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REVIEW ARTICLE

Utilization of Fish Waste Extraction as Organic Fertilizer for Crop Growth and Yield Improvement. A Review

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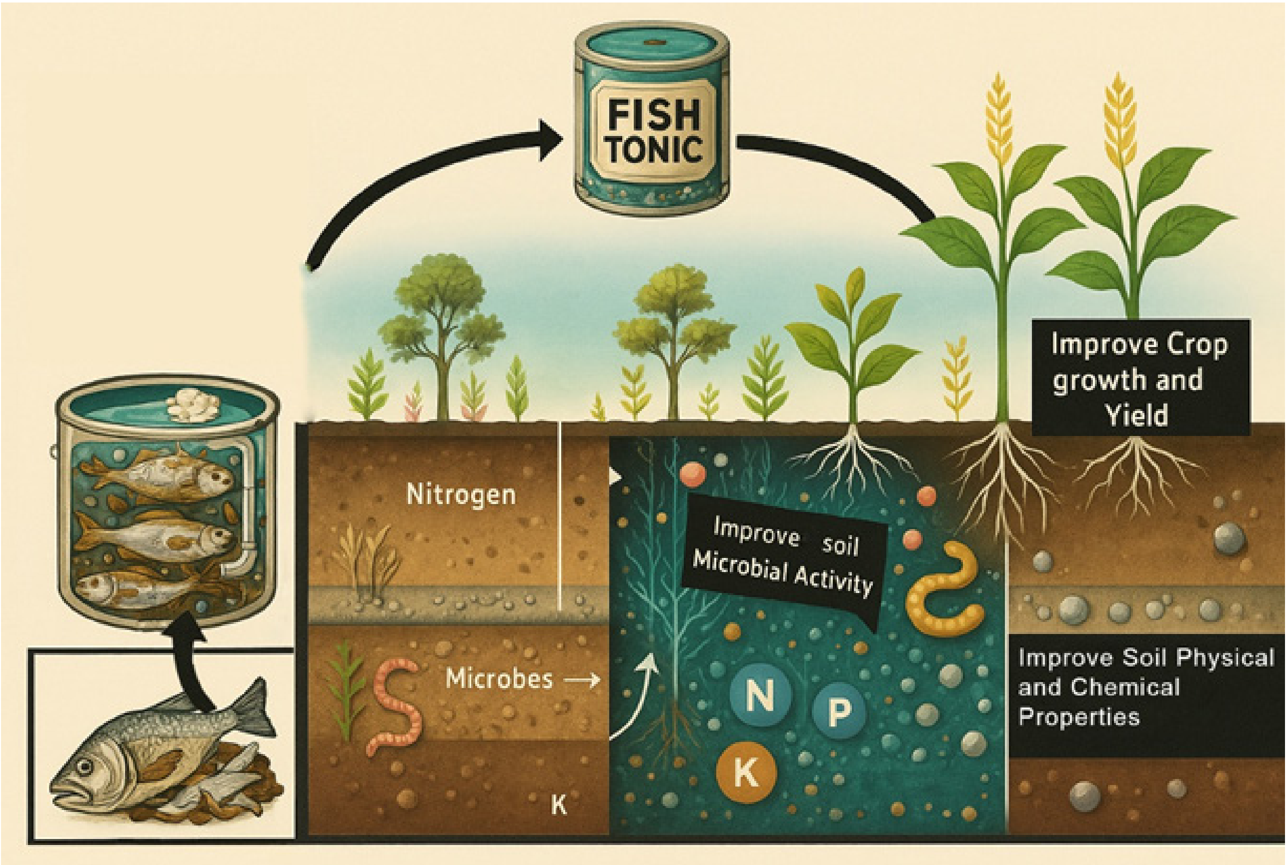
Graphical Abstract



Highlights

- Fish Amino Acid (FAA) enhances soil fertility, plant growth, and crop resilience to environmental stress
- FAA minimizes nutrient runoff, reducing water pollution and supporting sustainable agriculture
- Fish waste-derived fertilizers enhanced microbial activity, improving soil health and disease resistance
- Utilizing fish waste in farming promotes local economic approaches and reduces environmental impact

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Utilization of Fish Waste Extraction as Organic Fertilizer for Crop Growth and Yield Improvement. A Review

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Abstract

The fishing sector in Sri Lanka plays a crucial role in the national economy and food security, providing approximately 50% of the animal protein consumed and supporting the livelihoods of over a million individuals. However, fish processing generates substantial quantities of waste—up to 30–40% of the total catch, which poses environmental and public health challenges. Fish Amino Acids (FAA), derived from the fermentation of fish by-products such as heads, bones, skins, and viscera with sugar, have emerged as a promising organic fertilizer and plant growth enhancer. This review synthesizes the available literature on the production, nutrient composition, extraction methods, and agricultural applications of FAA. Relevant studies were identified through systematic searches of published literature, including reports, journal articles, and case studies focusing on fish waste valorization, fermentation technologies, and the impact of FAA on crop growth, soil health, and environmental sustainability. The review highlights that FAA is rich in macro- and micronutrients, enhances soil fertility, stimulates microbial activity, improves nutrient bioavailability, and promotes vegetative growth and yield in a wide range of crops, including cereals, vegetables, and fruits. Furthermore, FAA contributes to environmental sustainability by reducing reliance on synthetic fertilizers, mitigating nutrient runoff, and facilitating the circular economy in fisheries and agriculture. Despite its potential, challenges such as odor, storage stability, nutrient variability, and regulatory concerns must be addressed to optimize its adoption. Overall, FAA represents a sustainable, eco-friendly, and economically viable solution for improving soil health, crop productivity, and the management of fish processing waste in Sri Lanka.

keywords: Crop growth; Fish Amino Acids; Fish Waste; Organic Fertilizer; Yieldanalysis

INTRODUCTION

In Sri Lanka, the fishing sector is not only a major economic contributor but also plays a vital role in supporting livelihoods across the country. It is the lifeline of coastal villages. Fish makes up 50% of the animal protein consumed in Sri Lanka, which is three times more than the average for the world (NARA, 2022). The industry maintains the livelihoods of around a million fishermen, laborers, and their families, demonstrating its significance to the economy (Wijayaratne & Maldeniya, 2003). Increased export volumes have led to increased earnings from seafood exports, especially fresh fish. A total of $ 301.7 million was made for the nation through fish and fish preparation exports (Central Bank of Sri Lanka, 2023). Fish waste is a significant environmental issue in Sri Lanka, impacting both marine ecosystems and coastal communities. The fishing industry in Sri Lanka generates significant quantities of fish by-products and waste daily, with post-harvest losses reaching up to 30–40% of the total catch (FAO, 2018). Annually, this results in approximately 90,000 to 120,000 metric tons of wasted fish from an estimated marine catch of 300,000 metric tons (NARA, 2016). Addressing this issue is crucial for ecological balance, public health, and the sustainability of the fishing industry (FAO, 2020). Fertilizers are used in farming systems to enhance the production of food to feed the ever-increasing population in the world. Nevertheless, it is also necessary to identify the possible environmental effects arising from their application (Krasilnikov et al., 2022). Fish waste is considered an important organic fertilizer in agriculture because the utilization of inorganic fertilizer may lead to severe environmental problems (Zhang et al., 2018). FAA, as an organic product, not only contributes to environmentally friendly farming but also minimizes the chances of soil degradation, water pollution, and destruction of beneficial microorganisms (Ahuja et al., 2020). Application of fish waste as a fertilizer is also an

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environmentally sustainable approach since it reduces pollution emissions related to its disposal (Lopes et al., 2015).

Traditional methods of disposal, for instance, incineration, consume a lot of energy, thus incurring high costs and polluting the environment. On the other hand, the recycling of fish waste into fertilizers is a positive practice since fish waste is used to reduce the use of non-renewable fertilizers, which are environmentally unsuitable due to pollution and runoff effects. In addition, the reuse of fish waste helps to relieve the pressure on landfills, which in turn decreases methane emissions and the total amount of carbon dioxide produced by waste management systems (Coppola et al., 2021; Stevens et al., 2018). By incorporating fish waste fertilizer into agricultural lands, farmers can enhance crop health and yield while minimizing their ecological footprint and promoting long-term soil fertility and ecosystem balance. This review aims to debate the nutrient compositions, production techniques, environmental, and agricultural advantages of FAA obtained through fish waste, to review the existing practices and limitations, and offer the possible opportunities in implementing FAA into the sustainable agricultural base in Sri Lanka. Considering these objectives, the review will aim to reflect on the contribution of the FAA towards environmentally friendly farming practices, the enhancement of soil fertility, and the contribution to the agricultural sector.

Fish Amino Acid (FAA)

FAA is produced through the fermentation of fish wastes such as bones, heads, skin, and other residual parts with the help of sugar. FAA is a liquid organic supplement specifically beneficial to enhance crop development and growth. It serves as a natural farming supplement, rich in amino acids and essential nutrients, thereby supporting plant health and enhancing overall productivity (Priyanka et al., 2019). FAA to maintain water quality while increasing agricultural yields and soil N availability (Nissi & Debbarma, 2022). FAA serves as an effective nitrogen source, promoting improved plant growth and size. Applying FAA either as a foliar spray or through soil drenching can enhance nutrient uptake and minimize runoff or leaching, ensuring sufficient nitrogen availability for chlorophyll production and overall plant health (Panomjan & Sukkaew, 2023). Although commercial fertilizers offer an affordable means to enrich the soil with nitrogen for optimal plant growth and high crop yields, overuse or improper application of these fertilizers can contaminate ground or surface water with nitrates (Bijay-Singh & Craswell, 2021).

Composition of macronutrients in FAA

The species, age, sex, health, and nutritional status affect the nutritional composition of FAA. Fish waste, consisting of muscle cuttings, skin, fins, bones, heads, the internal organs, and scales, is an excellent source of proteins and degradable organics, which makes it ideal to utilize as a form of organic fertilizer (Coppola et al., 2021). Fish waste also contains nutrients that can enhance the quality of the compost and provide nutrients needed by plants in horticultural and agricultural production. Fish waste can be used as a pig diet since it has 58% of the crude protein, 22% of ash, 19% of ether extract, and 1% of the crude fiber (Esteban et al., 2007). The composition of fish waste is also determined based on which part of the fish is used in the preparation of food. For example, the viscera of different fish species have different levels of crude protein and lipids, which are an indication of the unique nutritional value of each species. According to Ovissipour et al. (2012), the content of crude protein and lipids in the internal organs of yellowfin tuna (*Thunnus albacares*) is 21.5 ± 0.5% and 5.08 % respectively. On the other hand, the viscera of Catla (*Catla catla*) contain 8.52% protein and lipid content of 12.5% (Bhaskar & Mahendrakar, 2008). Such variations in the nutrient content between the viscera of yellowfin tuna and Catla show the significance of species variation analysis for fish by-products for organic fertilizer. The head, bones, skin, and viscera of fish have different levels of protein, fat, minerals, and other nutrients (Zhang et al., 2018).

Table 1: Composition of macronutrients in fish amino acids derived from fish waste (includes heads, bones, skin, viscera, and occasionally whole fish and parsley) (Esteban et al., 2007)

Nutrient	Value
Crude protein (%)	57.92 ± 5.26
Fat (%)	19.10 ± 6.06
Crude fiber (%)	1.19 ± 1.21
Ash (%)	21.79 ± 3.52

Composition of micronutrients in FAA

Fish waste from the fish processing industry consists of the following components, but they differ by species: The remaining parts include muscle trimmings (15-20%), viscera (12-18%), bones (9-15%), heads (9-12%), scales (5%), and skins and fins (1-3%) (live weight) (Coppola et al., 2021). Bones contain calcium and phosphorus, while fish heads are rich in lipids and omega3 fatty acids, for instance (Ghaly et al., 2013).

Fish bones contain a large amount of calcium and phosphorus, whereas the fish head contains a large amount of lipids and omega-3 fatty acids (Ghaly et al., 2013). The organs, which include the liver and the intestines, are usually rich in enzymes and vitamins (Rustad et al., 2011).

Therefore, the overall nutrient composition of fish waste can be quite diverse when the main part used is the flesh or bone, skin, or internal organs of the fish. Fish waste also contains nutrients, which may vary depending on the improvements in nutrient recovery technologies. The number of proteins, lipids, minerals, and other valuable compounds that can be obtained from fish waste may vary depending on the recovery methods that have been used (Meers & Zhang, 2023; Zang et al., 2023). For the proper management of fish waste as an organic fertilizer, it becomes relevant to take into account the differences in its composition.

Table 2: Composition of micronutrients in fish amino acids from fish waste (including heads, bones, skin, viscera, and occasionally whole fish and parsley) (Esteban et al., 2007).

Nutrient	Value
Calcium (%)	5.80 ± 1.35
Phosphorous (%)	2.04 ± 0.64
Potassium (%)	0.68 ± 0.11
Sodium (%)	0.61 ± 0.08
Magnesium (%)	0.17 ± 0.04
Iron (ppm)	100.00 ± 42.00
Zinc (ppm)	62.00 ± 12.00
Manganese (ppm)	6.00 ± 7.00
Copper (ppm)	1.00 ± 1.00

Extraction and processing techniques of fish waste

Types of fish waste

The organic wastes and byproducts of fish, including head, bones, skin, fins, guts, and scales, are important sources of proteins, amino acids, micronutrients, and other bioactive agents. Yellow fin tuna waste, e.g., has been successfully used in the manufacture of fertilizers (Shama & Nimalan, 2023). Most of these organic wastes are not treated and may become a bane to the environment as they contribute to environmental degradation.

Source of Nutrients

The fish waste recovery technologies focus on converting the organic material into biofertilizers. Since the fish waste is highly hydrated and has abundant microorganisms, it can very quickly result in stench, creating a significant environmental hazard by being highly subject to putrefaction (Soni et al., 2021). Nevertheless, after being adequately processed, it is a strong source of macro- and micronutrients and supplements for plant and soil health. The objectives of extraction include the release of amino acids, nitrogen, phosphorus, and other elements supporting the development of crops (Ennouali et al., 2021).

Processing and Extraction Methods

Fermentation is one of the most common and effective methods of nutrient recovery from fish waste. It involves microbial activity that converts proteins and fats into amino acids and organic acids. Siddiqui et al. (2023) reported that fermenting fish heads with lactic acid bacteria resulted in a product rich in essential amino acids and antioxidants, offering additional benefits beyond basic fertilization. Aerobic digestion is another technique, wherein microorganisms decompose fish waste in the presence of oxygen to produce biogas and nutrient-rich digestate. Samoraj et al. (2022) reported that both solid and liquid fractions of this digestate contained high levels of nitrogen (N) and phosphorus (P), making them suitable as crop fertilizers. However, the high-water content of the liquid fraction can complicate storage and transportation (Ivanovs et al., 2018). Preparation methods can vary widely depending on the fish species, concentration, and additives used. Shama and Nimalan (2023) reported a fish tonic using yellowfin tuna waste mixed with jaggery in a 1:1 ratio. The mixture was fermented for 21 days in a ventilated container, with precautions taken to prevent contamination by coating the container with jaggery and covering it with breathable cotton cloth.

Forms of Fish-Based Fertilizers

Fish waste can be converted into various fertilizer forms such as FAA, fish emulsion, hydrolysate, or digestate. FAA, in particular, is gaining popularity due to its ease of use as a liquid fertilizer and its ability to provide micronutrients to plants while also nourishing beneficial soil bacteria (Panomjan & Sukkaew, 2023; Radziemska et al., 2019). The effectiveness of the FAA depends on the type of fish waste used, additives incorporated (e.g., fruits, molasses, jaggery), and fermentation conditions. Understanding these variables is crucial for optimizing nutrient content and maximizing plant response.

Effect of FAA on soil properties

FAA enhances soil fertility by stimulating favorable Physical, chemical, and Biological aspects in the soil environment.

Soil Structure and Organic Matter

The way soil particles and pore spaces are arranged in the fish tonic has an impact on nutrient availability, root penetration, and water retention. Organic matter enriches the soil, enhancing fertility and supporting microbial activity essential for nutrient cycling and plant health (López-Mosquera et al., 2011)

Nutrient Supply

Fish extracts are rich in micronutrients that are necessary for plant growth, such as potassium (K), phosphorus (P), and nitrogen (N). Plants receive a steady supply of nutrients from these nutrients as they are progressively released into the soil (Sivasankar et al., 2024).

Bioavailability of Nutrients

Fish tonic enhances nutrient bioavailability through organic matter and beneficial microbial communities. The FAA causes decomposition of organic matter, releasing nutrients in forms that plants can easily absorb. Soil structure is enhanced and microbial activity increased, leading to improved nutrient retention and utilization, which translates to healthier plant growth and greater resilience (Hartmann & Six, 2023).

pH Buffering

FAA is able to stabilize the soil pH and, with it, make the for nutrient availability more favorable. This improves nutrient uptake and enables optimal plant growth (Johari et al., 2020).

Microbial Activity

Microbial activity in fish tonic enhances soil health by promoting nutrient cycling, organic matter decomposition, and disease suppression. Healthy microbial communities foster soil structure and fertility, supporting robust plant growth and resilience to environmental stresses (Naikoo et al., 2022). According to Krishnamoorthy et al. (2019), the optimum liquid organic nutrient form to maintain soil fertility consists of jeevamirtham + FAA, as it enhances soil microbial populations and gives way to a more nutritious and sustainable food production system. It is easily absorbable and stimulates the metabolic activity of the soil microorganisms (Elavarasan, 2023). In particular, hydrolyzed fish protein helps the microorganisms absorb directly into the soil.

Environmental Sustainability

The use of FAA can contribute to environmental sustainability by reducing nutrient runoff and leaching compared to conventional fertilizers. This minimizes environmental pollution and preserves water quality (Qadir et al., 2024). FAA helps the natural cycle of soil (Ajmal et al., 2023). Amino acids from fish protect plants from a variety of diseases and aid in closing the quality-quantity divide in agricultural output (Ajmal et al., 2023). FAA can be applied to increase plant resistance to drought, salinity, and disease levels. Improved nutrient availability and plant vigor help achieve it (Mahdavi et al., 2024).

Disease Suppression

The peptides derived from fish by-products have been effective in inhibiting the proliferation of harmful microorganisms. Therefore, such bioactive substances might be crucial for plant health and decrease dependency on synthetic pesticides, thereby creating the ground for sustainable agriculture (Baraiya et al*.,* 2024). FAA is made by mixing jaggery that helps to fight crop pests (Ghaly, 2013). It enhances the fertility and productivity of the soil. Moreover, the addition of fish waste to the soil has been shown to increase microbial populations, thus selecting for beneficial organisms that naturally suppress the pathogens in the soil. This helps with the establishment of a better ecosystem in the soil for the production of crops with reduced diseases (Abdelhameed & Metwally, 2022).

FAA as a plant growth enhancer

FAA affects plant growth and development because it can enhance the physical characteristics of soil into a positive state that can balance the nutrient status of the soil profile. According to Priyanka et al. (2019), a significant improvement in growth and development was reported. The foliar application of FAA showed a tremendous effect on the growth parameters like plant height, leaves per plant, and leaf area index of *Amaranthus* grown using urea to rectify the balance composition (Ramesh et al*.,* 2020). Plant Height, leaf count, and chlorophyll content were increased by 16.5%, 12.6% and 8.1%, respectively, when 1% FAA was applied topically as compared to the control group. Enhanced metabolic activity, cell division, and absorption and assimilation of various nutrients found in the FAA may result in greater plant height, leaf count, and chlorophyll. However, heightened metabolic activity drives increased cell division, resulting in a greater number of leaves and increased chlorophyll content.

This, subsequently, promotes photosynthetic activity that ultimately improves yield characteristics and grain production (Priyanka et al., 2019). Improved soil nitrogen, and the foliar application of FAA stimulated increased cell division and metabolic activity, which led to increased plant height at all growth stages (Sanjutha et al., 2008; Vasumathi, 2001). A foliar spray of FAA combined with egg amino acid was found by Priyanka et al. (2019) to have considerably increased LAI, resulting in increased soluble protein and yield. Application of FAA and fertilizer in the proposed dose improves the yield due to faster absorption and assimilation of nitrogen, phosphorus, potassium, and micronutrients more than the aerobic ones (Priyanka et al., 2019). Watermelon (*Citrullus lanatus)* growth and development, production, and content of lycopene and total soluble solids are increased significantly by leaf soaking with FAA mix and Oriental Herbal Nutrient extract (Gasana & Kim, 2020). Amino acids are quickly taken by the plant and make up at least 60% of the total nitrogen ingested (Abd El-Aal et al., 2010).

Effect of FAA on the growth, yield, and quality of various crops

FAA is an extract that is produced by fish waste or residue, that used as a growth enhancer and a quality enhancer in different stages of crop growth, and it significantly impacts it. As per the findings of Sivasankar et al. (2021), the foliar application of FAAs and the application of organic manure have both greatly aided in the growth of plants. Applying organic manure has gradually increased the growth characteristics of the replicate at various levels. According to Amin et al. (2011), the amino acids included in FAA are known bio-stimulants that function as growth hormone equivalents to promote growth by stimulating photosynthesis. Sivasankar et al. (2021) reported that the use of FAA with farmyard manure and vermicompost led to *Tagetes erecta* L. (*African marigold*) producing the maximum number of leaves per plant, which was noted as 15.86 at 90 DAT. The investigation demonstrates that organic nutrient strategies hold promise for boosting the plant growth of African marigolds.

The level of FAA-fermentation to promote sweet corn harvest was considerable, and it showed the maximum mean yield of 15.12 kg per plot (Puhagan et al., 2019). In this context, as a nitrogen fertilizer, plant-based FAA is important to the enhancement of metabolism because nitrogen is essential for carbohydrate, protein, and lipid synthesis in plant tissue. Consequently, it significantly promotes vegetative plant (Shwe & Moe, 2018). Foliar nutrition offers premade building blocks for protein synthesis in the form of foliar spray and protein hydrolysate, also referred to as amino acid liquid (Shahrajabian et al., 2022). Shwe and Moe (2018) reported that FAA foliar application at a concentration of 12 mL/L significantly enhanced the plant height, number of young shoots and flowers, and superior fruit quality of pumpkin plants (*Cucurbita* spp.). These findings suggest that FAA foliar application can be an effective bio-stimulant for improving both vegetative and reproductive growth in pumpkin cultivation. The application of FAA mix with poultry yard manure reports significantly higher agronomic characteristics of fox tail millet, such as height, leaf number, leaf area, and higher values of harvest indices (Debbarma & Nissi, 2022). The findings are consistent with work on the use of waste, which considerably raised the fresh weight of the lettuce crop. Furthermore, Xu and Mou's (2017) reported that hydrolyzed proteins obtained from fish significantly increased chlorophyll content, photosynthetic rate, stomatal conductance, and transpiration rate of lettuce (*Lactuca sativa*) cultivated in a growth chamber condition.

FAA is used in cereal, vegetable, and fruit crops such as amaranths (Ramesh et al., 2020), watermelon (Gasana & Kim, 2020), African marigold (Sivasankar et al., 2021), okra (Johari et al., 2020), and green grams (Priyanka et al., 2019) indicated positive results on vegetative and yield characters. Moreover, FAA improves green gram cell proliferation and metabolic activity, claim Priyanka et al. (2019). These beneficial effects increase photosynthesis, which in turn raises the amount of green gram grain produced. Gasana and Kim (2020) reported yield and yield components of watermelon were all positively benefited by the combination of FAA and oriental herbal nutrient foliar that was sprayed. In rice plants, germination rates, seedling growth, leaf area, and chlorophyll content were all markedly enhanced by seed priming (0.10%) with FAA and foliar spray (0.15%), which eventually increased photosynthetic efficiency (Panomjan & Sukkaew, 2023). Recent researchers have focused on exploring the use of fish waste extracts as part of organic and sustainable farming systems aimed at reducing chemical inputs. These efforts align with the broader goal of promoting eco-friendly agricultural practices while enhancing crop productivity. In parallel, researchers are delving into natural variations and traits in crops to develop resilient and high-yielding varieties.

Rice, a staple crop, is also a subject of such studies, with significant research focused on understanding its agronomic, genetic, and yield traits (Pushpakumari & Geekiyange, 2015a; Pushpakumari & Geekiyanage, 2015b; Pushpakumari et al., 2017). For instance, variations in agronomic characters of traditional rice varieties like *Masuran* in response to planting dates have been documented, providing insights into optimizing cultivation practices under different environmental conditions (Pushpakumari et al., 2024). Research into reusing solid waste materials into organic fertilizer further exemplifies the shift toward recycling waste materials by effective warmiwash like foliar fertilizer application to different crops (Pushpakumari & Suthajini, 2023). Taken together, these studies highlight the critical importance of organic methods and the utilization of natural variations in shaping a sustainable future for agriculture.

In actuality, the fish emulsion impact appears to be more associated with the nutritional base property for isolates of bacteria and actinomycetes than with a straightforward improvement of the overall soil microflora. In order to assist radish growth in difficult soils, EI-Tarabily (2003) reports the first application of fish emulsion as an efficient food source for rhizobacteria that promote plant growth. Since amino acids are the building blocks of protein, the fundamental component of all living cells, they are widely known for raising crop yield and quality overall. According to Stephen et al. (2016), the application of FAA affects okra and brinjal's nutrient intake, yield, quality indicators, and crop growth. Several factors resulting from FAA applications, together with various sampling periods, affected the measured lengths of okra shoots (*Abelmoschus esculentus*). The amount of FAA applied to the soil substantially affected pH measurements, and the number of weeks determined soil water levels. Results indicate that FAA treatment serves as a vital factor for optimizing plant development and soil functionality, which makes it suitable for creating sustainable okra cultivation systems.

According to Buang et al. (2018) indicated that 20 mL of fish waste extract was the most effective treatment, significantly increasing vine length, leaf number, chlorophyll content (SPAD), stomatal conductance, and leaf total soluble solids (TSS) of cucumber compared to other six treatments of control, NPK fertilizer, and fish waste extract at concentrations of 10 mL, 40 mL, and 50 mL. The highest leaf area was observed in plants treated with 50 mL of fish waste extract. Additionally, fish waste extract positively influenced chlorophyll concentration, carotene content, chlorophyll fluorescence, and photosynthetic efficiency.

Yield-related parameters such as flower number, fruit number, and individual fruit weight were also significantly improved. The study concludes that 20 mL of fish waste extract is the optimal treatment for enhancing cucumber growth, yield, and quality, suggesting that further research on its foliar application in Cucurbitaceae crops is warranted. Cucumbers' growth and yield are strongly influenced by soil and climate conditions. Differentiating the soil and climate conditions is necessary for the optimal performance of each species. Nutrition is one of the main agro techniques that influences the growth and yield of cucumbers. The type, fertility, agroclimatic conditions, and variety of the soil all affect the crop's nutritional requirements. The crop's roots should spread out and expand swiftly because of its short lifespan and rapid growth (Buang et al., 2018). Hence, for good production and quality of cucumber yield, without inorganic fertilizers, FAA can be used as an alternative. A light foliar mist or soil drench could be used to improve absorption and decrease runoff or leaching. In order to maintain plant health, the plant would receive exactly enough nutrients for optimal uptake and chlorophyll production (Ajmal et al., 2023). Therefore, bacterial and actinomycete isolates were investigated in the commercial fish emulsion as a medium for plant growth and as a nutritional foundation to encourage the growth of cucumbers (*Cucumis sativus* L.). Three actinomycetes were among the six bacterial isolates that were chosen from a screening of 54 bacteria, 23 of which were actinomycetes, based on their capacity to colonize cucumber plants and produce plant growth regulators (PGRs). These isolates were cultured on autoclaved and non-autoclaved fish emulsion media with and without inorganic fertilizers. Analysis of plant growth regulator (PGR) types and concentrations, as well as nutrient contents in treated plant tissues, was conducted to elucidate the mechanism by which growth promotion was mediated. Fish emulsion acts on plant growth in sandy soil just as efficiently as inorganic fertilizers. Further examination of the effects revealed that both autoclaved and unautoclaved fish emulsion markedly boosted plant growth, with bacterial and actinomycete isolates being more effective growth promoters than inorganic fertilizers (El-Tarabily et al., 2003).

Table 3: Key findings on the effects of Fish Amino Acid (FAA) application on the growth, physiological traits, and yield of various crops, as reported in previous studies.

Crop	Key findings of the FAA effect	References
Green Chilli *Capsicum annum*	Improved plant height, leaf length, leaf width, and yield	Shama & Nimalan, 2023
Cucumber *Cucumis sativus*	Improved vine length, number of leaves, chlorophyll content, flower production, fruit numbers, and fruit weight	Buang et al., 2018
Watermelon *Citrullus lanatus*	Improved vine length, length of internodes, number of leaves, fruit weight, and length.	Gasana & Kim, 2020
Okra *Abelmoschus Esculentus*	Increased root and shoot length, plant biomass.	Johari et al., 2020
Rice *Oryza sativa*	Improved total chlorophyll content.	Priyanka et al., 2019
Amaranthus *Amaranthus sp*	Increased plant height, number of leaves, chlorophyll content, and yield.	Ramesh et al., 2020
Ash Gourd	Improved nutrient contents.	Dhanushkodi & Nageswari, 2022
Green gram *Vigna radiata*	Increased plant height, number of leaves, and chlorophyll content.	Priyanka et al., 2019
Tomato *Solanum liycopersicum*	Increased fruit weight	Rebuza et al., 2022
Pumpkin Cucubita mxima	Increased plant length, fruit size, and yield.	Shwe & Moe, 2018

Environmental and economic impact

Management of waste is one of the most important environmental challenges today, especially organic waste from food industries. Fish processing generates large amounts of by-products such as fish heads, bones, skins, and viscera, which are often discarded and can cause pollution if not properly handled. Water contamination of fish waste can be controlled by producing FAA (Ahuja et al., 2020). This not only recycles waste that would be sent into the environment but also helps to recycle resources instead of discarding them. FAA, when used as a land application or as a foliar spray, rejuvenates the soil, adding amino acids, nitrogen, and other substances that are necessary in the growth of plants. Plants need amino acids from fish to grow rapidly and endure stress better; these acids form proteins and enzymes in plants (Bano et al., 2025). FAA boosts the growth of good microorganisms in the soil, which has a significant role in nutrient recycling and organic matter decay. FAA stimulates the microbial activity, strengthens the soil structure, boosts the bioavailability of the nutrients, and aids natural fertility of the soil (Ajmal et al., 2023). This biological practice minimizes the use of chemical fertilizers, which are linked with adverse environmental effects like acidification of soil, eutrophication of water bodies, and emissions of greenhouse gases. The FAA aids in mitigating the negative agricultural impact on the environment by undertaking regenerative activities. When compared to traditional chemical fertilizers, whose impact typically involves destabilizing soil ecology, FAA's preference is for biodiversity, both on land and under land. The presence of pests, healthier soils, wider range of microbial populations are resistant to ecosystem shocks, including diseases and climatic changes.

Economically, the potential of FAAs as an agricultural input is immense owing to their ability to upcycle unused fisheries by-products into novel biostimulants that promote plant growth and nutrient efficiency, with the added advantage of converting waste substances into crop coproducts. FAA is economically beneficial to the smallholder as well as the resource-poor farmers, among other benefits. The primary raw materials used in the production of FAA, which are fish waste and brown sugar, are available at affordable costs (Ajmal et al., 2023). FAAs, which are isolated by enzyme- or microbe-mediated hydrolysis of fish processing byproducts, can deliver organic amino acids to crops that enhance nutrition absorption and abiotic stress resilience in addition to decreasing the demand on synthetic fertilizers, which might hence decrease farmers' input expenditures and stabilize crop yields (Coppola et al., 2021; Lu et al., 2024).

From the fisheries industry's point of view, the potential to turn the fish waste into amino acid-rich fertilizers can turn the liability of disposing of waste into generating value by supporting the stakeholders and circular bioeconomy models and enhancing the economic sustainability in both industries (Zhang et al., 2021). Furthermore, although the use of FAA-based fertilizers has proved to raise crop yields and quality in the case of vegetables and hydroponic production systems, it has to compete with established inorganic fertilizers, necessitating both product enhancement and the need to educate interested farmers to increase demand (Ahmed et al., 2021; Kechasov et al., 2021). Moreover, the replacement or supplementation of mineral fertilizers with organic (fish-derived) amino acids were found to increase nitrogen use efficiency and soil fertility as well as decrease on environmental externalities, which could be converted into long-term economic gains as low environmental external costs and sustainable land management occur as well as environment relevant laws are followed (Lu et al., 2024; Wei et al., 2020). The rising economic potential of FAA and their application as a multifunctional input bridging the gap between sustainable agriculture and fisheries wastes management is founded on technological development to bring production down to cost levels, to enhance nutrient standardization, and integrating them into combined fertilization regimes, as well as, growing market demand of organic and environmentally friendly agricultural inputs (Kim, 2011; Lu et al., 2024).

Fish waste processing plants, whether small-scale or large-scale, have the potential to supply employment, earn fishers/fish processors more money, and build their own local economies. Moreover, this waste collection can be supplemented by the current agricultural experience and industrial complements of fisheries and aquaculture and farming commodities. Fish farms, as an example, could have closed-loop systems, with the fish waste being used on the same farm to become a fertilizer or bio stimulant on other farms, thus eliminating transportation and further supporting the concept of local, self-sustaining food systems. Moreover, the advancement of extraction technologies has demonstrated the potential to contribute to a drastic increase in the efficiency and intensity of fish waste valorization. Fish waste can be used to extract high-value compounds through effective enzymatic hydrolysis, supercritical fluid extraction, and ultrasonic extraction, causing minimal damage to the environment. As an example, the fish proteins are digested to generate an available form of peptides through enzymatic hydrolysis without the use of any severe chemicals. This specific lipid extraction can be done using carbon dioxide as the solvent, and supercritical fluid extraction can be used to selectively extract lipids and bioactive compounds without altering the functional properties. These more sophisticated extraction processes could lead to the production of tailored, fish-based fertilizers and bio-stimulants and allow their blanket application across the full crop supply chain using precision agriculture, and, at the same time, maximize efficacy and applicability.

Limitations and challenges

Constrains and challenges of FAAs as organic fertilizers and bio stimulants are economic, technical, environmental, and regulatory. The odor inherent to products of products hence fish, poses a challenge to user acceptance and creates complexities in storage stability due to microbial spoilage unless stabilized, and there is a challenge with limited shelf time and transportability. Irregularity in nutrient content caused by variation in feedstock source and agricultural processing interferes with uniform formulations, which are essential to ensure accurate application rates and regulations. Due to clogging of irrigation infrastructure and reductions in nutrient transport with organic residues in FAA formulations, more filtration or treatment steps may be necessary, and biomass accumulation may be negatively affected compared to inorganic nutrient solutions, as seen in its trials with lettuce and tomatoes (Ahmed et al., 2021; Kechasov et al., 2021). Regulatory challenges are based on pathogen and heavy metal contamination potential present with fish waste, and to be used safely, these materials should be well-squared up well through rigorous pretreatment and quality assurance strategies. The inadequate farmer awareness, uncertainty of efficacy with synthetic fertilizers and lack of extension support hinder market adoption. The possible effects on the environment are the risks of phosphorus buildup and eutrophication as a result of FAA overapplication or its unbalanced use, requiring close nutrient control (Lu et al., 2024). Furthermore, FAA's production environmental footprint is susceptible to the amount of energy it consumes and may be sustainable through the use of non-renewable sources of energy or long haulage distances, partially negating the effect on sustainability benefits (Badagliacca et al., 2024). Technical issues still exist, such as in improving reactions of hydrolysis processes, to produce the highest yields of amino acids with minimal degradation, e.g., by controlling the temperature and duration of a reaction in hydrolysis of sub- and supercritical water, affecting the quality and cost of products (Kang et al., 2001). The combined effects of these limitations limit the wider application of FAAs, even though they have agronomic and environmental benefits. To overcome these limitations, researchers should work on the following: effective and affordable production technologies, deodorization, and standardization of nutrient delivery protocols, regulatory standards, and the use of system-specific integrated nutrition approaches to integrate FAA into sustainable farming to maximize their potential.

Future implications of fish waste extraction

Perhaps the most promising component of the whole fish waste extraction process is the ability to make organic fertilizers and soil conditioners that will support plant growth and soil health while bypassing the environmental impact of synthetic fertilizers. The nitrogen, phosphorus, potassium, calcium, and trace minerals found in fish waste are all critical for the growth and productivity of plants. Liquid fish waste is are traditional fish emulsion fertilizer that plants can readily absorb, and is the preferred organic fertilizer by many farmers. In addition to supplying necessary nutrients, fish-based fertilizers applied to the soil also raise microbial activity, improving soil structure, water retention, and the availability of nutrients. In particular, this method is an absolute winner for depleted soils: fish waste extracts, as time goes by, do rejuvenate and restore soil fertility. But also, fish-based fertilizers release nutrients slowly, giving long-lasting nourishment to grow crops, requiring way less frequent fertilizing. One of the other promising applications to fish waste extraction is capable of improving crop resilience to environmental stressors. Fish protein hydrolysates, which are proteins broken down into smaller peptides and free amino acids, have been demonstrated to possess bio-stimulant qualities that can enhance plants' resistance to abiotic stressors such as salinity, drought, and temperature fluctuations. Sometimes the term bio stimulant is also used to refer to plant stimulants that act at a physiological level; they promote root growth, increase water influx, and enhance the photosynthetic efficiency of the plant. In particular, certain amino acids such as proline, glycine, and glutamic acid (and abundant in fish hydrolysates) are involved in osmotic regulation and protection from stress in plants. Agricultural development is increasingly dependent on the climate resilience of crops, and research shows that incorporating fish waste-derived bio-stimulants like Fishel could help farmers increase their resilience to adverse environmental conditions.

Fish waste extraction also has soil and plant health benefits, and removes pests and disease threats to agriculture. There is potential for fish oil and fish waste in terms of some of the fatty acids it contains as biopesticides to deter pests and reduce the use of chemical pesticides. Additionally, emulsions from fish waste lipid-rich extracts can be sprayed onto the crops and provide a protective layer on the leaves so that the insects are less attracted to those leaves. Furthermore, fish waste-derived chitosan, a biopolymer that is extracted from fish scales, shells, and that has been evaluated for its antimicrobial properties, has also been shown to protect plants against the pathogens of fungal and bacterial origin. As a foliar spray, chitosan works as a stimulator of a natural defense response in plants, strengthening their immune system and preventing disease in plants. Farmers moving toward more ecologically friendly pest and disease control solutions can do so by merging fish waste-derived biopesticides and antimicrobial agents into their crop management practices.

Fish waste-derived fertilizers and bio-stimulants are practical in terms of application across different agricultural systems: traditional farming, organic farming, and urban agriculture. Fish waste-based products are also very much in favor of organic farming for organic farmers in particular, as they align with the sustainability and eco-friendly farming principles as a substitute for synthetic fertilizers and pesticides. Additionally, the reality that urban agriculture is becoming increasingly popular in response to increased demand for food security could help feed crops in small spaces, including rooftop gardens, hydroponic systems, and community gardens, with fish waste-based fertilizers. Small spaces in places like the city present problems for urban farmers, who need efficient nutrient solutions for high yield, but fish-based products are compact and high in nutrients, therefore ideal for urban farmers.

CONCLUSIONS

The application of Fish Amino Acid (FAA) demonstrates significant positive effects on the growth, physiological traits, and yield of a wide range of crops. Across vegetables, cereals, and legumes, FAA consistently enhanced plant height, leaf and vine development, chlorophyll content, fruit and seed production, and overall biomass. These findings highlight FAA as a sustainable and effective organic growth enhancer, capable of improving both crop productivity and nutrient content. Incorporating FAA into crop management practices can serve as a viable alternative to synthetic fertilizers, promoting eco-friendly agriculture while supporting higher yield and crop quality. Future studies should focus on optimizing application rates and assessing long-term soil health and economic benefits to establish broader agricultural recommendations.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflicts of interest

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AUTHOR CONTRIBUTION

Conceptualization: **W.H.D.U.P.;** Writing the first draft: **W.M.A.P.W.**; Editing and reviewing: **P.H**. All authors have accepted responsibility for the content of the manuscript, reviewed all Headings and subheadings, and approved the final version.

DATA AVAILABILITY STATEMENT

Data sharing does not apply to this article, as no new datasets were generated or analyzed for this study.

REFERENCES

Abd El-Aal, F. S., Shaheen, A. M., Ahmed, A. A. & Mahmoud, A. R. (2010). Effect of foliar application of urea and amino acids mixtures as antioxidants on growth, yield, and characteristics of squash. *Research Journal of Agriculture and Biological Sciences,* **6**(5), 583–588

Abdelhameed, R.E. & Metwally, R.A., (2022). Assessment of beneficial fungal microorganisms' bio-efficacy in stimulating morphological and physiological parameters of Allium cepa plants grown in soil amended with fish wastes. *BMC Plant Biology*, **22**(1), 617.

Ahmed, Z., Alnuaimi, A. K. H., Askri, A. & Tzortzakis, N. (2021). Evaluation of Lettuce (*Lactuca sativa* L.) Production under Hydroponic System: Nutrient Solution Derived from Fish Waste vs. Inorganic

Nutrient Solution. *Horticulturae*. **7(**9) DOI: 10.3390/horticulturae7090292

Ahuja, I., Dauksas, E., Remme, J. F., Richardsen, R. & Løes, A. K. (2020). Fish and fish waste-based fertilizers in organic farming – With status in Norway: A review. *Waste Management,* **115**, 95–112. https://doi.org/10.1016/j.wasman.2020.07.025

Ajmal Siddique, S. A., Indianraj, N., Reshma, J., & Harish, N. (2023). Fish amino acid: A review. *International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), 3(1).* https://www.ijarsct.co.in/Paper13637.pdf

Amin, A. A., Gharib, F. A., El-Awadi, M., & Rashad, E. S. M. (2011). Physiological response of onion plants to foliar application of putrescine and glutamine. *Scientia Horticulturae, **129***(3), 353–360. https://doi.org/10.1016/j.scienta.2011.03.052

Badagliacca, G., Testa, G., Malfa, S. L. L., Cafaro, V., Presti, E. L. & Monti, M. (2024). Organic Fertilizers and Bio-Waste for Sustainable Soil Management to Support Crops and Control Greenhouse Gas Emissions in Mediterranean Agroecosystems: A Review. *Horticulturae*. DOI: 10.3390/horticulturae10050427

Bano, S., Batool, M., Khan, N., Haider, R., Tahir, M., Saeed, K., Tanveer, A., Aftab, S. & Nazir, S. (2025). Role of amino acids in stress management and growth in aquatic species. In T. Şahin, K. Ameer, M. Abid, & S. Tahir (Eds.), Nutritional Foundations of Holistic Health: From Supplements to Feed Strategies. 1–8. Unique Scientific Publishers, Faisalabad, Pakistan. https://doi.org/10.47278/book.HH/2025.156

Baraiya, R., Anandan, R., Elavarasan, K., Prakash, P., Rathod, S. K., Rajasree, S. R., & Renuka, V. (2024). Potential of fish bioactive peptides for the prevention of global pandemic non-communicable disease: production, purification, identification, and health benefits. *Discover Food*, **4**(1), 34. DOI:10.1007/s44187-024-00097-5

Bhaskar, N. B. N. S. & Mahendrakar, N. S. (2008). Protein hydrolysate from visceral waste proteins of *Catla* (*Catla catla*): Optimization of hydrolysis conditions for a commercial neutral protease. *Bioresource Technology, **99***(10), 4105–4111. https://doi.org/10.1016/j.biortech.2007.09.006

Bijay-Singh, C. & Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: An increasingly pervasive global problem. *SN Applied Sciences, **3,*** 518. https://doi.org/10.1007/s42452-021-04521-8

Buang, E. A., Nornasuha, Y., Nashriyah, M. & Khandaker, M. M. (2018). Effects of fish waste effluent on the growth, yield, and quality *of Cucumis sativus L. Journal of Agrobiotechnology*, **9**(1S), 258–267.

Central Bank of Sri Lanka. (2023). *Annual report 2023*. https://www.srilankabusiness.com/news/sri-lanka-s-export-performance-in-july-2024.html

Coppola, D., Lauritano, C., Palma Esposito, F., Riccio, G., Rizzo, C. & de Pascale, D. (2021). Fish waste: From problem to valuable resource. *Marine Drugs, **19(***2), 116. https://doi.org/10.3390/md19020116

Debbarma, V. & Nissi, W. I. (2022). Effect of organic manures and fish amino acids on growth and yield of foxtail millet (*Setaria italica* L.). *International Journal of Plant & Soil Science, **34***(23), 601–607. https://doi.org/10.9734/ijpss/2022/v34i232523

Dhanushkodi, V. & Nageswari, R. (2022). Influence of foliar application of Panchagavya and fish extracts and application of organic substances on yield and quality of ash gourd under organic farming. *International Journal of Plant & Soil Science, **34***(23), 1110–1114. https://doi.org/10.9734/ijpss/2022/v34i232523

Elavarasan, K. (2023). Agricultural application of fish amino acids. *Agri Tech Today: Agriculture and Applied Sciences E-Magazine, **1***(3), 70. https://doi.org/10.12928/joves.v3i2.2932

El-Tarabily, K. A., Nassar, A. H., Hardy, G. E. St. J. & Sivasithamparam, K. (2003). Fish emulsion as a food base for rhizobacteria promoting the growth of radish (*Raphanus sativus* L. var. *sativus*) in a sandy soil. *Plant and Soil, **252,*** 397–411. https://doi.org/10.1023/A:1024729620154

Ennouali, M., Elmoualdi, L., Ouhsine, M. & Elyachioui, M. (2021). Biotransformation of the fish waste by fermentation. *African Journal of Biotechnology, **5***(19), 1733–1737. https://doi.org/10.4314/ajb.v5i19.55842

Esteban, M. B., García, A. J., Ramos, P. & Márquez, M. C. (2007). Evaluation of fruit-vegetable and fish wastes as alternative feedstuffs in pig diets. *Waste Management, **27***(2), 193–200. https://doi.org/10.1016/j.wasman.2006.01.004

FAO. (2018). *Fishery and aquaculture country profiles: Sri Lanka*. Food and Agriculture Organization of the United Nations. Rome, Italy

Food and Agriculture Organization of the United Nations (FAO). (2020). *The State of World Fisheries and Aquaculture 2020: Sustainability in action*. FAO. https://openknowledge.fao.org/handle/20.500.14283/ca9229en

Gasana, Q. G. & Kim, D. H. (2020). Effect of foliar spraying mixed with fish amino acids (FAA) and oriental herbal nutrient (OHN) extract on growth, yield, and quality of watermelon (*Citrullus lanatus*). *Rwanda Journal of Agricultural Sciences, **2(***1), 127–136.

Ghaly, A. E., Ramakrishnan, V. V., Brooks, M. S., Budge, S. M., & Dave, D. (2013). Fish processing wastes as a potential source of proteins, amino acids, and oils: A critical review. *Journal of Microbial & Biochemical Technology, **5,*** 107–129. https://doi.org/10.4172/1948-5948.1000110

Hartmann, M. & Six, J. (2023). Soil structure and microbiome functions in agroecosystems. Nature Reviews Earth & Environment, **4**(1), 4-18.

Ivanovs, K., Spalvins, K. & Blumberga, D. (2018). Approach for modelling anaerobic digestion processes of fish waste. *Energy Procedia, **147***, 390–396. https://doi.org/10.1016/j.egypro.2018.07.108

Johari, N. S., Asilah, A. M., Zalina, I., Fazhana, I., Ab-Latif, Z., Shaibatul'Islamiah, C. M. & Tang, J. R. (2020). Effects of fish amino acid (FAA) application on growth and development of okra (*Abelmoschus esculentus*) at different sampling times. *Journal of Vocational Education Studies, **3***(2), 35–42. https://doi.

org/10.12928/joves.v3i2.2932

Kang, K., Quitain, A., Daimon, H., Noda, R., Goto, N., Hu, H. & Fujie, K. (2001). Optimization of Amino Acids Production from Waste Fish Entrails by Hydrolysis in Sub- and Supercritical Water. *Canadian Journal of Chemical Engineering*, **79**, 65-70. DOI: 10.1002/CJCE.5450790110

Kechasov, D., Verheul, M., Paponov, M., Panosyan, A. & Paponov, I. (2021). Organic Waste-Based Fertilizer in Hydroponics Increases Tomato Fruit Size but Reduces Fruit Quality. *Frontiers in Plant Science, 12*. DOI: 10.3389/fpls.2021.680030

Kim, J. (2011). Cost-Effectiveness of Converting Fish Waste into Liquid Fertilizer. *Fisheries and Aquatic Sciences,* **14,** 230-233. DOI: 10.5657/FAS.2011.0230

Krasilnikov, P., Taboada, M. A. & Amanullah. (2022). Fertilizer use, soil health, and agricultural sustainability. *Agriculture, **12**,* Article 462. https://doi.org/10.3390/agriculture12040462

Krishnamoorthy, R., Alshatwi, A. A., Subbarayan, S., Vadivel, B., Periyasamy, V. S., Al-Shuniaber, M. A., & Athinarayanan, J. (2019). Impact of farm-made liquid organic nutrients, Jevamirtham, and fish amino acid on growth and nutritional status in different seasons of *Abelmoschus esculentus*: A self-sustainable field trial. *Organic Agriculture, **9**,* 65–79. https://doi.org/10.51193/IJAER.2022.8309

Lopes, C., Antelo, L. T., Franco-Uría, A., Alonso, A. A. & Pérez-Martín, R. (2015). Valorisation of fish by-products against waste management treatments: Comparison of environmental impacts. *Waste Management, **46**,* 103–112. https://doi.org/10.1016/j.wasman.2015.08.017

López-Mosquera, M. E., Fernández-Lema, E., Villares, R., Corral, R., Alonso, B. & Blanco, C. (2011). Composting fish waste and seaweed to produce a fertilizer for use in organic agriculture. *Procedia Environmental Sciences, **9**,* 113–117. https://doi.org/10.1016/j.proenv.2011.11.018

Lu, W., Hao, Z., Ma, X., Gao, J., Fan, X., Guo, J., Li, J., Lin, M. & Zhou, Y. (2024). Effects of Different Proportions of Organic Fertilizer Replacing Chemical Fertilizer on Soil Nutrients and Fertilizer Utilization in Gray Desert Soil. *Agronomy*. **14**(1) , DOI: 10.3390/agronomy14010228

Mahdavi, Z., Esmailpour, B., Azarmi, R., Panahirad, S., Ntatsi, G., Gohari, G. & Fotopoulos, V. (2024). Fish waste: A novel bio-fertilizer for *Stevia rebaudiana Bertoni* under salinity-induced stress. *Plants, **13***(14), 1909. https://doi.org/10.3390/plants13141909

Meers, E. & Zhang, J. (2023). Nutrient recovery and recycling from fishery waste and by-products. *Journal of Environmental Management, **348***, 119266. https://doi.org/10.1016/j.jenvman.2023.119266

Naikoo, N. B., Chesti, M. H., Bhat, M. A., Mir, A. H., Bashir, O., Bhat, T. A., Mir, M. S., Gull, A., & ZA, A. L. (2022). Biostimulants towards soil health improvement: A review. *Agricultural Reviews*, 1–8. https://doi.org/10.18805/ag.R-2526

National Aquatic Resources Research and Development Agency (NARA). (2016). *Proceedings of the National Aquatic Resources Research and Development Agency (NARA), Scientific Sessions.* 1.178

National Aquatic Resources Research and Development Agency (NARA). (2022). *Sri Lanka Fisheries Industry Outlook*. 1-35

Nissi, W. I. & Debbarma, V. (2022). Effect of organic manures and fish amino acids on growth and yield of foxtail millet (*Setaria italica* L.). *International Journal of Plant and Soil Science, **34**,* 601–607. https://doi.org/10.9734/IJECC/2023/v13i8195

Ovissipour, M., Abedian Kenari, A., Motamedzadegan, A. & Nazari, R. M. (2012). Optimization of enzymatic hydrolysis of visceral waste proteins of yellowfin tuna (*Thunnus albacares*). *Food and Bioprocess Technology, **5**,* 696–705. https://doi.org/10.1007/s11947-010-0357-x

Panomjan, N. & Sukkaew, J. (2023). Stimulation of seedling growth in rice by seed priming and foliar application with fish amino acids. *Songklanakarin Journal of Plant Science, **10**,* 25–34. https://doi.org/10.3390/agriculture12020144

Priyanka, B., Anoob, D., Gowsika, M., Kavin, A., Sri, S.K., Kumar, R.K., Gomathi, R.S., Sivamonica, B., Devi, G., & Theradimani, M. (2019). Effect of fish amino acid and egg amino acid as foliar application to increase the growth and yield of green gram. *The Pharma Innovation Journal, **8***(6), 684–686. https://doi.org/10.12928/joves.v3i2.2932

Priyanka, B., Ramesh, T., Rathika, S. & Balasubramaniam, P. (2019). Foliar application of fish amino acid and egg amino acid to improve the physiological parameters of rice. *International Journal of Current Microbiology and Applied Sciences, **8**,* 3005–3009. https://doi.org/10.20546/ijcmas.2019.802.351

Puhagan, E. M., Juljani, N., Puhagan, A. I. & Kennedy, A. M. S. (2019). The influence of different rates of fermented fish amino acid (FFAA) on the yield of sweet corn under the nalil soil and climatic conditions. *Asian Journal of Agriculture and Allied Sciences*, 31–38. https://doi.org/10.56557/ajaas/2019/v2i16

Pushpakumari, W. H. D. U. & Geekiyanage, S. (2015a, October). Morphological variation of vegetative phase among Ma Wee (*Oryza sativa* L.) accessions during a non-inductive growing season for flowering. In *Proceedings of International Forestry and Environment Symposium, V* (p. 20).

Pushpakumari, W. H. D. U. & Geekiyanage, S. (2015b). Evaluation of yield variation in Sri Lankan traditional rice (*Oryza sativa* L.) Kalu Heenati. In *Proceedings of KDU International Research Symposium* (pp. 24–26). http://ir.kdu.ac.lk/handle/345/997

Pushpakumari, W. H. D. U. & Suthajini, T. (2023). Bioconversion of solid waste into an organic liquid fertilizer for improving crop growth and yield. In *Self-Sustaining Agriculture: Way Forward for Food Security and Safety, Proceedings of 3rd International Symposium on Agriculture* (p. 209).

Pushpakumari, W. H. D. U., Jayasekara, L., Senanayake, G. & Geekiyanage, S. (2024). Environmental effect on variations in flowering time and yield-related traits in Sri Lankan traditional rice variety 'Masuran'. *Journal of Food and Agriculture, **17***(2), 64–78.

Pushpakumari, W. H. D. U., Senanayake, G. & Geekiyanage, S. (2017). Photoperiod-driven days to flowering variation affects vegetative growth and yield in Sri Lankan traditional rice (*Oryza sativa* L.) Ma Wee. *Pakistan Journal of Botany, **49***(3), 945–954.

Radziemska, M., Vaverková, M. D., Adamcová, D., Brtnický, M. & Mazur, Z. (2019). Valorization of fish waste compost as a fertilizer for agricultural use. *Waste and Biomass Valorization, **10**,* 2537–2545. https://doi.org/10.1007/s12649-018-0288-8

Qadir, M., Hussain, A., Iqbal, A., Shah, F., Wu, W., & Cai, H. (2024). Microbial utilization to nurture robust agroecosystems for food security. *Agronomy*, **14**(9), 1891.

Ramesh, T., Rathika, S., Murugan, A., Soniya, R. R., Mohanta, K. K. & Prabharani, B. (2020). Foliar spray of fish amino acid as liquid organic manure on the growth and yield of *Amaranthus*. *Chemical Science Review and Letters, **9***(34), 511–515. https://doi.org/10.37273/chesci.CS205101114

Rebuza, A. O. & Tabal, E. P. (2022). Enriched and deodorized fish amino acids as a source of nutrients for tomato production in Zamboanga City, Philippines. *International Journal of Agriculture and Environmental Research, **8***(3), 503–515. https://doi.org/10.51193/IJAER.2022.8309

Rustad, T., Storrø, I. & Slizyte, R. (2011). Possibilities for the utilization of marine by-products. *International Journal of Food Science & Technology,* **46**(10), 2001–2014. https://doi.org/10.1111/j.1365-2621.2011.02736.x

Samoraj, M., Mironiuk, M., Izydorczyk, G., Witek-Krowiak, A., Szopa, D., Moustakas, K. & Chojnacka, K. (2022). The challenges and perspectives for anaerobic digestion of animal waste and fertilizer application of the digestate. *Chemosphere,* **295**, 133799. https://doi.org/10.1016/j.biombioe.2023.106991

Sanjutha, S., Subramanian, S., Rani, C. I. & Maheswari, J. (2008). Integrated nutrient management in *Andrographis paniculata*. *Research Journal of Agriculture and Biological Sciences,* **4**(2), 141–145.

Shama, A. F. & Nimalan, J. (2023). Effects of foliar application of fermented fish waste solution from yellowfin tuna (*Thunnus albacares*) on growth and yield of MI-2 chilli (*Capsicum annuum*). *Ceylon Journal of Science,* **52**, 331–337. https://doi.org/10.4038/cjs.v52i3.8073

Shahrajabian, M.H., Cheng, Q., & Sun, W. (2022). The effects of amino acids, phenols, and protein hydrolysates as biostimulants on sustainable crop production and alleviating stress. Recent Patents on Biotechnology, **16**(4), 319-328.

Shwe, S. S. & Moe, M. M. (2018). Different types and rates of fish amino acid (FAA) on the growth and yield of pumpkin. *2nd Myanmar Korea Conference Research Journal*, 369–376. https://www.dagonuniversity.edu.mm/wp-content/uploads/2019/08/37-Su-Su-Shwe-1.pdf

Siddiqui, S. A., Lakshmikanth, D., Pradhan, C., Castro-Muñoz, R. & Sasidharan, A. (2023). Implementing fermentation technology for comprehensive valorisation of seafood processing by-products: A critical review on recovering valuable nutrients and enhancing utilization. *Critical Reviews in Food Science and Nutrition*, 1–28. https://doi.org/10.1080/10408398.2023.2286623

Sivasankar, S., Ilakkiya, P., Rameshkumar, S., Muruganandam, C., & Karthikeyan, P. K. (2021). Effect of organic manures and foliar application of fish amino acid on vegetative growth and dry matter production of African marigold (*Tagetes erecta* L.). *Plant Archives,* **21**(1), 2535–2537. https://doi.org/10.51470/plantarchives.2021.v21.s1.413

Sivasankar, S., Kumaresan, M., Abhirami, V. A., & Khanchana, K. (2024). Effect of organic manures and foliar application on growth, yield, and nutrient uptake of kalmegh (*Andrographis paniculata* Nees.). *International Journal of Plant & Soil Science,* **36**(5), 696–705. https://doi.org/10.9734/ijpss/2024/v36i54568

Soni D., P., Meher, P., Shetty, A., Umtol, A. & Kirloskar, S. (2021). Waste management in the fishery industry: A review. *International Journal of Engineering Research & Technology,* **9**, 206–209.

Stephen, Praveena, Mariappan, G., Radhika, Krishnan, & Swaminathan, H. (2016). Influence of amino acid formulation on okra and brinjal. *An Asian Journal of Soil Science,* **11**, 115–119. https://doi.org/10.15740/HAS/AJSS/11.1/115-119

Stevens, J. R., Newton, R. W., Tlusty, M., & Little, D. C. (2018). The rise of aquaculture by-products: Increasing food production, value, and sustainability through strategic utilization. *Marine Policy,* **90**, 115–124. https://doi.org/10.1016/j.marpol.2017.12.027

Vasumathi, R. (2001). Influence of organic manures, biofertilizers, and plant density on growth, yield, and alkaloid content of Bhumyamalaki (*Phyllanthus amarus* Schum. and Thonn.) [M.Sc. (Hort.) Thesis]. Tamil Nadu Agricultural University, Coimbatore. https://doi.org/10.3126/ijasbt.v3i1.12137

Wei, Z., Ying, H., Guo, X., Zhuang, M., Cui, Z. & Zhang, F. (2020). Substitution of Mineral Fertilizer with Organic Fertilizer in Maize Systems: A Meta-Analysis of Reduced Nitrogen and Carbon Emissions. *Agronomy***.** **10**(8), DOI: 10.3390/agronomy10081149

Wijayaratne, B. & Maldeniya, R. (2003). The role of the fisheries sector in the coastal fishing communities of Sri Lanka. In *Assessment, management and future directions for coastal fisheries in Asian countries,* WorldFish Center Conference Proceedings. 629–656).

Xu, C. & Mou, B. (2017). Dre,nch application of fish-derived protein hydrolysates affects lettuce growth, chlorophyll content, and gas exchange. *HortTechnology,* **27**(4), 539–543. https://doi.org/10.21273/HORTTECH03723-17

Zhang, H., Gao, Y., Liu, J., Lin, Z., Lee, C., Hashim, H., Wu, W., & Li, C. (2021). Recovery of Nutrients from Fish Sludge as Liquid Fertilizer to Enhance Sustainability of Aquaponics: A Review. *Chemical engineering transactions,* **83,** 55-60. DOI: 10.3303/CET2183010

Zhang, J., Akyol, Ç. & Meers, E. (2023). Nutrient recovery and recycling from fishery waste and by-products. *Journal of Environmental Management,* **348**, 119266. https://doi.org/10.1016/j.jenvman.2023.119266

Zhang, L., Yan, C., Guo, Q., Zhang, J. & Ruiz-Menjivar, J. (2018). The impact of agricultural chemical inputs on the environment: Global evidence from informetric analysis and visualization. *International Journal of Low-Carbon Technologies,* **13**, 338–352. https://doi.org/10.1093/ijlct/cty039