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EXPLORING ECOLOGICAL FUNCTIONS OF RICE-FISH INTEGRATION IN THE AGRICULTURAL LANDSCAPE: A REVIEW TO INVESTIGATE FEASIBILITY OF IMPLEMENTING RICE-FISH INTEGRATION IN SRI LANKA

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ABSTRACT

Rice-fish integration is, a symbiotic farming system where fish are reared in rice fields. Although this farming method widespread in many Asian countries, it is relatively new to Sri Lanka, and consequently information on its ecological functions under Sri Lankan context is scarce. Therefore, detailed investigation on the ecological function of rice fish integration would provide necessary information to establish rice-fish integration in Sri Lanka. This study followed a qualitative case study approach, including literature review and extensive document analysis. The results highlighted the rice-fish integration approach presents an array of ecological functions, underscoring its potential as a sustainable agricultural practice. Ecologically, the presence of fish in the system contributes to increase nutrient availability for rice plants, and biologically control weed and pest. Further, rice-fish integration promotes soil fertility of rice fields which improves growth and nutrient uptake of rice plants. The rice plants, in turn, play a pivotal role to maintain biodiversity in rice fields through water purification, establishing optimal water temperature conditions, and providing an array of micro habitats for a diverse aquatic fauna and flora. On the other hand, rice fish integration promotes water use efficiency, higher economic return and animal protein requirement of local farming communities. Considering ecological, economical and health benefits, integration of tilapia fish with suitable rice varieties available in Sri Lanka is proposed. In conclusion, the rice-fish integration is an ecologically balanced farming system which has a potential to enhance the sustainability of rice field farming systems in Sri Lanka.

Keywords: Ecological benefits, Rice-fish integration, Symbiotic farming, Tilapia

INTRODUCTION

\Rice-fish integration (RFI), an innovative and symbiotic agricultural practice that integrates agriculture and aquaculture within the same landscape has garnered considerable attention as it secures the main staple food for a large portion of the world's human population especially in Asia (Frei and Becker, 2005), together with high-quality animal protein. Further, this farming system has also been identified as ecologically sound, low cost approach to produce both fish and rice in a sustainable manner (Ahmed and Garnett, 2011). This multifunctional farming system presents an opportunity to address the challenges associated with traditional monoculture practices by creating a resilient landscape that simultaneously enhances agricultural productivity and promotes environmental conservation (Frei and Becker, 2005).

Conventional agriculture practices largely depend upon inorganic fertilizers, and the average fertilizer usage in Sri Lankan during the period between 2002-2016 was approximately 131.9 kg/ha (Jisna *et al.*, 2021). The majority of imported agrochemicals in Sri Lanka have been directed towards rice cultivation, with rice accounting for over 70% of the national fertilizer usage (Jayasumana *et al.*, 2013). Although the usage of inorganic fertilizers is necessary to obtain the target production to meet the growing need for food, the inherent environmental concerns of inorganic fertilizers are significant (Roy and Sathoria, 2022). Among them, eutrophication of aquatic ecosystems, biomagnification, and bioconcentration of certain pollutants specifically heavy metals, nitrate contamination of drinking water sources, and salinization of both soil and water have been highlighted in the literature (Camargo and Alonso, 2006; Savci, 2012). Under this context, RFI makes significant reduction of environmental impacts caused by the excess use of inorganic fertilizers and other agro chemicals in paddy farming (Weimin 2010). In the context of RFI, the fish actively contribute to nutrient recycling through feeding, excretion, and the deposition of feces into the settled soil of the field bed. This process leads to an enhancement in the concentration of elements, including nitrogen (N) and phosphorus (P) (Noorhosseini and Bagherzadeh, 2013). Further, Li *et al.* (2022) recommended this integration for humid areas with low total nitrogen content (TN≤ 1.5 g/kg) in soil as the most promising strategy to simultaneously achieve the highest rice yield with good quality. The behaviors of fish promote mobility of nutrients in soil and consequently improve the fertility of soils. Specifically, nest making at the bottom of their habitat by cichlids, such as tilapia (*Oreochromis* sp.) not only improves the soil aeration, but also mobilizes soil nutrients (Inayat *et al.,* 2023). Further, fish excretions and metabolically excreted ammonia provides essential macro and micronutrients for paddy (Sathoria and Roy, 2022). Fish, by feeding and subsequently depositing their feces in the settled soil of the field bed, recycle essential nutrients, enhancing soil phosphorus and nitrogen levels and promoting the fertility of the soil beneath the plots (Frei and Becker, 2005). The biologic control of pests, diseases, and weeds is another significant benefit of fish culture in paddy fields, as it promotes a natural balance that minimizes the need for chemical applications (Fahad *et al.,* 2021; Kathiresan, 2007). The consumption of insects' larvae, leaf and stem feeding worms by fish like carp release to rice fields contributes to their growth and development, further biological control of rice pest population in the system (Noorhosseini and Bagherzadeh, 2013). Besides to rice and fish production that secure food security, RFI makes efficient use of land and water, maintain biodiversity, regulate water flows and water quality (Freed *et al.,* 2020)

While it has been proven success in various regions specially in the Asian continent, RFI is not popular or widely practiced in Sri Lanka. Therefore, a comprehensive study to scrutinize the effects and benefits of RFI in the Sri Lankan context is essential to signify its potential application in the country. Moreover, investigation of the effect of RFI on soil, water, and biodiversity is yet to be explored to promote RFI among farmers, specifically to adopt it as a sustainable and responsible agricultural practice. On the other hand, this information not only benefits in developing guidelines, and decision-making, but also to ensure their sustainability in terms of environmental, social, and economic aspects. Therefore, this paper discusses the potential ecological effects and benefits of RFI in the agricultural landscape of Sri Lanka with special emphasis on its feasibility of adopting in the Sri Lankan context.

MATERIALS AND METHODS

Literature search

The research employed a qualitative case study methodology, which encompassed an extensive literature review and document analysis. The study specifically investigated the importance of RFI as a sustainable agricultural practice in fostering the development of rural communities. The various research databases such as Google Scholar, PubMed, Scopus, and Science Direct were employed for exploring journal articles. In addition, references from retrieved articles and textbooks were also considered.

Data Extraction Process

Article titles were carefully selected, and documents considered 'irrelevant,' which did not provide information regarding the significance of RFI as a sustainable agricultural practice for the socioeconomic advancement of rural communities, were excluded. All studies offering qualitative or quantitative information related to the subject area were incorporated into the study. Initially, 105 papers were retrieved, reduced to 94 unique ones after removing duplicates using Zotero. The full articles corresponding to these 89 papers were retrieved and thoroughly examined. Ultimately, 86 papers met our inclusion criteria, and the information from these papers was included in this study.

The ecological functions of rice in rice-fish integration system

In RFI, rice plays an important role in providing a natural habitat and shelter for fish, particularly during the high-water temperature in the rice fields (Figure.1).

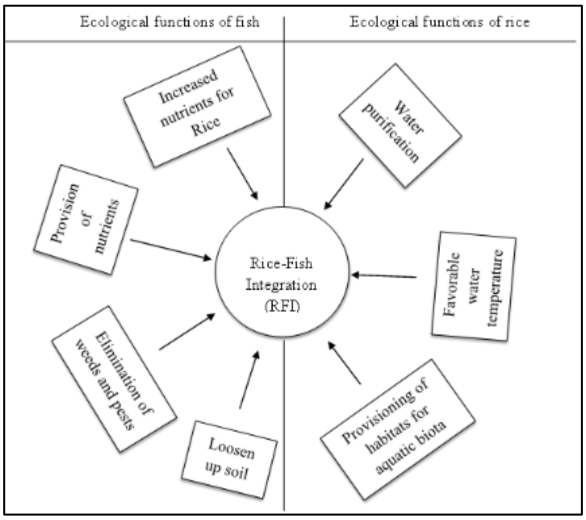

Figure 1: The functions of fish and rice in RFI

A network of interconnecting leaves of rice plants acts as a shelter, that minimizes the water temperature fluctuations benefiting fish especially in the summer season (Kunda *et al.,* 2008). Further, rice plants regulate the water quality in the rice field, by absorbing nutrients such as excess nitrogen and phosphorus from the soil. Availability of nutrients including nitrate, phosphate, potassium, and ammonia is being augmented by fish due to their direct and indirect behaviors (Chakraborty and Chakraborty, 1998, Zhang *et al.,* 1991). Nutrient retention in rice fields is comparatively low as those elements are easily absorbed by rice plants, and thus, there is less chance to develop harmful algal blooms that make severe detrimental problems for both fish and human beings. Additionally, the decaying leaves of rice offer favorable conditions for the multiplication of microorganisms, which are one of the natural feeds of fish (Lu and Li, 2006). These natural feeds improve growth and survival rates of fish. Compared to monocultures, RFI accelerates the overall production of the system (Kumara et al., 2023; Madhawa et al., 2023; Wang and Lei, 2000).

The ecological functions of fish in rice-fish integration

Fish in the RFI helps to loosen up soil surface, increase soil permeability, improve soil aeration, and enhance the vitality of soil microbes (Figure 1). Rice plants make it easy to absorb soil nutrients as the decomposition of nutrients in the soil is accelerated by microbes in the system. The occurrence of loach in rice fields has been demonstrated to enhance the proliferation of soil microorganisms, including nitrogen-fixing bacteria, cellulose-decomposing bacteria, nitrobacteria, sulfur bacteria, and ammonifying bacteria. This phenomenon contributes positively to augmenting the availability of soil nutrients (Wan *et al.*, 2010). Further, the behaviors of fish can induce soil aeration in rice fields (Mondol *et al.*, 2013), while they also control pests and parasites in the rice fields. Certain fish species feed on insects, snails, and other pests that destroy rice plants, reducing the need for chemical pesticides (Frei and Becker, 2005). Compared to monoculture rice fields, a significant reduction in pests and weeds has been reported in RFI with fresh water aquaculture species like tilapia, carps, etc. (Nayak *et al.*, 2020) and in rice-duck integration (Poonam *et al.*, 2019). Further, fish excreta serve as both a natural fertilizer for rice and enrichment for soil which can further enhance rice growth and yield (Lu and Li, 2006) while promoting the growth of phytoplankton and zooplankton, which are then consumed as feed by fish for their growth and development (Sha *et al.,* 2017; Wongkiew *et al.,* 2018). The phosphorous and nitrogen contains in the fecal matter of fish improves soil fertility, nutrient recycling (Nayak *et al.,* 2018) and reduction of fertilizer usage (Xie *et al.,* 2011). Fish contribute to the nutrient cycling process in the rice field ecosystem specially to nitrate cycle via the excretion of ammonia through their gills during their respiration. In addition, fish excreta are rich in nitrogen and phosphorus, essential nutrients for plant growth (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). The movement of fish help to enhance soil porosity and stir up sediments in the rice field, which helps to increase oxygen levels and reduce the buildup of toxic gases as convert an anaerobic system to an aerobic system (Bashir *et al.,* 2020). Fish, as they move through the water, disturb the sediment at the bottom of rice fields. This action helps to prevent sedimentation, which can otherwise lead to the formation of anaerobic (oxygen-deprived) pockets in the soil (Inayat *et al.*, 2023). Moreover, as fish move through the water, they create disturbances that lead to the formation of channels and pockets within the soil. These channels increase soil porosity, and the higher soil porosity allows for better air and water movement, facilitating gas exchange and nutrient uptake by rice plants. Further the rice plants have some special adaptations to breathe under inundated conditions (Mitin, 2009). Rice plants possess specialized tissues called aerenchyma, which are hollow, air-filled channels that allow for the exchange of gases between the roots and the above-ground parts of the plant. In addition, rice plants develop adventitious roots, known as "pneumatophores," which protrude above the water surface in flooded conditions (Rich, 2011). These roots help to facilitate gas exchange by allowing oxygen to enter the root system and carbon dioxide to exit, despite the inundated environment. By combining the natural adaptations of rice plants with the beneficial effects of fish movement in rice fields, RFI creates synergistic relationships that enhance soil health, promote better oxygenation, and ultimately contribute to improved crop yields.

Effects of rice-fish integration on soil fertility of rice field systems in Sri Lanka

Rice paddies are unique, artificial wetland ecosystems rich habitat for an array of aquatic flora and fauna. In Sri Lanka, paddy soils face challenges of overexploitation, with nutrient depletion emerging as a prevalent issue across the entire island. The extensive use of agrochemicals has led to soil pollution, particularly with toxic trace elements, contributing to a decline in soil fertility over recent decades (Rubasinghe *et al.,* 2021). Paddy soils, especially those integrated with fish cultivation, serve as favored habitats for numerous soil microorganisms. These microorganisms, including nitrogen-fixing bacteria, cellulose-decomposing bacteria, nitrobacteria, sulfur bacteria, and ammonifying bacteria, play a crucial role in sustaining nutrient cycles and soil fertility (Wan *et al.,* 2019).

The intensive application of agrochemicals in Sri Lankan paddy farming has exerted severe impacts on both the biotic and abiotic environments within these fields (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). Furthermore, the current levels of pesticide use in rice production are deemed unsustainable from both economic and ecological perspectives (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). Addressing these challenges calls for the adoption of eco-friendly farming technologies aimed at minimizing inorganic fertilizer usage while ensuring adequate productivity and enhancing soil fertility.

Therefore, the implementation of RFI in potential paddy fields as an eco-friendly farming technology would facilitate improving soil fertility and quality in an environmentally friendly manner in Sri Lanka.

According to Cagauan (1995), fish integration improves nutrient composition of floodwater, the oxidized surface of paddy soil, and the growth of rice plants, and there were four mechanism behind these actions, viz (i) fish contribute nutrients to the rice field through their feces excretion and the decomposition of deceased fish, (ii) fish behavior including swim and reproduction disturb the soil-water interface, while facilitating to release fixed nutrients from the soil into the water and disperse soil particles, (iii) fish make the soil more porous, enhancing nutrient uptake by rice, and (iv) nutrient recycling by grazing on the photosynthetic biomass and other components of the ecosystem.

The excrement produced by fish serves as a nutrient-rich organic fertilizer for rice, thereby decreasing the reliance on inorganic fertilizers for rice cultivation. The fish feces can provide nutrients equivalent to chemical fertilizers. For example, the amount of fish feces produced by 375 kg/ha of fish was comparable to the application of 93.8 kg/ha of ammonium sulfate and 33.8 kg/ha of calcium superphosphate (Weimin, 2010). According to Lu and Li (2006), the nitrogen-fixing function of the system has the potential to elevate the organic matter content, total nitrogen, and total phosphorus in the soil by 15.6-38.5%. Additionally, Madhawa et al. (2023) found notable enhancements in electrical conductivity, organic matter content, soil phosphate, and potassium levels in plots integrated with Tilapia compared to those without fish.

Effects of rice-fish integration on biodiversity of the rice field system in Sri Lanka

The rice field ecosystems are rich in biodiversity, as there is an array of habitats for both fauna and flora. Dynamics of rice field biodiversity largely influence by several factors such as inundation level and its frequency, irrigation mechanisms and systems, elevations, soil conditions, and various management interventions (Jayasiri *et al.*, 2022). According to Bambaradeniya *et al.* (2004), there were 494 invertebrate species, 103 vertebrate species, 89 macrophyte species, and three macro fungi species in rice field ecosystem at Bathalagoda, in the Kurunegala district, belonging to the Intermediate Zone of Sri Lanka. Among them, arthropods were particularly dominant accounting for 405 species. Additionally, a broad spectrum of freshwater invertebrates and a high density of aquatic birds have also been reported in Sri Lankan rice ecosystems (Bambaradeniya *et al.*, 2004; Bellio *et al.*, 2009).

Although the Sri Lankan government prioritizes rice production through rice intensification, an expansion of paddy lands in Sri Lanka face practical difficulties due to paddy land scarcity. Thus, alternative options including the usage of agrochemicals have been employed to increase rice production. However, this approach is not an environmentally friendly technique due to its inherent environmental consequences such as biomagnification, bio concentrations. Further, direct, and indirect impacts on non-target aquatic flora and fauna are also significant (Weerakoon *et al.*, 2018). In spite of the nation's prohibition on numerous pesticides and the adoption of guidelines from the World Health Organization (WHO) advocating restrictions, the persistent issue of excessive pesticide application and insufficient enforcement of policies has resulted in significant environmental pollution in Sri Lanka (Jayasiri *et al.,* 2022). However, the utilization of agricultural pesticides in Sri Lanka experienced a substantial increase of 43% from 1991 to 2018 (Jayasiri *et al.*, 2022).

Pesticide contamination in irrigation water can have adverse impacts on biodiversity within rice field ecosystems (Pandey *et al.*, 2020). The direct exposure to pesticides poses risks to non-target species, soils, and water bodies (Barbieri *et al.*, 2021; Weerakoon *et al.,* 2018). Detrimental effects encompass enzyme function inhibition, bioaccumulation, and tissue damage in fish (Clasen *et al.,* 2018; Gao *et al.,* 2020; Rossi *et al.*, 2020), disruptions in the swimming behaviors of fish and amphibians (Shuman-Goodier *et al.,* 2017), hormonal disruption in frogs (Shuman-Goodier *et al.*, 2017), developmental and biological activity restrictions in beetles (Khan *et al.*, 2018), mortality and altered feeding behavior in spiders, mortality of bees and wasps (Cheng *et al.*, 2018; Yasuda *et al.*, 2017), weight loss, and shifts in enzymatic activity of earthworms (Rico *et al.*, 2016), as well as a reduction in soil microbe populations (Nicomrat *et al.*, 2016). By actively consuming pests and weed propagules, the presence of fish in rice fields contributes to natural pest and weed control, reducing the need for chemical pesticides and herbicides. Consequently, it can help to mitigate the bio magnification of certain substances, such as toxins or pollutants, in food webs.

Moreover, RFI, recognized as an eco-friendly method, often minimizes the need for agrochemicals in pest and weed control, thereby preserving a diverse rice field biota (Weimin 2010) of the country. Madhawa *et al.* (2023) reported a higher biodiversity index (Shannon diversity index (H) of 3.09) in the RFI compared to rice monoculture, indicating greater aquatic biodiversity. Lu and Li, (2006) found that pesticide application can be reduced by 50% compared to modern high-input rice production, and sometimes, very minimum pesticide application is needed when rice is cultivated alongside fish. Therefore, the RFI actively contributes to the preservation of biodiversity of rice field ecosystems (Madhawa *et al.,* 2023).

Rice fish integration and efficient use of water in agriculture practices of Sri Lanka

Paddy cultivation in Sri Lanka follows diverse agricultural practices, with rainfed cultivation predominant in the lowlands wet zone and irrigated practices in the dry and intermediate zones. Notably, over 65% of paddy cultivation relies on major and medium irrigation schemes, with around 20% under minor irrigation schemes and 10% being rainfed (Salman *et al.,* 2022). Despite the country's self-sufficiency in paddy production, Sri Lanka exhibits relatively low levels of water productivity and efficient usage (Salman *et al.,* 2022).

Paddy cultivation, characterized by the continuous inundation of fields during the growing season, is inherently water-intensive. Studies suggest that for rice cultivation, a minimum of 1,000 to 1,500 mm of water is required, with 34% of the total cultivated area dedicated to high water-intensive paddy, consuming over 70% of the total water allocation for food production in Sri Lanka (Shantha & Alli, 2014). Notably, if a hectare of rice field produces 10 metric tons of rice, it still requires 1 to 1.5 m^3 of water to yield 1 kg of paddy (Sevilleja *et al.,* 1992).

In drier areas, irrigated agriculture, primarily focused on paddy production, accounts for 96% of water withdrawals. Despite this substantial water usage, the overall irrigation efficiency in the country stands at a mere 30%, significantly below its potential (Salman et al., 2022).

Recognizing this challenge, the promotion of RFI emerges as a timely and important holistic approach to enhance water use efficiency in Sri Lanka's rice fields. This RFI, where the same water is utilized for both rice and fish production simultaneously, facilitates the coupling of returns from a single paddy field and it also significantly improves irrigation water use efficiency when compared to traditional rice monoculture (Frei and Becker, 2005).

Effects of rice-fish integration on sustainability of rice field systems in Sri Lanka

Wet rice cultivation, with a history spanning at least 4,000 years, suggests that traditional rice farming is fundamentally sustainable. However, uncertainties arise regarding the sustainability of the substantial increases in rice production facilitated by the 'green revolution' (Greenland, 1997). Factors such as global warming, sea level rise, increased ultraviolet radiation, and water availability pose potential threats to rice production. The cultivation of fish in rice fields emerges as a potential enhancer of the sustainability of rice farming, contributing to a more balanced and stable ecosystem. This natural approach not only fosters a healthier environment but also minimizes the necessity for chemical interventions (Wan *et al.,* 2019). Additionally, by actively participating in the regulation of the rice field ecosystem, fish contribute to mitigating the risks of water and soil contamination. Weed removal by fish like tilapia, common carp, silver carp prevents the degradation of water and soil quality attributed to agrochemicals, thereby promoting a more sustainable and resilient farming system (Fahad *et al.,* 2021; Kathiresan, 2007).

Consequently, the integrated cultivation of fish alongside rice holds the potential to mitigate the adverse environmental impacts associated with traditional rice farming practices. By leveraging the inherent behaviors of fish, such as weed consumption and pest control, this approach aligns with the principles of ecological balance and sustainability. Ultimately, the system efficiently utilizes any fertilizers or feeds employed, converting them effectively into food production while minimizing nutrient discharge into the natural environment. Furthermore, RFI has been shown to decrease CH_4 emissions by approximately 30% in comparison to conventional rice farming (Lu and Li, 2006).

Potential rice varieties and fish species to enhance the ecological and economical functions in the RFI

Rice verities

Prior to the introduction of improved rice varieties in Sri Lanka, farmers predominantly cultivated traditional rice varieties (Rambukwella and Priyankara, 2016). However, in recent times, improved rice varieties are grown the majority of rice farmers all over the country (Paddy statistics 2022). Most of popular rice verities cultivate in all over the country is listed in Table 1. With the development of improved rice, several concern affecting rice-fish integration have emerged. The reduced growing period may be of greater concern, as many new varieties mature within approximately 105 days or less (Halwart and Gupta, 2004). With such a short culture period for fish there is a need to either stock large fingerlings or use of refuge pond to facilitate to reach reasonable fish size in fish integration with improved popular rice varieties in Sri Lanka. A fish refuge is a deeper area where it can provide a space for the fish within a rice field to facilitate to contain fish for further grow whilst the rice is harvested (Halwart 1998). Farmers could also introduce larger size fingerlings with short culture period rice because of their high survival rate, as well as their high growth rate (Haque *et al.*, 2014). This is also agreed with study conducted in Bangladesh with rice-fish farmers, where in general all rice-fish farmers in Bangladesh use a slightly larger size of fingerling in a RFI, believing that fingerlings that start out a bit bigger will grow faster than those that start out smaller (Islam, 2016).

Consumers today (both locally and globally) are more health conscious and more interested in consuming traditional rice, as opposed to improved verities (Ginigaddara and Disanayake, 2018; Rodrigo, 2013). Therefore, at the moment there is a motivation and incentives for farmers to engage in traditional paddy cultivation. A study conducted in Anuradhapura district revealed that 67% of male farmers were willing to cultivate traditional rice varieties over improved verities (Ginigaddara and Disanayake, 2018). There are only handful of traditional rice varieties in existence today. These are: Suwadel, Kuruluthuda, Kalu Heenati, Madathawalu etc. (Table 1). These traditional verities have strong .characteristics which suited for RFI specifically tall and strong stems along with a long cultivation period, enabling them to withstand heavy rains, winds, and floods (Rodrigo, 2013). Therefore, traditional rice varieties could be better suited for RFI in Sri Lanka even with floods and heavy rains especially in low-lying areas.

Table 1 : The most popular rice varieties (improved and traditional) in Sri Lanka – 2016

Improved rice varieties			Traditional rice varieties		
Name	Age (Month)	Distribution (%)	Name	Age (Month)	Distribution (%)
BG 352	3.5	16.4	Suwadel	3.5	0.075
AT 362	3.5	15.4	Kuruluthuda	4 – 4.5	0.022
BG 360	3.5	13.3	Kalu Heenati	3.5	0.012
BG 358	3.5	8.0	Madathawalu	3.5	0.007

Source: *Department of Agriculture, Sri Lanka*

Potential fish species

The key to success of this RFI in Sri Lanka may lie in the use of the right fish. The fish to be stocked in rice fields should be capable of tolerating a harsh environment characterized by: shallow water, high (up to 40°C) and variable temperatures (range of 10°C in one day), low oxygen levels and high turbidity (Khoo and Tan 1980). Fast growth is also mentioned as a desirable characteristic so that the fish could attain marketable size when the rice is ready for harvest (Halwart and Gupta, 2004). Potential inland fish species that could be tried in rice fields for integration with paddy listed in Table 2.

Among the many species available for raising in rice fields, the choice is based on availability, marketability or desirability as food fish (Halwart and Gupta, 2004). In Sri Lanka, tilapia, snakehead murrel, catfishes, barbs and eels are the most demanded freshwater fish varieties and consumers have favorable attitudes towards freshwater fish consumption despite of its smell (Samarasinghe and Dushani, 2012).

Table 2: Potential inland fish species that could be tried in rice fields of Sri Lanka for integration with paddy

Scientific Name	Common Name(s)
Oreochromis niloticus	Nile tilapia
Cyprinus barbus	Barbs
Anguilliformes	Eels
Channa striata	Snakehead murrel
Heteropneustes fossilis	Sting catfish
Clarias batrachus	Walking catfish

(Samarasinghe and Dushani, 2012)

Preferable fish species over inland fish consumption

Tilapia stands out as the primary choice among inland fish species consumed in Sri Lanka, representing a significant portion of dietary intake. A study conducted across six villages in the Northwest province revealed that 60% of respondents included fresh inland fish in their meals, with tilapia accounting for 75–85% of these meals (Murray and Little, 2022). Among university students, tilapia consumption dominates at 64.79%, followed by a preference for Chinese and Indian carps at 19.72% (HMTNB and Radampola, 2016). Additionally, other inland fish, including native species, hold a preference value of 15.49% (HMTNB and Radampola, 2016). The consistent demand for tilapia can be attributed to its delicate taste, mild flavor, and tender flakes when cooked, making it a favored choice for daily consumption (Suresh and Bhujel, 2012).

Ecological, economical and health benefits of tilapia fish in rice-fish integration

Ecologically, tilapia contribute to nutrient cycling within the system by consuming organic matter, detritus, and excess algae (Lowe-McConnell, 2000). Their excretion and waste products serve as natural fertilizers for rice plants, enhancing soil fertility and productivity (HAQUE, 2019). Tilapia feed on various aquatic organisms, including insect larvae, snails, and weeds, helping to control populations of pests and unwanted vegetation in the rice fields (Halwart *et al.*, 2012). Tilapia actively stir up the water column through their feeding, reproduction and swimming activities, which increases oxygen levels in the water and this helps to prevent oxygen depletion, particularly in areas with dense vegetation or organic matter decomposition, thereby improving overall water quality and supporting other aquatic life (Bashir *et al.*, 2020). Tilapia exhibit resistance to certain diseases and parasites, and their presence in rice fields can help to regulate populations of harmful pathogens by preying on them or competing for resources (Halwart and Gupta 2004).

Economically, tilapia contribute to increased overall productivity of the RFI by providing an additional source of protein and income through fish sales (Cai *et al.*, 2017). Tilapia excrete waste that serves as natural fertilizer (HAQUE, 2019). This reduces the need for chemical fertilizers, thereby cutting down on input costs for farmers. Tilapia feed on pests and insects that may harm rice crops (Halwart *et al.*, 2012). This reduces the need for chemical pesticides, leading to cost savings for farmers. Integrating tilapia into rice farming provides farmers with an additional source of income diversification (Cai *et al.*, 2017). This helps to stabilize farm income and reduce the risk associated with relying solely on rice cultivation (Pollock, 2005). Tilapia farming in rice fields can help mitigate risks associated with fluctuating rice prices or crop failure. The dual-purpose system provides farmers with alternative income sources, reducing vulnerability to market fluctuations or unforeseen events (Islam *et al.* 2015). The consumption of tilapia offers numerous health benefits, including weight reduction, increased metabolism, strengthened bones, and a reduced risk of chronic diseases, owing to the high nutritional content of its flesh (Alam *et al.*, 2016).

Characteristics of tilapia that make them well-suited for rice-fish integration

Tilapia possess several characteristics that make them well-suited for aquaculture and integration. Tilapia has high growth rates, adaptability to a wide range of environmental conditions and ease in rearing (El-Sayed, 2006; Kumara *et al.*, 2023). They can thrive in shallow and turbid waters, have high market value, adapt to various culture systems, exhibit high resistance to diseases and parasites, and are easily bred and maintained in captive environments (Pullin, 1983; Gupta and Acosta, 2001a; Ng and Romano, 2013). Moreover, tilapia demonstrate remarkable tolerance to crowding and can endure relatively stressful and unfavorable conditions, such as low dissolved oxygen levels (<2mg/l) and high ammonia levels (~50 mg/l), for longer durations compared to many other cultured fish species (Suresh and Bhujel, 2012). Additionally, tilapia display versatility in their diet, being able to consume various types of food and thrive on low-cost diets sourced from terrestrial sources (Ng and Romano, 2013).

Integrated farming of tilapia is practiced extensively worldwide. In Southeast Asia, especially Indonesia, Thailand, Vietnam, Cambodia and Myanmar, tilapia culture is widely integrated with agriculture & animal farming (Dey *et al.*, 2000; Little 2000; Gupta & Acosta 2004). Tilapia integrated with crop farming e.g., vegetables, rice and other field crops, was economically attractive and environmentally friendly compared to non-integrated ponds (Jamu 2001). A study conducted in Bangladesh indicated that the hardy fish like tilapia performed better in terms of production and economics than that of others fish species (*Puntius gonionotus* and *Cyprinus carpio*) in RFI. And same study recommended that tilapia can be a good option while selecting aquaculture species for rice field of Bangladesh (Jewel *et al.*, 2018).

Hence, tilapia emerges as an excellent choice for aquaculture species in RFI initiatives in Sri Lanka. This selection not only promote ecological balance within rice fields but also enhances economic viability and promotes better health outcomes among rural rice farmers in the region.

CONCLUSIONS

The findings of the present study clearly highlight that RFI significantly changes the ecological functions of rice fields through their intervention in water, soil nutrients and biodiversity. Further results reveal the usage of chemical inputs like chemical fertilizers, herbicides and pesticide applications are reduced by the biological control of weeds and pests in RFI forming an environmentally friendly farming system and minimize bioaccumulation of toxic substances. Irrigation water use efficiency of RFI is comparatively higher than that of rice monoculture systems, due to dual usage of same water for fish and rice plants. Considering ecological, economical and health benefits, integration of tilapia fish with suitable rice varieties available in Sri Lanka is proposed.

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