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Animal Waste and Agro-by-Products: Valuable Resources for Producing Fish at Low Costs in Sub-Saharan Countries

Renalda N. Munubi and Hieromin A. Lamtane

Abstract

Animal and crop production throughout the world generate high amounts of wastes or by-products annually that may possess added value compounds with high functionality. These wastes and by-products may cause negative environmental impacts and significant expenses if not well managed and or controlled. Much of these wastes and by-products is valuable and cheaper source of potentially functional compounds such as proteins, lipids, starch, micronutrients, bioactive compounds, and dietary fibbers. In aquaculture, feed is expensive, and the existing body of literature has shown that animal manure and its extracts can be successfully incorporated into fishpond to increase fish production at a low cost. In addition, crop residues such as rice bran, maize bran, and seed cakes are commonly used as pond inputs in small-scale aquaculture. Animal waste and crop residues are added in a fishpond that filter-feeding fish can use directly as feed, and these may form a major proportion of the detritus in the pond. These resources also stimulate the growth of phytoplankton that are rich in protein and are the basis of the food web that can support the growth of a range of herbivorous and omnivorous fish. Therefore, technically, wastes are used as direct feed, a source of minerals for autotrophic production and a source of organic matter for heterotrophic production. In this context, animal manure and crop residues have been used to provide great opportunities to improve food security. The purpose of this review is to project the potential of animal waste and agro-by-products as a sustainable alternative as aquaculture inputs to reduce poverty, malnutrition, and hunger in developing countries.

Keywords: animal waste, fish farming, crop residues, farming systems, valorization

1. Introduction

Aquaculture is one of the world's fastest growing food production sectors with great potential for food supply, poverty alleviation, and enhanced trade and economic benefits, as targeted by sustainable development goals SDGs. The contribution of aquaculture to global fish supply increased from 3.9 percent in 1970 to over 41.3 percent in 2011 amounting to 63.7 million metric tonnes valued over USD

119 billion [1]. Its average growth rate of 8.8 percent has outpaced capture fisheries (1.2%) and terrestrial farmed meat production (2.8%) [1]. Aquaculture accounts for around 50 percent of seafood supply globally [2]. This quantity is expected to increase substantially as population increases (**Figure 1**). Aquaculture has gained much importance globally due to a decline in wild stock from natural water bodies; thus, aquaculture plays a key role in augmenting dwindling catch capture fisheries. It is well known that among other challenges facing the aquaculture sector, availability and quality of feeds affect its growth particularly in sub-Saharan (see for example [4–10]). Despite this challenge, aquaculture has been considered as one of the economic activities that contribute to poverty reduction, food security, and nutrition in the sub-Saharan Africa [4, 11, 12] and Asian countries [1, 13–17].

In order to realize the contribution of aquaculture in the alleviation of poverty and improvement of food security, development agencies should broaden their focus beyond poor/subsistence producers to include small and medium enterprises adopting a value chain perspective [18]. Bangladesh, which is among developing countries, has proven that aquaculture intervention in resource poor and marginalized group marked an increase in income savings and frequency of fish consumption [19]. Although small-scale fish farmers play a big role in poverty reduction and food security, the intensification from extensive to semi-intensive is essential [20]. However, for the intensification to take place, there should be an increase in investment in technological innovation and transfer through (i) Nutrition, feeds and feeding management, and (ii) low-impact production systems. This paper discusses

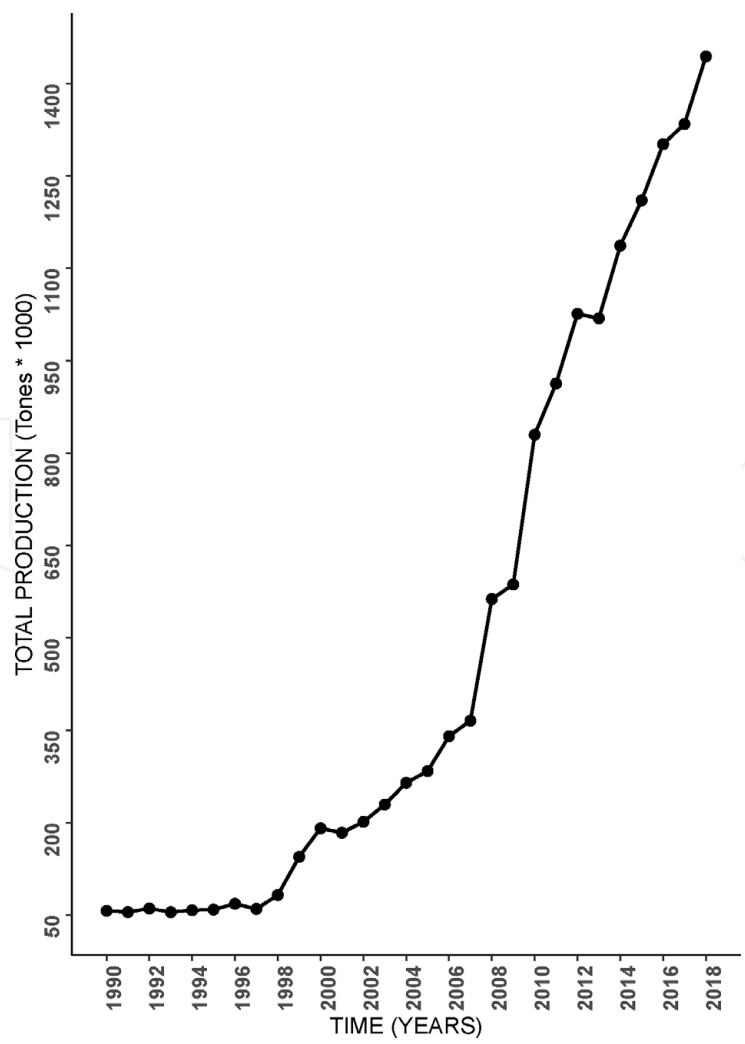


Figure 1.
Freshwater Aquaculture trend for African countries from 1990 to 2018 (data analyzed by this study see [3]).

the valorization of animal waste/by products and plants/crops-by-products to produce fish at low cost in order to increase nutrition and reduce food insecurity.

2. Aquaculture production in Africa

Africa’s fisheries output is dominated by capture fisheries, but the contribution of aquaculture to the total amount of fish produced in the region has grown at a steady pace over the past decade (**Figure 1**). In these countries, fish is produced from capture fisheries and aquaculture. However, fish catches from wild sources have been declining, due to multiple anthropogenic pressures including climate change, overfishing, habitat destruction, invasion of non-native species, illegal, and unregulated fishing, and poor governance [21]. For example, consumption in the Eastern Africa region was projected to increase from 4.80 kg in 2013 to 5.49 kg by 2022 [22]. This implies that in order to meet the gap between fish production and the increasing demand for food fish, aquaculture production must double by 2050 to satisfy the Africa’s fast-growing human population [23]. An appropriate way of keeping this sector growing constantly is the development of new researches aimed at determining the benefits of using different and cheap resources of feeds and determining how these strategies influence economic and productive parameters.

Country	Total production	Percent
Egypt	930,344	70.476
Nigeria	160,114	12.129
Ghana	70,628	5.350
Uganda	70,095	5.310
Zambia	17,500	1.326
Kenya	12,160	0.921
Tanzania	11,000	0.833
Zimbabwe	10,500	0.795
Malawi	5036	0.381
Rwanda	4526	0.343
Mali	3524	0.267
Congo	3185	0.241
Côte d’Ivoire	3000	0.227
Benin	2802	0.212
Lesotho	2500	0.189
Madagascar	2372	0.180
Algeria	2045	0.155
Angola	1752	0.133
South Africa	1503	0.114
Burundi	1455	0.110
Others	4045	0.306
Total	1,320,086.62	100

Table 1.
Freshwater aquaculture production (tones) in Africa by country in 2018. (data analyzed by this study see [3]).

In the aquaculture sector, Africa produced about 1400 tonnes of fish from freshwater aquaculture in 2018, but most of this came from Egypt, which contributed more than 70 percent of the total production (**Figure 1**, Data obtained in [3]). Major aquaculture producers in 2018 with more than 10,000 tonnes include Egypt, Nigeria, Ghana, Uganda, Zambia, Kenya, Tanzania, and Zimbabwe. Production has increased three times for the past ten years from 563,000 in 2008 to 1,440,000 in 2018 (**Figure 1**, [3]). In general, African aquaculture production is overwhelmingly dominated by finfishes (99.3%), with only a small fraction of production from marine shrimps and mollusks [23]. Among the freshwater cultured finfishes, tilapia farming is the main product, which is also the most popular fish from a consumer perspective. Aquaculture production in Africa is also increasing as presented in **Table 1**.

3. Aquaculture production systems

In Africa, aquaculture systems are made up of extensive and semi-intensive systems. Small-scale earthen ponds (extensive systems) are characterized by low inputs and low yields. However, semi-intensive systems are characterized by human intervention where by fertilization is done to improve feed availability, hence, improved fish yield. In East Africa, semi intensive mainly used to produce *Oreochromis niloticus* and *Clarias gariepinus* in either monoculture or polyculture [24]. They consist mostly of earthen ponds, liner ponds and concrete ponds.

Other systems include cage particularly in areas with large water bodies including East Africa great lakes. Cage culture involves holding organisms under captivity within an enclosed space while maintaining free exchange of water. Cages use the existing water bodies, therefore, require comparatively low capital outlay and use simple technology, they can be used not only as a method for producing cheaply and high-quality protein but also for cleaning up eutrophicated waters through the culture and harvesting of caged planktivorous species. Although fish farming in cages in the existing water body is considered inexpensive relative to pond construction and its associated infrastructures [25], the feasibility and profitability of fish cage culture is influenced by the cost of input invested and revenue collected from output.

Although not common, re-circulating aquaculture system (RAS) has been used in some countries particularly South Africa. RAS refers to a fish farming technology that reuse wastewater from tanks/rearing premises [26]. Water reuse in RAS is supported by both inline and end pipe treatment using a series of mechanical filter for solid waste removal, bio-filter for dissolved nitrogenous waste removal and sludge pond to settle suspended solid [27]. RAS technology is termed as sustainable advanced production system that provides constant and independent production conditions and reduces water consumption compared with semi-intensive pond aquaculture, RAS technology provides high fish productivity with better effluent control of environmental conservation [28, 29]. Some of the sub Saharan countries have benefited from high temperature to which RAS performs efficiently [30]. The adoption of the system is low due to high cost of initial capital investment in tanks and high cost of electricity required in running the system and feeds. This has therefore called for sustainable aquaculture by integration of fish with livestock. Such integration involves the recycling of livestock wastes and processing by-products as manure and/or direct food for fish. Today, aquaculture in developing countries is mostly a small-scale activity and is usually not practiced as

a stand-alone economic activity, but rather as subsistence farming integrated with agricultural activities such as horticulture and rearing of livestock.

4. Organic manure and fish growth

The production volume and market share of aquaculture products are advancing extremely rapidly. However, feed is usually recognized as the single largest cost to producers, hence, the best way of reducing the cost of fish production is using organic manure and supplementary feed when available. Animal manure is widely used in developing countries in fish production in earthen ponds. The quality of manure as a fertilizer varies depending on the source of animal and the quality of feed fed to the animal [31, 32]. Research showed that pig, chicken and duck manures increase fish production more than cow and sheep manure. For example, in Asia, fish farming is probably the only branch of animal husbandry in which the use of manures is a traditional management tool. In Sub-Saharan Africa, ponds are fertilized using organic manures such as cow dung, sheep, poultry or rabbit manure [33]. The use of animal manure to fertilize ponds has been widely practiced in many countries in order to increase plankton so that there is more natural food for fish to eat, hence, high fish production. Manuring is therefore considered a cheap and preferred source of nutrient to increase fish production.

Pond fertilization with animal manure stimulates production of bacteria, phytoplankton, zooplankton, and benthic organisms [34]. The use of animal waste (livestock) has been studied under integration systems in Africa [35–37] and extensively in Asian countries [38, 39]. Benefits of integrated Agro-aquaculture systems have been reported in resource poor areas particularly in developing countries [38, 40, 41]. Studies conducted in sub-Saharan countries on the integrated aquaculture and agricultural systems are presented in **Table 2**.

Several studies showed that organic supplements contributed to fish yields by supplying P, N and C for algal growth and by stimulating detritus production and heterotrophic utilization. It is well known that high fish yields can be achieved through abundance of plankton in the cultural system [46]. Africa has vast resources of livestock and poultry, which play a vital role in pond fertilization. Livestock wastes including animal manure and poultry by-products are valuable resources in fish farming [47]. Livestock manure contains protein content of about 15 percent, energy (1250) kilocalories per kilogram, manure, and soluble vitamins [48].

Name of IAA	Country	Fish spp.	Livestock	Author(s)
Fish-cum-vegetable	Kenya	Various	—	[42]
Unknown	Malawi	Tilapia	—	[41]
Fish-cum-vegetable	Tanzania	Tilapia	—	[43]
Fish-cum-vegetable	Tanzania	Tilapia & Catfish	—	[36]
Fish-poultry-vegetable	Tanzania	Tilapia	Poultry	[44]
Fish-poultry-vegetable	Tanzania	Tilapia & catfish	Poultry	[45]
Fish-cum-poultry	Tanzania	Tilapia	Poultry	[37]
Fish-cum-rabbit	Rwanda	Tilapia	Rabbit	[35]

Table 2.
Studies on the integrated agro-aquaculture in sub-Saharan countries.

5. Fish feed availability and the concept of valorization

One of the solutions of fish feed availability is to entice animal feeds producing industries to consider also the production of fish feed [49]. However, the big issue here will be affordability; of these industrial feed products; most of our farmers belong to subsistence income bracket, hence, they might not afford these feed products. The use of floating pellets needs higher investment [50], which in most cases is lacking among smallholders; and unless the government intervenes in addressing the problems through either credit facilities or the provision of subsidies, the situation is not likely to get any better. It has been established that profitability in aquaculture is influenced by the cost of feed [51]. In Sub-Saharan countries, justification for industrial scale production of fish feed is not a priority despite the availability of raw materials [4]. Therefore, in order to feed fish, farm-made feeds can be made using locally available ingredients including animal by-products and plant residues.

In Tanzania, more than 80 percent of fish farmers relied on locally available feed ingredients as a major feed supplement for their cultured fish [43]. These local feed ingredients are categorized into four groups, (i) animal by-products, (ii) agricultural by-products, (iii) plant leaves and weed, and (iv) industrial by-products. It has been reported that the early growth phase of tilapia in 1991–2000 was significantly contributed by the use of alternative sources of protein including fishery by-products, terrestrial animal by-products, and a wide range of plant by-products [52]. In this chapter, discussion is cantered on the valorization of two broad categories of ingredients, plant and animal based ingredients.

5.1 Plant based ingredients and by-products

In addition to fertilization, feeding in ponds is done using supplementary feeds formulated on farm or purchased from cottage fish feed production industries. In some cases, cereal bran such as grains as energy source (**Figure 2**) and soybeans as

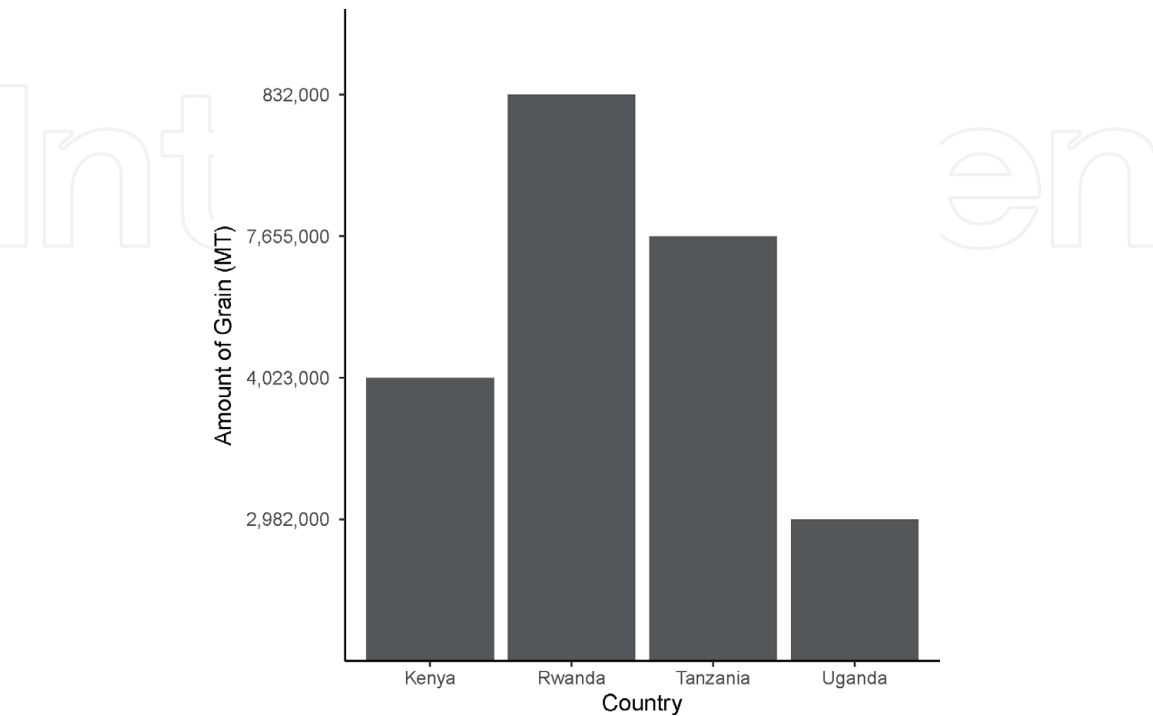


Figure 2.
Amount of grains required for fish feed compounding in East Africa. Source [53].

source of protein (**Figure 3**) are used in aquafeeds to increase pond productivity. The production from this system ranges from 1000 to 2500 kg/ha/year [33]. Most farmers prefer this system since it is less expensive in terms of feed inputs. Ten edible plant leaves were evaluated (see in [54]) as potential feed ingredients for aquatic animal, the results suggested that some of the plant leaves used contributed on growth performance, immune system, and disease resistance for the fish. Other important plant leaves which have been subjected to experiments to see whether they can be used as ingredients for fish feed formulation includes cassava leaves [55] and *Moringa* leaf [56]. In another study results showed that the integration of vegetables (*Brassica oleracea*) as pond inputs increased fish production and net yield than those reared under non-integrated systems [57]. In general, the amount of grain and soybean required in the four East African countries is given in **Figures 2** and **3**. Another experiment (see [58]), showed that when wheat bran, rice bran, and groundnut bran were used as agro-industrial by-products to examine their economic effectiveness in fish production, there were variability in growth rate and economic benefits, suggesting that variability of agro-by products reflects the growth rate of fish.

5.2 Animal based ingredients and by-products

According to the circular economy approach which focuses on the “reduce, reuse and recycle” of resources, waste from animal and food can be valorized leading to the production of proteins and other valuable compounds [59, 60]. For example, chicken, pig and cattle manures are substrates for production of housefly (*Musca domestica*) maggots which are in turn used as fish feed, or as supplement to fish meal in fish feed formulation [61]. Maggots are readily available and are accredited for having high nutritional value with an amino acid profile with biological value

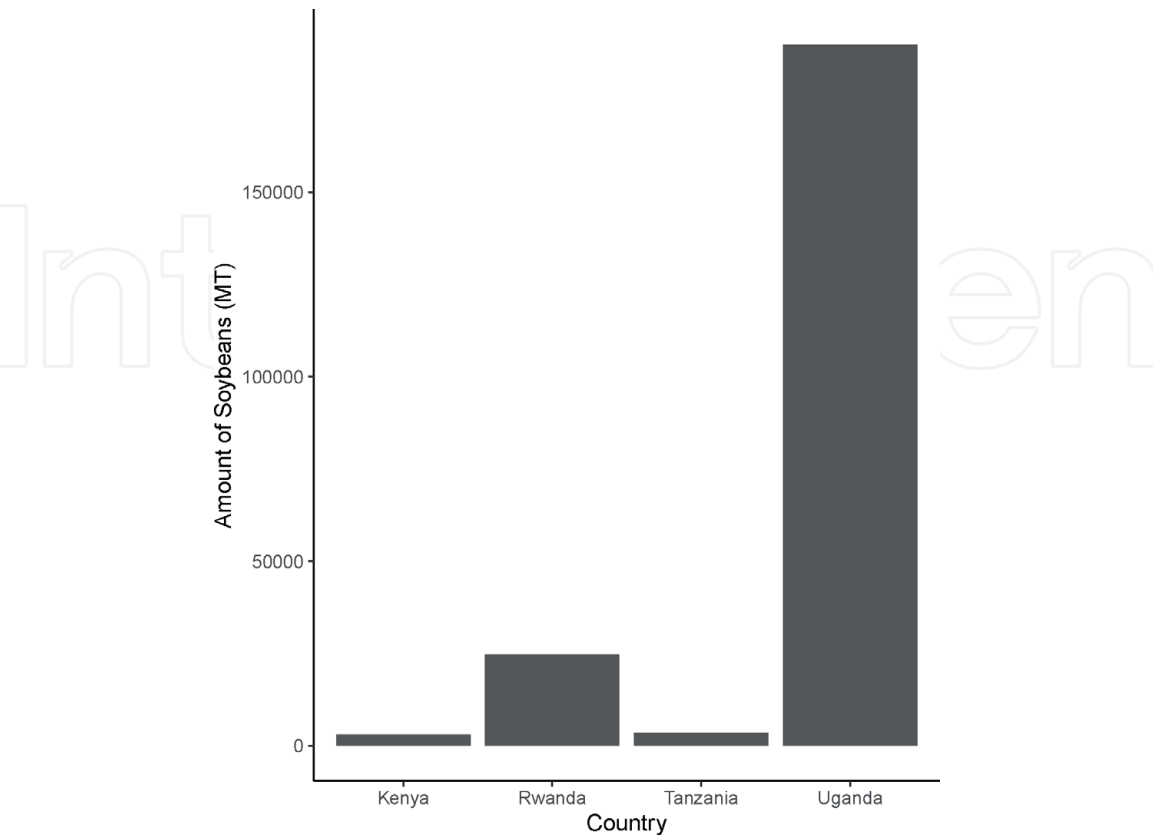


Figure 3.
Amount of soybean required for fish feed coumpound in four countries of East Africa. Source [53].

exceeding that of soybean and groundnut. Maggots can be harvested, processed into a meal that can be used to substitute or replace fish meal [61, 62]. Maggot grown on a mixture of cattle blood and wheat bran contained 92.7% dry matter, 47.6% crude protein, 25.3% fat, 7.5% crude fiber, 6.25% ash, and an amino acid profile comparable to fish meal [59] suggesting that animal wastes utilization can be used to produce insects which can be utilized as fish feed hence, reduce feed cost significantly, thus leading to a viable and sustainable aquaculture industry. The replacement of 25 percent fishmeal in catfish feed, culture with maggot gave high growth performance and profitability than fishmeal based diet [63, 64]. Several researches [65, 66] have been reporting on the use of red worms, black soldier fly, common housefly, and yellow mealworm as a source of protein to replace fishmeal. It is envisaged that the valorization of animal and animal by-products such as animal blood, offal of poultry, residues of traditional brewery waste, animal manure and fish wastes may contribute significantly on fish production hence, food nutrition and security.

6. Conclusion

It is clear that fish consumption in Sub-Saharan Africa is increasing. In order to maintain the present amount of fish consumption, considerable additional quantities of fish are required through aquaculture. In turn, aquaculture requires feed as a major input for increasing production. Since commercial fish feed production in most of the sub-Saharan countries is limited, considerable investments are required in local and low costs feed manufacturing. Raw materials of plant and animal origin are sufficiently available in the region albeit the possible competition from livestock and human consumption. Therefore, valorisation of animal and agro-products in the Sub-Saharan countries is imperative/inevitable for increasing fish production at low cost.

6.1 Recommendations

In order to increase food nutrition from aquaculture production through valorization of agro-by-products in the sub-Saharan countries, the following are recommended:

- Strengthen the use of Public Private partnering by putting more emphasis in services related to the collection of feed ingredients and preservation
- Public Private partnering must be embedded into an economic vision for aquaculture development
- Recognize small scale farmers as commercial ones and encourage small-scale farmers to work together by forming associations (work groups)
- Provide credit facilities for the private sector particularly for the small-scale holders
- Put emphasis on public private research partnerships and knowledge sharing on valorisation
- Provide capacity building and general education for small holders in order to improve their technological, managerial and commercial skills in handling agro by-products

6.2 The way forward

With the ever-increasing human populations in sub-Saharan countries, the demand for food would increase and natural resources will become even scarcer. This situation will be more worsen with severe climate changes. These trends necessitate for a critical assessment of the situation to enable devise informed solutions in addressing issues pertaining to agro by-product processing and valorization.

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References

- [1] Moffitt CM, Cajas-Cano L. Blue Growth: The 2014 FAO State of the World Fisheries and Aquaculture. *Fisheries*. 2014;39(11):552-3.
- [2] Little DC, Newton RW, Beveridge MC. Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proceedings of the Nutrition Society*. 2016 Aug;75(3):274-86.
- [3] Fisheries and aquaculture software. FishStatJ - software for fishery and Aquaculture statistical time series. In: *FAO Fisheries Division* [online]. Rome. Updated 14 September 2020. [Cited 16 November 2020]. <http://www.fao.org/fishery/>
- [4] Brummett RE, Lazard J, Moehl J. African aquaculture: Realizing the potential. *Food policy*. 2008 Oct 1;33(5):371-85.
- [5] FAO. Report of the FAO Expert Workshop on On-farm Feeding and Feed Management in Aquaculture.
- [6] Hecht T, De Silva SS, Tacon AG. Study and analysis of feeds and fertilizers for sustainable aquaculture development. Hasan MR, editor. Rome: Food and Agriculture Organization of the United Nations; 2007.
- [7] Huntington TC, Hasan MR. Fish as feed inputs for aquaculture—practices, sustainability and implications: a global synthesis. *FAO Fisheries and Aquaculture Technical Paper*. 2009 Jan;518:1-61.
- [8] Poumogne V, Brummett RE, Gatchouko M. Impacts of aquaculture development projects in western Cameroon. *Journal of applied aquaculture*. 2010 May 6;22(2):93-108.
- [9] FAO. Aquaculture development. 5. Use of wild fish as feed in aquaculture. FAO. Technical guidelines for responsible fisheries. 2011.
- [10] Tacon AG, Hasan MR, Metian M. Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects. *FAO Fisheries and Aquaculture technical paper*. 2011(564):I.
- [11] Kassam L, Dorward A. A comparative assessment of the poverty impacts of pond and cage aquaculture in Ghana. *Aquaculture*. 2017 Mar 1;470:110-22.
- [12] Béné C, Arthur R, Norbury H, Allison EH, Beveridge M, Bush S, Campling L, Leschen W, Little D, Squires D, Thilsted SH. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Development*. 2016 Mar 1;79:177-96.
- [13] De Silva SS, Davy FB. Aquaculture successes in Asia: contributing to sustained development and poverty alleviation. In *Success stories in Asian aquaculture 2010* (pp. 1-14). Springer, Dordrecht.
- [14] Béné C, Arthur R, Norbury H, Allison EH, Beveridge M, Bush S, Campling L, Leschen W, Little D, Squires D, Thilsted SH. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Development*. 2016 Mar 1;79:177-96.
- [15] Bogard JR, Farook S, Marks GC, Waid J, Belton B, Ali M, Toufique K, Mamun A, Thilsted SH. Higher fish but lower micronutrient intakes: Temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh. *PloS one*. 2017 Apr 6;12(4):e0175098.
- [16] Golden CD, Seto KL, Dey MM, Chen OL, Gephart JA, Myers SS, Smith M,

Vaitla B, Allison EH. Does aquaculture support the needs of nutritionally vulnerable nations? *Frontiers in Marine Science*. 2017 May 29;4:159.

[17] Teneva LT, Schemmel E, Kittinger JN. State of the plate: Assessing present and future contribution of fisheries and aquaculture to Hawai 'i's food security. *Marine Policy*. 2018 Aug 1;94:28-38.

[18] Beveridge M, Phillips M, Dugan P, Brummet R. Barriers to aquaculture development as a pathway to poverty alleviation and food security. (*Proceedings of the Advancing the Aquaculture Agenda, Paris, 2010*). Organization for Economic Cooperation and Development, 2010 Sep 14

[19] Pant J, Barman BK, Murshed-E-Jahan K, Belton B, Beveridge M. Can aquaculture benefit the extreme poor? A case study of landless and socially marginalized Adivasi (ethnic) communities in Bangladesh. *Aquaculture*. 2014 Jan 1;418:1-0.

[20] Waite R, Beveridge M, Brummett R, Castine S, Chaiyawannakarn N, Kaushik S, Mungkung R, Nawapakpilai SU, Phillips MI. Improving productivity and environmental performance of aquaculture. *WorldFish*; 2014 Sep 1.

[21] Chan CY, Tran N, Pethiyagoda S, Crissman CC, Sulser TB, Phillips MJ. Prospects and challenges of fish for food security in Africa. *Global food security*. 2019 Mar 1;20:17-25.

[22] Obiero K, Meulenbroek P, Drexler S, Dagne A, Akoll P, Odong R, Kaunda-Arara B, Waidbacher H. The contribution of fish to food and nutrition security in Eastern Africa: Emerging trends and future outlooks. *Sustainability*. 2019 Jan;11(6):1636.

[23] Cai J, Zhou X, Yan X, Lucente D, Lagana C. Top 10 species groups in

global aquaculture 2017. Retrieved from Rome, Italy: <http://www.fao.org/3/ca5224en/CA5224EN.pdf>. 2019.

[24] Munguti JM, Musa S, Orina PS, Kyule DN, Opiyo MA, Charo-Karisa H, Ogello EO. An overview of current status of Kenyan fish feed industry and feed management practices, challenges and opportunities. *International Journal of Fisheries and Aquatic Studies*. 2014;1(6):128-37.

[25] Masser MP. Cage culture in freshwater and protected marine areas. *Aquaculture production systems*. 2012 May 11:50014-8300.

[26] Ebeling JM, Timmons MB. Recirculating aquaculture. Cayuga Aqua Ventures; 2010.

[27] Van Rijn J. Waste treatment in recirculating aquaculture systems. *Aquacultural Engineering*. 2013 Mar 1;53:49-

[28] Martins CI, Eding EH, Verdegem MC, Heinsbroek LT, Schneider O, Blancheton JP, d'Orbcastel ER, Verreth JA. New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. *Aquacultural engineering*. 2010 Nov 1;43(3):83-93.

[29] Bartelme RP, McLellan SL, Newton RJ. Freshwater recirculating aquaculture system operations drive biofilter bacterial community shifts around a stable nitrifying consortium of ammonia-oxidizing archaea and comammox Nitrospira. *Frontiers in microbiology*. 2017 Jan 30;8:101.

[30] Kinyage JP, Pedersen LF. Impact of temperature on ammonium and nitrite removal rates in RAS moving bed biofilters. *Aquacultural Engineering*. 2016 Nov 1;75:51-5.

[31] Boyd CE, Tucker CS. Pond aquaculture water quality management.

Springer Science & Business Media; 2012 Dec 6.

[32] Leip A, Ledgard S, Uwizeye A, Palhares JC, Aller MF, Amon B, Binder M, Cordovil CM, De Camillis C, Dong H, Fusi A. The value of manure-Manure as co-product in life cycle assessment. *Journal of environmental management*. 2019 Jul 1;241:293-304.

[33] Opiyo MA, Marijani E, Muendo P, Odede R, Leschen W, Charo-Karisa H. A review of aquaculture production and health management practices of farmed fish in Kenya. *International Journal of Veterinary Science and Medicine*. 2018 Dec 1;6(2):141-8.

[34] Kang'ombe J, Brown JA, Halfyard LC. Effect of using different types of organic animal manure on plankton abundance, and on growth and survival of *Tilapia rendalli* (Boulenger) in ponds. *Aquaculture Research*. 2006 Sep;37(13):1360-71.

[35] Tabaro SR, Mutanga O, Rugege D, Micha JC. Optimum rabbit density over fish ponds to optimize Nile tilapia production in an integrated rabbit-fish system in Rwanda. *African Journal of Aquatic Science*. 2012 Aug 1;37(2):165-74.

[36] Limbu SM, Shoko AP, Lamtane HA, Kishe-Machumu MA, Joram MC, Mbonde AS, Mgana HF, Mgaya YD. Fish polyculture system integrated with vegetable farming improves yield and economic benefits of small-scale farmers. *Aquaculture Research*. 2017 Jul;48(7):3631-44.

[37] Shoko AP, Limbu SM, Lamtane HA, Kishe-Machumu MA, Sekadende B, Ulotu EE, Masanja JC, Mgaya YD. The role of fish-poultry integration on fish growth performance, yields and economic benefits among smallholder farmers in sub-Saharan Africa, Tanzania. *African Journal of Aquatic Science*. 2019 May 2;44(1):15-24.

[38] Prein M. Integration of aquaculture into crop-animal systems in Asia. *Agricultural systems*. 2002 Jan 1;71(1-2):127-46.

[39] Bhatt BP, Bujarbaruah KM, Vinod K, Karunakaran M. Integrated fish farming for nutritional security in Eastern Himalayas, India. *Journal of Applied Aquaculture*. 2011 Apr 1;23(2):157-65.

[40] Cavalett O, De Queiroz JF, Ortega E. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil. *Ecological Modelling*. 2006 Mar 15;193(3-4):205-24.

[41] Dey MM, Paraguas FJ, Kambewa P, Pemsl DE. The impact of integrated aquaculture-agriculture on small-scale farms in Southern Malawi. *Agricultural Economics*. 2010 Jan;41(1):67-79.

[42] Kipkemboi J, van Dam AA, Denny P. Environmental impact of seasonal integrated aquaculture ponds ('fingerponds') in the wetlands of Lake Victoria, Kenya: an assessment, with the aid of Bayesian Networks. *African Journal of Aquatic Science*. 2007 Nov 1;32(3):219-34.

[43] Mmanda FP, Mulokozi DP, Lindberg JE, Norman Haldén A, Mtolera M, Kitula R, Lundh T. Fish farming in Tanzania: the availability and nutritive value of local feed ingredients. *Journal of Applied Aquaculture*. 2020 Jan 4:1-20.

[44] Mlelwa TI. *Growth performance and economic benefit of nile tilapia (Oreochromis niloticus) and chinese cabbage (Brassica rapachinensis) in aquaculture integration* (Doctoral dissertation, Sokoine University of Agriculture).

[45] Limbu SM, Shoko AP, Lamtane HA, Kishe-Machumu MA, Joram MC, Mbonde AS, Mgana HF,

Mgaya YD. Supplemental effects of mixed ingredients and rice bran on the growth performance, survival and yield of Nile tilapia, *Oreochromis niloticus* reared in fertilized earthen ponds. SpringerPlus. 2016 Dec;5(1):1-3.

[46] Jha P, Sarkar K, Barat S. Effect of different application rates of cow dung and poultry excreta on water quality and growth of ornamental carp, *Cyprinus carpio* vr. koi, in concrete tanks. Turkish Journal of fisheries and aquatic Sciences. 2004 Jan 1;4(1):17-22.

[47] Adewumi AA, Adewumi IK, Olaleye VF. Livestock wastes: fish-wealth solution. WIT Transactions on Ecology and the Environment. 2011 May 9;145:793-800.

[48] Kausar R. Review on recycling of animal wastes as a source of nutrients for freshwater fish culture within an integrated livestock system. Retrieved April. 2009;24:2009.

[49] Brugère C, Ridler N, Haylor G, Macfadyen G, Hishamunda N. Aquaculture planning: policy formulation and implementation for sustainable development. FAO Fisheries and Aquaculture Technical Paper. 2010(542)

[50] Ansah YB, Frimpong EA. Impact of the adoption of BMPs on social welfare: A case study of commercial floating feeds for pond culture of tilapia in Ghana. Cogent Food & Agriculture. 2015 Dec 31;1(1):1048579.

[51] Neira I, Engle CR, Ngugi C. Economic and risk analysis of tilapia production in Kenya. Journal of Applied Aquaculture. 2009 May 19;21(2):73-95.

[52] Kumar G, Engle CR. Technological advances that led to growth of shrimp, salmon, and tilapia farming. Reviews in Fisheries Science & Aquaculture. 2016 Apr 2;24(2):136-52.

[53] Rothuis AJ, Turenhout MN, van Duijn A, Roem AJ, Rurangwa E, Katunzi EF, Shoko A, Kabagambe JB. Aquaculture in East Africa: a regional approach. IMARES/LEI; 2014.

[54] Olusola SE, Olaifa FE. Evaluation of some edible leaves as potential feed ingredients in aquatic animal nutrition and health. Journal of Fisheries. 2018 Mar 8;6(1):569-78.

[55] Madalla N. Novel. Feed Ingredients for Nile Tilapia (*Oreochromis niloticus* L.). Doctoral dissertation, University of Sterling

[56] Shigulu H. Effect of substituting sunflower seed cake meal and soya meal with *Moringa oleifera* leaf meal in Nile Tilapia (*Oreochromis niloticus*) diets (Doctoral dissertation, Dissertation for award of Msc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 84pp).

[57] Shoko AP, Getabu A, Mwayuli G. Growth performance, yields and economic benefits of Nile tilapia *Oreochromis niloticus* and Kales *Brassica oleracea* cultured under vegetable-fish culture integration. Tanzania Journal of Science. 2011;37(1).

[58] Abarike ED, Attipoe FY, Alhassan EH. Effects of feeding fry of *Oreochromis niloticus* on different agro-industrial by-products. International Journal of Fisheries and Aquaculture. 2012 Sep 30;4(8):178-85.

[59] Gasco L, Acuti G, Bani P, Dalle Zotte A, Danieli PP, De Angelis A, Fortina R, Marino R, Parisi G, Piccolo G, Pinotti L. Insect and fish by-products as sustainable alternatives to conventional animal proteins in animal nutrition. Italian Journal of Animal Science. 2020 Dec 14;19(1):360-72.

[60] Stevens JR, Newton RW, Tlusty M, Little DC. The rise of aquaculture

by-products: Increasing food production, value, and sustainability through strategic utilisation. Marine Policy. 2018 Apr 1;90:115-24.

[61] Hezron L, Madalla N, Chenyambuga SW. Mass production of maggots for fish feed using naturally occurring adult houseflies (*Musca domestica*). Livestock Research for Rural Development. 2019;31(4).

[62] Hezron L, Madalla N, Chenyambuga SW. Alternate daily ration as a feeding strategy for optimum growth, nutrient utilization and reducing feed cost in Nile tilapia production. Livestock Research for Rural Development. 2019;31(7).

[63] Sogbesan OA. Nutritive potentials and utilization of garden snail (*Limicolaria aurora*) meat meal in the diet of *Clarias gariepinus* fingerlings. African Journal of Biotechnology. 2006;5(20).

[64] Djissou AS, Adjahouinou DC, Koshio S, Fiogbe ED. Complete replacement of fish meal by other animal protein sources on growth performance of *Clarias gariepinus* fingerlings. International Aquatic Research. 2016 Dec 1;8(4):333-41.

[65] Ghosh C. Integrated vermi-pisciculture—an alternative option for recycling of solid municipal waste in rural India. Bioresource Technology. 2004 May 1;93(1):71-5.

[66] Musyoka SN, Liti D, Ogello EO, Meulenbroek P, Waidbacher H. Earthworm, *Eisenia fetida*, bedding meal as potential cheap fishmeal replacement ingredient for semi-intensive farming of Nile Tilapia, (*Oreochromis niloticus*). Aquaculture Research. 2020 Jun;51(6):2359-68.