which produced 540.6 metric tonnes by April 2022 (URT, 2021/2022). However, in the same year, the government provided permits to import 1615.5 metric tonnes representing 75% of fish feeds used (URT, 2021/2022) suggesting the current fish feed production does not meet demand. Similar to fish seed, the estimated 120,000 metric tonnes will be needed to produce an additional 100,000 metric tonnes of fish required to meet the 10.5 kg per capita consumption as stipulated in the National Five Year Development Plan 2021/2022 to 2025/2026 (MoFP, 2021). Indeed, during the study period, imported feeds accounted for 74% of all industrially made feeds in the studied regions and 90% of the extruded pellets were imported. Contrary, almost all aquafeeds were locally produced in Egypt (El-Sayed et al., 2015). More likely, the high fish production in Egypt is partly contributed to the availability of locally produced feeds because they have been reported to increase fish production in other countries (El-Sayed et al., 2022; Gabriel et al., 2007; Limbu, 2020).

To seize the opportunity, we found a large group of farmers named 'on-farm local feed producers' who were making their own feeds by using locally available ingredients. It is no surprise that a previous study reported majority of fish farmers (80%) relied on locally available feed ingredients as supplements to their fish (Mmanda et al., 2020). This is contrary to Egypt, where despite the high development attained in aquaculture, between 50% and 99% of feed ingredients were imported (El-Sayed et al., 2015; Tacon et al., 2012). The availability of local ingredients in Tanzania is due to the fact that agriculture is the main economic activity in the country employing more than 60% of the population (Kassie et al., 2013). The abundance of locally available ingredients offers potential for producing affordable feeds for aquaculture growth in the country considering the relatively high feed price ranging from USD 1.50 to 3.50/kg for both brooders and fingerlings feeds, with an average price of USD 1.34/kg. The relatively high feed price is more likely to attract investment in fish feed production similar to what happened in Egypt (El-Sayed et al., 2022). In general, both the fish seed and feed values chains offer investment opportunities for the private sector due to high demand for the two inputs. In fact, private sector investments have led to aquaculture expansion across sub-Saharan Africa, particularly in inland waters (Ragasa et al., 2022). More likely, future expansion of aquaculture in Tanzania is tied to the private sector involvement in the industry.

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TABLE 2 Type and capacity of fish feed producers, geographical location and their marketing strategy

Region	Feed producer	Feeds produced/imported	Types of feeds	Capacity (tonnes per year)	Contribution (%)	Market strategy
Coastal	Ruvu Fish Farm Ltd.	Imported	Extruded pellets and granules	720	74	Directly
Coastal	Salibaba Pellet Ltd.	Local fish feed industry	Extruded pellets and granules	60	6	Agents all over the country
Dar es Salaam	Eden Agri-Aqua Farming Ltd.	Local fish feed industry	Compressed pellets and powder	180	18	Directly to and retailers
Dar es Salaam	Green Feed Investment Ltd.	Local Fish feed industry	Compressed pellets and Powder	4.8	1	Directly
Morogoro	International Tanfeeds Ltd.	Local Fish feed industry	Compressed pellets and Powder	21.6	1	Directly
Total				1026.4	100	

4.2 | Employment opportunities offered by seed and feed value chains

The 10 hatcheries and five feed producers visited employed 137 and 107 employees, respectively. Interestingly, youth dominated the seed value chain employment (60%). This finding suggests that aquaculture offers a potential solution to the youth unemployment crisis in sub-Saharan Africa, including Tanzania (Ackah-Baidoo, 2016). The sector has been reported to contain tremendous potential to contribute to jobs and youth employment in sub-Saharan Africa, including Tanzania (Ragasa et al., 2022). Further results showed dominance of males both in the seed (70%) and feed (63%) value chains, with more part-time workers (70%). The dominance of part-timers in the seed and feed value chains is probably due to cost saving because fish farming is deemed as a part-time activity due to the current limited scale and production (Charisiadou et al., 2022). Part-timers are common in aquaculture particularly in Asia and Africa (Weeratunge et al., 2010). The existence of more men reflects women identities being closely linked to reproductive work and the household domain (Weeratunge et al., 2010) and the subservient role of women (Bosma et al., 2019). Fish farming requires more men to culture the tilapia for at least 6 to 7 months and 6 to12 months for African catfish before harvesting. During this period, muscular work force is required to feed the fish, clean the ponds, grade and harvest them. Moreover, more men labour was also required to process the fish by frying, smoking or transporting them to the market for selling. Such activities are mainly conducted by men resulting in their dominance in the seed and feed value chains. In general, the fish seed and feed production value chains in Tanzania offer opportunities for income and employment to different age groups, particularly youth.

4.3 | The contribution of seed and feed value chains to the aquaculture development in Tanzania

The aquaculture industry depends partly on seed and feed as input resources for its development. Therefore, we analyzed the contribution of seed and feed value chains on fish farming development in Tanzania. We found that seeds and feeds were the main input supplies obtained either directly from producers or indirectly from traders. The produced tilapia and African catfish seeds were sold to fish farmers or marketers/traders. The fish farmers sold their fish directly to individual consumers and restaurants or indirectly through marketers/traders. The sold fish led to the increased fish farming activities reported in this study (Figure 4). The increased farming activities might be due to several reasons. First, the availability of fish seeds and feeds as input resources, which are the main reasons for low aquaculture development in most sub-Saharan African countries (Tacon & Metian, 2009; Tacon et al., 2010) and in Tanzania (Charisiadou et al., 2022; Mmanda et al., 2020; Mndeme et al., 2020). About a quarter of the fish farmers (25%) reported using on-farm feeds made from locally available ingredients similar to previous reports in the country (Mmanda et al., 2020).

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TABLE 3 The source of ingredients for feed inputs at Ruvu Fish Farm Ltd. in Tanzania

Feed ingredients, additives, and raw material	Source
Import whole made feeds.	German
Ingredients/raw materials (sardines, soybeans, rice bran, cassava meal).	Locally obtained
Additives (vitamin c, aqua-mix and premix)	Thailand
Feed ingredients (maize, soybeans and cakes, sardines, sunflower cake, and rice bran)	Locally obtained
Soybean	Zambia and Malawi
Additives (premix, methionine, lysine, DCP, MCP, pellet binder and enzymes)	Spain, the Netherlands and Tunisia
Ingredients/raw materials (maize, sunflower cake, wheat bran, sardines, shrimps and soybeans)	Locally obtained
Additives (vitamin C and pellet binder)	Locally obtained
Feed ingredients (maize, soybeans, sardines, sunflower cake, maize bran, bones, lime and blood meal)	Locally obtained
Additives (premix, methionine, lysine, DCP, MCP, pellet binder and enzymes)	Imported

Abbreviations: MCP, monocalcium phosphate; DCP, dicalcium phosphate.

Locally produced feeds have been advocated to improve aquaculture production in sub-Saharan Africa countries (Gabriel et al., 2007; Limbu, 2020). Second, the government has made efforts to sensitize people to practice fish farming as a business activity in the era of the blue economy. Third, limited employment opportunities attracted youths to engage in fish farming, which represented more than quarter of the fish farmers. The involvement of youths in fish farming activities indicates the importance of the sector in creating employment for the young generation (URT, 2007). Fourth, the increased fish demand for food is due to the growing population particularly in urban areas (Mzula et al., 2021). Aquaculture reduces the ever-increasing food fish demand due to population growth in the country and dwindling wild stock production as has been reported in other sub-Saharan African countries (Ragasa et al., 2022). In general, aquaculture is a business, an employment opportunity and food source in Tanzania.

To further understand the contribution of the seed value chain to aquaculture development in the country, we analyzed the species cultured by fish farmers. We found that most cultured fish species in Tanzania were tilapia and African sharptooth catfish, which were exclusively stocked in ponds as monoculture and polyculture, which are common culture systems practised in the country (Limbu et al., 2017; Limbu et al., 2015; Shoko et al., 2016; Shoko et al., 2014). Ponds are the main culture structures used for fish production in Tanzania as reported by the government, whereby 31,407 ponds were available in the country compared to 780 cages (URT, 2021/2022). The stocking of fish seeds in ponds highlights its contribution to the development of the aquaculture industry in the country. We found most tilapia farmers (70%) stocked mixed-sex fingerlings compared to only 30% who stocked monosex fingerlings. Monosex tilapia culture controls overcrowding in ponds (Mbiru et al., 2016). It thus increases fish production (Kapinga et al., 2019), resulting in the improved livelihood of fish farmers (Mwaijande & Lugendo, 2015). Fish farming has been estimated to contribute 13% of household income in Tanzania (Mulokozi et al., 2020). The lack of information on income generation and food source aspects are some of the limitations of this study requiring future studies to explore. Unfortunately, most farmers (76%) were unaware of the advantages of culturing monosex tilapia, highlighting inadequate extension services of the fish farmers in the surveyed areas. In general, the seed and feed value chains are the drivers of aquaculture production development in Tanzania as suppliers of inputs to the fish farmers in the industry.

4.4 | The critical factors limiting aquaculture development in Tanzania

During the present study, 10 critical issues affecting the performance of fish seed and feed value chains and general aquaculture production were identified. We categorized the factors identified into those related to seed and feed value chains and overall factors for aquaculture development in the country. The main critical factor specific to the seed value chain was inadequate quality seed. Inadequate quality seed affects freshwater aquaculture production and development in Tanzania (Mndeme et al., 2020), similar to other African countries (Brummett et al., 2008). Moreover, reduced fingerlings availability including wild-caught is still a challenge in Tanzania mariculture despite availability of few hatcheries (Charisiadou et al., 2022). The limited availability of quality fish seed might be caused by limited larviculture knowledge due to inadequate extension services. Many hatchery operators did not know the quality of the wild collected broodstock due to inadequate knowledge. Production of fish seeds without knowledge of the quality of brooders causes poor quality fingerlings (Mndeme et al., 2020) leading to an inadequate supply of seeds. In a nutshell, the absence of quality fish seed limits the speed of aquaculture development in Tanzania.

The fish feed value chain was mainly explicitly limited by two factors. First was the higher price of feed raw materials. Despite the local availability of ingredients, fish farmers reported high price of feed ingredients, particularly of animal origin chiefly due to competition from other users (Munguti et al., 2012) and seasonal availability as

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TABLE 4 Perception of farmers on the quality of industrial and local feeds found in surveyed regions

Types of feeds		Feed quality			Total	Percentage
		Good	Moderate	Poor		
Type 1	Industrial feeds	22	0	0	22	33
	Local feeds	5	9	30	44	66
	Industrial and local feeds	1	0	0	1	1
	Total responses (%)	28 (42)	9 (13)	30 (45)	67	100
Type 2	Non-extruded pellet	11	0	0	11	16
	Extruded pellet	8	0	0	8	12
	Brans and other local ingredients	5	9	30	44	66
	Extruded and non-extruded pellets	3	0	0	3	5
	Extruded and live foods	1	0	0	1	1
	Total responses (%)	28	9	30	67	100

determined by the agricultural calendar (Chimatiro & Chirwa, 2007; Obirikorang et al., 2015). Second, the feed value chain was limited in terms of quality and quantity. Currently, the feed industry in Tanzania is dominated by the private sector characterized by small-scale plants with limited capacity to produce adequate quantities of high-quality feeds. This explains the high proportion of imports amounting to 74% of all commercial feeds reported in this study, similar to 75% of imported feeds reported by the government (URT, 2021/2022). The quantity and quality of feeds produced from the private producers are yet to meet the estimated demand of 120,000 metric tonnes required to achieve the 10.5 kg per capita consumption (MoFP, 2021). However, most smallholder fish farmers cannot afford to purchase commercial feeds; hence, they rely on on-farm made feeds compounded by using locally available ingredients. During the study period, most farmers (66%) using farm-made feeds spent less than USD 0.50 per kg compared to an average of USD 1.34 per kg for those using commercial pelleted feeds. This might be a reason for the fish farmers to use a mixed on-farm and commercial feeds feeding strategy reported earlier in this study. The fish farmers possibly used this strategy to spare the limited available commercial feeds, balance the nutrients for increased growth rate and reduce feeds expenditure. High-cost feed also explains the large proportion (80%) of the fish farmers reported to fertilize their ponds by using animal manure mostly from poultry. Fertilizing ponds might be a strategy to reduce production costs by leveraging natural food organisms to supplement the expensive commercial feeds (El-Sayed et al., 2015; Limbu, 2020; Limbu et al., 2016; Shoko et al., 2019). Generally, the high price of ingredients and limited quality and quantity of feed slowdown the speed of aquaculture development in Tanzania.

Apart from the specific factors on fish seeds and feeds, we found seven general critical factors affecting aquaculture development in Tanzania. First, inadequate knowledge on fish farming due to limited aquaculture extension services. Most fish farmers pointed out that they did not have sufficient technical knowledge of fish farming. The visited hatcheries and feed producers had a shortage of skilled workers due to limited aquaculture extension services. The inadequate technical knowledge of fish farmers (Charisiadou et al., 2022) might be the reason for some of them producing poor quality seeds and feeds, leading to low fish growth performance in most farms in Tanzania (Mndeme et al., 2020).

The second general critical factor limiting aquaculture development in the studied regions was insufficient extension services. Only 58% of fish farmers in the studied areas accessed extension services. The importance of access to extension services was evidenced by majority (95%) of the fish farmers who received extension services reporting improved fish farming activities, similar to a previous study (Kumar et al., 2018). The low cultured fish production reported in the country (Charisiadou et al., 2022; Mmanda et al., 2020; Mndeme et al., 2020; Mulokozi et al., 2020) might be caused by a lack of training in aquaculture as reported by most fish farmers (70%) in this study. This coincides with the report from the government, which indicated that 12,902 fish farmers received extension services, which is 40% of the total 31,998 fish farmers in the country (URT, 2021/2022). The insufficient extension services were contributed by inadequate fisheries extension

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TABLE 5 Demographic characteristics of value chain actors

Variables		Number of respondents	Percentage
Gender	Male	58	87
	Female	9	13
Age	15–35	19	29
	36–55	32	48
	56–65	9	13
	>65	7	10
Education	Primary education	35	52
	Secondary education	10	15
	Diploma	8	12
	Bachelor degree	11	16
	Master's degree	3	5

TABLE 6 The price (percentage) of fish produced in the studied regions in Tanzania

	Fish price per kilogram			
Region	USD 1.35–2.25	USD 2.25–3.15	USD >3.15–4.50	Total (%)
Morogoro	65	35	0	100
Coastal region	21.74	34.78	43.48	100
Dar es Salaam	0	11.1	88.89	100
Lindi	50	25	25	100

TABLE 7 The general critical factors for the development of aquaculture production value chain in the study regions

Critical factors among fish farmers	Number of respondents	Percentage
Insufficient extension officers	12	18
Fish predators	15	22
Absence of quality feed	25	37
The higher price of feed raw materials	30	45
Absence of quality seed	27	40
Higher price seeds	6	9
Distant to quality seed	4	6
Fish death	1	2
Lack farmers network	6	9
Power failures	4	6
Lack of education	45	67
Absence of farming infrastructure	12	18
Lack of sufficient water or too expensive water	18	27
Water seepage in ponds	4	6
Lack of proper harvesting technique	2	3
Absence of reliable fish market	13	20
Flooding	1	2
Lack of capital	33	49

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personnel. The country has a total of 677 fisheries extension officers compared to the demand of 16,000 with a deficit of 15,323 personnel (URT, 2021/2022). These results show that insufficient extension services hamper aquaculture development in Tanzania.

The third general specific factor was the lack of capital for fish farming. Fish farmers did not know reliable financial sources to establish farms, buy seeds and feeds. Insufficient initial and operational funds interrupted some operators from upgrading their hatchery facilities and a few withdrew from the sector. The operators faced difficulties obtaining credit from banks due to limited financial and business skills. The inclusion of capital investment has recently been mentioned to improve aquaculture production (El-Sayed et al., 2022). The fourth general critical factor for aquaculture development was inadequate access to fish farming equipment. The aquaculture industry in Tanzania has limited access to equipment including excavators for ponds, feed machines, hatchery facilities, ice plants, cold storage, fish transport facilities, fish processing units and water quality monitoring tools. The fish farmers had poor knowledge and skills in ponds construction mainly due to inadequate extension services. Indeed, aquaculture equipment has been reported as an obstacle to mariculture development in Tanzania (Charisiadou et al., 2022). The fish farmers reported predators as the fifth factor hindering aquaculture development. Fish predators reduce the survival and yield of fish through consumption, particularly at night. Since fish cultured in ponds cannot be clearly observed and counted, farmers are disappointed by harvesting fewer fish than stocked ones. The regions studied have been reported to have high fish predation due to animals, birds and theft (Wetengere, 2011), possibly due to inadequate knowledge on predator control as evidenced by limited extension services. Accordingly, the fish farmers reported fish predators as a challenge facing aquaculture development in the regions visited.

Fish farmers reported insufficient water or too expensive water for fish rearing as the sixth general critical factor for aquaculture development. The majority of fish farmers (70%) had no reliable good quality water source and thus they depended on insufficient, poor quality and expensive water. It has been reported that well drilling is costly for local farmers in Tanzania (Mulokozi et al., 2020). More likely, the farmers have limited knowledge on site selection, limited technology to harvest rainwater and adopting water saving techniques for aquaculture production because the country has enormous water supply sources for aquaculture practices (Rukanda & Sigurgeirsson, 2018). A few seed producers could not afford public water supply charges. The lack of water quality monitoring tools accelerated the water problem whereby many hatcheries had no water quality monitoring apparatus. Consequently, fish were subjected to uncertain water quality parameters. This challenge was blamed for causing occasional broodstock mortalities and difficulties in monitoring hatching conditions for African catfish.

The fish farmers reported the absence of reliable fish market as the last general critical factor affecting aquaculture development in Tanzania. The fish farmers in the studied regions did not know the available avenues to sell their fish due to limited access to markets (Mwaijande & Lugendo, 2015). Little information exists on the whereabouts of selling their fish due to inadequate knowledge of business and marketing skills. The fish market in Tanzania is fragmented whereby fish farmers do not know where to sell their fish. Consequently, fish farmers are exploited by selling their fish to mediators at a low price. Generally, fish farmers lack farmer-owned organizations to facilitate better access to market services. Organizing fish farmers into farmer-owned associations could improve knowledge on access to markets.

4.5 | Suggested actions for improving aquaculture value chains in Tanzania

The seed and feed industries are the most important value chains in aquaculture production. For the seed industry to advance, we suggest establishing breeding programmes and more hatcheries for mass production of fingerlings. We further recommend the government to establish a code of conduct for quality assurance of seed certification, which will have to be adhered to by all seed producers. To reduce seed cost, we suggest using medicinal plants such as *Aspilia mossambicensis* and *Azadirachta indica* (Kapinga et al., 2019) to minimize the use of expensive hormones on sex reversal and hybridization (Mbiru et al., 2016; Mtaki et al., 2022) during seed production. Furthermore, the government and private sector may introduce cost-sharing scheme for seed production. Moreover, the government should put more emphasis on genetic improvement to enhance availability of good quality broodstock.

For the feed value chain, we suggest reducing the high price of ingredients and commercial fish feeds by forging a working collaboration between industrial, commercial fish feed producers, and researchers to develop locally and affordable protein sources such as black soldier fly larvae (Limbu et al., 2022) and algae (Ahmad et al., 2022; Yossa et al., 2021) to replace expensive and limited available fishmeal in feed formulations and production. We recommend the government to continue promoting fish farming in order to build a critical mass for fish farmers to justify investment in large commercial feed plants. Furthermore, we suggest enhancing access to industrial and commercial training/knowledge at different levels of education in order to provide practical training skills in colleges and universities to equip graduates with the required skills for producing quality fish feeds. This may involve arrangements such as internships and aquaculture innovation hubs. We also suggest conducting joint research between universities and research centres and the industry.

We suggest training of the fish farmers on aquaculture production technologies based on the aforementioned general challenges. We further recommend a proper implementation framework for delivering extension services to all fish farmers on seed and feed production, predator control, site selection and pond construction. The number of extension workers should be increased through employment, and the government should facilitate their visits to fish farmers more frequently. The government should also enhance research-training-extension and research-famers-extension linkage to ensure dissemination of research to end-users in the aquaculture value chain. We also encourage the private sector to establish aquaculture advisory and

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technical services to complement efforts by the government extension services.

Moreover, deliberate efforts should be made to improve access to specialized financial loans and support to fish farmers by enhancing their financial and business skills through training. Increasing the supply of microfinance to farmers has been shown to increase directly access to improved fingerlings and feeds in aquaculture (Ataguba & Olowosegun, 2010). Likewise, while commending the government efforts on exempting value-added tax and import duty on some aquaculture goods and services, we suggest the government to continue enhancing fish farmers understanding on item specific exemptions provided in order to increase availability of equipment required for aquaculture production such as tax holiday and tax rebate for investment. The government should also consider lowering water user fees for fish farmers in order to stimulate fish farming. Finally, we recommend a campaign to promote fish consumption through public events and mass media to increase market for farmed fish.

5 | CONCLUSION

This study demonstrated the existence of different actors in fish seed and feed production value chains in Tanzania. The seed and feed value chains supply tilapia and African sharptooth catfish cultured in the country . The progress made in aquaculture development in Tanzania is partly contributed to the availability of seeds and on-farm and commercial feeds. The seed and feed value chain production in Tanzania offers opportunities for the private sector for increased fish production for income, employment and consumption. However, aquaculture in Tanzania has inadequate quality and quantity of seeds and feeds because of a shortage of trained and skilled personnel and inadequate extension services. The industry has limited equipment, expensive water supply mainly due to insufficient capital for investment, and fragmented fish market. All these challenges impede aquaculture development in the country, requiring appropriate interventions. Required suitable intervention measures include providing more practical training and skills to expertise and fish farmers on seed, feed and aquaculture production technologies and reducing inadequate fish feeds, and improving their quality through collaborative research between producers and researchers. Moreover, delivering extension services to all fish farmers, improving access to financial services and sensitizing and organizing fish farmers into associations for market campaigns are all required. These measures aim to ensure continued sustainable development of aquaculture in the country for income, employment and food generation for the society.

AUTHOR CONTRIBUTIONS

Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Supervision, Writing – original draft, Writing – review & editing: Amon Paul Shoko. Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing: Samwel Mchele Limbu. Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing: Eusebia Ernest Ulotu. Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing: Salome Daniel Shayo. Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing: Mathew Ogalo Silas. Writing – review & editing: Sloans K. Chimatiro. Writing – review & editing: Nazael Amos Madalla. Writing – review & editing: Rashid Adam Tamatamah.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. The study was carried out in accordance with the Tanzanian laws and guidelines for the experiments involving humans. Accordingly, all participants were requested to express their willingness to voluntarily participate in the study before administering the questionnaires.

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