

Feature Review

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The Role and Mechanism of Integrated Rice-fish Farming in Enhancing Rice Quality

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Abstract As a typical ecological agricultural model, integrated rice-fish farming has been widely promoted in many major rice-producing areas in China in recent years. This study systematically sorted out the model types, ecological structures and functional characteristics of the rice-fish system, deeply analyzed its multi-faceted effects on the appearance quality, edible quality and nutritional quality of rice, and further explored its scientific principles for improving rice quality through mechanisms such as soil nutrient cycling, microbial community improvement and plant physiological metabolism regulation. At the same time, combined with case empirical studies in typical regions, the mechanism of the influence of water and fertilizer dynamics on the formation of rice quality was revealed. The results show that integrated rice-fish farming not only helps to improve the overall quality of rice, but also provides a new path for the green and efficient development of modern agriculture. This study hopes to provide theoretical support and practical guidance for the optimization and promotion of the rice-fish model in the future.

Keywords Integrated rice-fish farming; Rice quality; Ecological mechanism; Soil nutrients; Microbial community

1 Introduction

Integrated rice-fish farming means growing rice and raising aquatic products in the same rice field. Common combinations include rice-fish, rice-shrimp, rice-crab, rice-duck, etc. This method allows rice and fish (or other aquatic products) to live together and help each other. Fish can help rice get rid of insects and weeds, and rice also provides living space and food for fish. The two promote each other and make better use of the space and resources of paddy fields. This model can increase the number of biological species in the field, the resource utilization rate is also higher, and the ecological benefits are obvious, so many people now recognize this method. For example, fish can eat insects and weeds in the field, so that less pesticides and herbicides can be used; fish excrement can also be used as fertilizer to promote soil nutrient circulation and improve soil fertility (Nayak et al., 2018). At present, this farming method has been promoted in many places, such as the Mekong Delta in Vietnam and some areas in China. In terms of yield and ecological benefits, this method is better than growing rice alone (Ahmed & Garnett, 2011; Wan et al., 2019).

The quality of rice is affected by many factors, such as soil conditions, water management methods, and the presence of pests and diseases. In the rice-fish system, the presence of fish can improve these problems. They can promote nutrient circulation and reduce dependence on chemical fertilizers, making the soil healthier and the quality of rice better. If you want to know whether the rice is good, several indicators that are often looked at include protein content, chalkiness, gel consistency, and the amount of amylose. Studies have found that rice-fish farming can improve soil nutrients and reduce the occurrence of pests and diseases, so these indicators perform better and the quality of rice produced is higher (Nayak et al., 2018; Wan et al., 2019; Yassi et al., 2023). In this system, some organic fertilizers are usually used, and some comprehensive pest and disease control methods are also used. These measures also help farmers grow higher quality rice (Yassi et al., 2023; Pearlin et al., 2024).

This study will explore the impact of integrated rice-fish farming on improving rice quality and its mechanism of action. By analyzing the ecological, economic and social dimensions of this model, we will try to fully understand how rice-fish farming can help agricultural sustainable development and food security. The article introduces the

development history and advantages of integrated rice-fish farming, and then analyzes the key indicators of rice quality and their influencing factors; then it explores in depth the specific mechanism of rice-fish system to improve rice quality, and analyzes it in combination with recent research and experimental evidence; finally, it points out the challenges and opportunities faced by integrated rice-fish farming in the process of promotion, providing reference for future research directions and policy formulation.

2 Rice-Fish Co-Culture Systems

2.1 Common types of rice-fish systems

There are many ways to farm rice and fish, the most common ones are rice-fish, rice-shrimp, rice-crab and other combinations. The purpose of each method is to make better use of land and water resources and increase production. For example, the rice-fish model is to put fish in rice fields, common fish are carp and tilapia. These fish can eat pests and help circulate nutrients in the fields (Wan et al., 2019; Arunrat and Sereenonchai, 2022). The rice-shrimp model is more common in coastal areas. The water there is a bit salty, which is suitable for both growing rice and raising shrimp (Hu et al., 2016). The rice-crab model is generally used in places where crabs are suitable for growth. This practice not only allows farmers to earn more income, but also improves the ecological environment in the fields (Feng et al., 2016).

2.2 Ecological structure and functional attributes of co-culture systems

The structure of the rice-fish system is very special. It is an ecosystem where rice and aquatic animals interact together. There are multi-level nutritional relationships between them, which makes the biological species more diverse and the ecological function stronger. This system can increase the organic matter and effective nutrients in the soil, which is very helpful for rice growth and can also increase yields (Figure 1) (Lv et al., 2020; Arunrat et al., 2022). There are fish or shrimps in the fields, which can also eat pests and weeds, so less pesticides and fertilizers are used. This method is not only more environmentally friendly, but also makes the rice quality better (Wan et al., 2019; Liu et al., 2023). The rice-fish system also saves water and nutrients can be recycled, which is a more environmentally friendly practice than traditional agriculture.



Figure 1 Photographs of the paddies in the field investigation (A) and plots in the mesocosm experiment (B) (Adopted from Lv et al., 2020)

2.3 Comparison with traditional rice monoculture

Compared with the traditional method of growing only rice, rice-fish farming has obvious advantages in both ecology and economy. Studies have found that using this system can increase economic benefits by about 25.4%. Because in addition to selling rice, farmers can also earn an extra income by raising fish. Moreover, fish can help control pests and weeds, so less pesticides and fertilizers are used, saving costs. From an ecological perspective, the rice-fish system can also make the soil more fertile, reduce greenhouse gas emissions, be more environmentally friendly, and be conducive to long-term development (Li et al., 2022; Xie et al., 2024). Raising fish in the fields can also increase beneficial microorganisms in the soil and improve nutrient cycles. These

advantages are not easy to achieve in fields that only grow rice. Rice-fish farming not only increases yields, but also protects the environment. It is a more stable and long-term agricultural method (Hu et al., 2016; Arunrat and Sereenonchai, 2022; Ye et al., 2024).

3 Effects on Rice Grain Quality

3.1 Appearance quality

Rice-fish farming has many benefits for the appearance of rice. Indicators such as rice milling rate and transparency perform better under this method. Studies have found that rice-fish farming can significantly increase the rate of whole rice polishing, that is, the rice is more complete after milling. When fish swim in the fields, they can also reduce the chalkiness of rice grains, making the rice look brighter, more shiny, and better looking (Wan et al., 2019; Wang et al., 2023). The main reason for these changes is that there are more nutrients in the soil, fewer pests and diseases in the rice fields, and the rice grows stronger and healthier (Tsuruta et al., 2010).

3.2 Eating quality

The edible quality of rice, including gelatin consistency, amylose content and taste score, has also been significantly improved in the rice-fish farming system. Studies have shown that this system can make the cooked rice softer and more glutinous, with a better taste, and consumers prefer it (Li et al., 2022). Fish excrement can provide natural nutrients, reduce dependence on chemical fertilizers, make the proportion of amylose in rice more moderate, and also affect the stickiness and taste of rice. The combination of multiple factors makes rice in the cooperative farming system more popular.

3.3 Nutritional quality

The rice-fish system can also make rice more nutritious. After raising fish in the fields, the protein content in the rice increased, and trace elements such as iron and zinc, as well as some antioxidant components, also increased. The presence of fish improves the nutrient cycle of the soil and allows rice to absorb more nutrients (Tsuruta et al., 2010; Li et al., 2025). This improvement is particularly important in areas where rice is the staple food, which can alleviate the problem of insufficient nutrition intake to a certain extent and help improve the dietary health of local people.

4 Underlying Mechanisms of Quality Improvement

4.1 Enhanced soil nutrient cycling

Rice-fish farming can make the nutrient cycle in the soil better, which is one of the important reasons for improving the quality of rice. When fish are raised in rice fields, they will defecate. These feces can increase the organic matter in the soil and supplement the nitrogen, phosphorus, potassium and other nutrients needed for rice growth (Nayak et al., 2018; Kaewpuangdee et al., 2024). With these nutrients, rice grows faster and better, and the quality of rice is naturally improved. In addition, when fish move in the field, they can also help speed up the decomposition of organic matter. In this way, the roots of rice can absorb nutrients faster. The nutrient flow in the entire field is also more stable and efficient (Li et al., 2025).

4.2 Alteration of microbial community composition

Fish swimming around in rice fields will affect the microorganisms in the soil. This effect is good and helps the growth of rice. There will be interactions between fish and soil, which will increase the variety of microorganisms in the soil and make them more active. In this way, the soil will be healthier and nutrients will be converted faster (Nayak et al., 2018; Ranjith et al., 2024). Microorganisms can decompose organic matter and release nutrients that can be absorbed by plants. In this way, the soil is more fertile and the rice can grow stronger. A good microbial environment can also suppress some diseases transmitted in the soil, which is also beneficial to improving the quality of rice.

4.3 Regulation of plant metabolism

The rice-fish system can also affect the physiological metabolic process of rice. After raising fish, there are fewer pests and diseases in the fields, and the rice is less "injured", so more energy can be used to grow taller and longer

grains. The environmental improvement and nutrient increase brought by fish also make the metabolic function of rice stronger, and it has a stronger ability to adapt to drought, high temperature and other conditions, and better overall health (Wan et al., 2019; Li et al., 2025). These changes will eventually be reflected in the rice, which will be more nutritious and taste better.

5 Water and Fertilizer Dynamics in Integrated Systems

5.1 Impact of redox conditions on rice quality

In the rice-fish system, the redox state of water and soil affects the quality of rice. The presence of aquatic animals such as fish will change the redox potential in the rice field. This change will affect the nutrient activity in the soil and the efficiency of rice nutrient absorption (Nayak et al., 2018; Kaewpuangdee et al., 2024). The activity of fish makes the redox process more active, and also makes the soil more aerated and the nutrient cycle smoother. These changes help the rice root system develop better, and also improve the whole polished rice rate and transparency, making the rice quality better (Li et al., 2021).

5.2 Nutrient input from aquatic animal waste

When fish swim in rice fields, they excrete a lot of feces. These feces are natural fertilizers, containing nitrogen, phosphorus, and potassium, which are very important nutrients for rice growth (Liu et al., 2023; Lv et al., 2020). With this method, you don't need to apply too much chemical fertilizer. In this way, the soil becomes more fertile and the rice grows better. If there are enough nutrients in the soil, the protein in the rice will also increase, and the nutrition will naturally be higher.

5.3 Enhanced nutrient use efficiency through system buffering

The rice-fish system itself has the ability to regulate, which can help stabilize the supply of nutrients and reduce loss. Fish swimming back and forth in the system will promote nutrient circulation and reduce the situation where fertilizers are washed away or leaked by rainwater (Xie et al., 2011). This mechanism allows rice to have sufficient nutrient support throughout the growth period, which helps rice grow stronger and produce higher yields. This buffering capacity of the system can also reduce the impact of some adverse external conditions on rice, and improve the stress resistance and sustainable development of rice fields.

6 Case Studies and Empirical Evidence

6.1 Guangxi's "high-quality rice + high-quality fish" ecological and efficient breeding technology

The "rice-fish symbiosis" model cleverly combines rice planting with fish farming, which not only improves the ecological benefits of farmland, but also brings tangible economic benefits to farmers. The Hehua carp mixed in the rice field can effectively reduce rice pests and diseases by foraging for pests and residues in the rice field without additional feed, thereby reducing the use of pesticides, fertilizers and herbicides (Figure 2) (Li et al., 2022). This all-weather "symbiosis and co-growth" model not only improves the ecological environment of the rice field, but also helps to improve the quality of rice and fish, and achieve green and sustainable development of agriculture.

Guangxi rice field fish farming has a long history. Traditional rice field fish farming is mainly based on Hehua carp, with mature breeding models and breeding technologies, including Hehua fish brand building and publicity and other industrial links. According to statistics, the current rice field fish farming area in Guangxi is about 53 000 hectares, mainly distributed in Guilin and Liuzhou, accounting for more than 90% of the total rice field fish farming area in the region. Among them, Quanzhou County, Sanjiang Dong Autonomous County, and Rongshui Miao Autonomous County have the largest area, followed by Guanyang County and Xing'an County. In the past 10 years, with the support of relevant departments, the infrastructure of traditional rice field fish farming, such as pits (ditches), shade sheds, escape prevention fences, and shed melon planting, has been greatly improved, and the breeding output has increased from the original 15 kg/mu to 30 kg/mu. Among them, the ditch-pit rice field breeding model performed best, with a high yield of 50 kg/mu, making a huge contribution to the rice field fish farming industry in Guangxi. Under the "high-quality rice + high-quality fish" ecological high-yield breeding

model, the yield of Wan Tai Youmei can reach 500 kg/mu, and the yield of Hefang crucian carp can reach 120 kg/mu, which has broadened the space for rice field fish farming in Guangxi, tapped the potential of rice field utilization, and greatly improved the economic benefits of rice field ecological breeding.

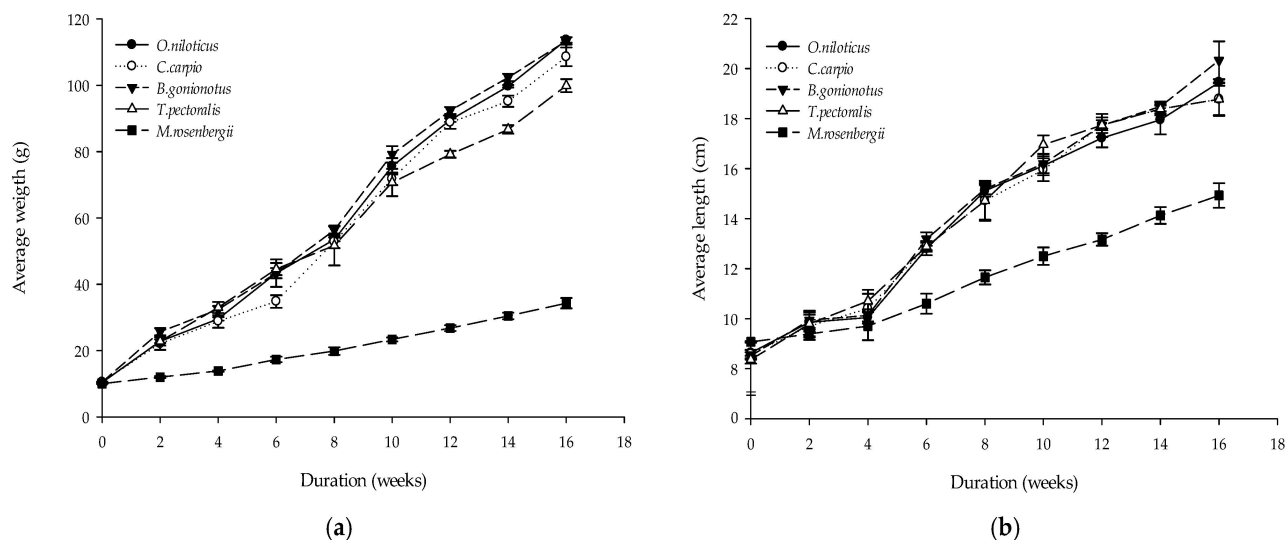


Figure 2 Growth of the stocked aquatic animals in the rice field after 120 days of experiment. (a) Growth in weight (g); (b) growth in length (cm total length) (Adopted from Li et al., 2022)

6.2 Ecological green farming model of rice-shrimp symbiosis in Sichuan

The ecological green farming model of rice-shrimp symbiosis enables rice fields to provide natural bait and habitat for freshwater lobsters, while freshwater lobsters can remove pests from rice fields. Their excrement can also become fertilizer for farmland, promoting the growth of organic and pollution-free rice, and ultimately forming a win-win situation of "raising shrimp in rice fields and raising rice with shrimp" ecological cycle (Kaewpuangdee et al., 2024).

Raising three crops a year, one mu of rice field produces 400 kilograms of crayfish and one mu of rice, with an income of 10 000 yuan. The "3411" rice-shrimp symbiosis and "double rice and double shrimp" farming model in Xuantan Town, Lu County, Luzhou City, Sichuan Province, allows people to taste the joy of a good harvest. "Double rice" means one season of rice plus one season of regenerated rice, and "double shrimp" means feeding big-headed shrimp in May after the first season of rice seedlings are planted, and raising shrimp from September to November, and then raising crayfish from November to April of the following year. In this way, after the rice fields are fully, efficiently and safely utilized, the average net income per mu can reach up to 13,000 yuan. Rice-shrimp farming mainly utilizes the temporal and spatial differences in the growth of rice and lobsters to carry out green cycle operations in a paddy field. Lobsters "weed, loosen the soil, and increase fertilizer" for rice fields, and rice fields "supply bait, shade, and avoid harm" for lobsters. This model of "one water for two uses, one field for two harvests, and win-win for grain and shrimp" not only improves the output efficiency of the land, but also realizes a virtuous cycle of ecological breeding.

6.3 Summary of comparative trials and extension potential

Comparative experiments conducted in many places have shown that integrated farming methods such as rice-fish and rice-shrimp are better than traditional single rice farming in terms of yield and rice quality. This type of co-farming model can significantly increase rice yields and improve rice quality, especially in subtropical areas. In these systems, farmers often use both organic and inorganic fertilizers. This combination can further improve rice quality and make this farming method a good choice for sustainable agriculture. This model has great prospects for promotion. It can not only improve food security, but also promote green development of agriculture. At the same time, farmers' income can also increase, and the economic benefits are also considerable (Hu et al., 2016; Li et al., 2022).

7 Concluding Remarks

The rice-fish system can help improve the quality of rice in many ways. It can make the nutrient cycle in the soil smoother, it can also allow more different plants and animals to appear in the fields, and it can reduce pests and diseases. These aspects work together to improve the overall quality of rice. Raising aquatic animals such as fish in the system helps nutrient circulation and reduces the use of pesticides and fertilizers. This method not only makes the rice higher in protein, but also makes the rice taste and look better. In addition, the ecological environment in the field is also healthier, which has a positive impact on the nutrition and appearance of rice.

Another important significance of the rice-fish system is that it can improve the sustainability of agriculture and contribute to food security. Studies have found that this system can not only increase rice production, but also increase farmers' income. For small farmers, this is a good method worth promoting. However, there will be some problems in the process of promotion. For example, some places have incomplete infrastructure and some farmers have not mastered the relevant technology. Some people are also affected by the difficulty of obtaining loans and land, which affects the actual operation. Moreover, natural conditions vary greatly from place to place, so when promoting the system, adjustments need to be made according to actual conditions, which also makes the promotion work more complicated.

Future research can focus on improving the design and management of this system. Researchers need to find ways to improve the operating efficiency of the system and adapt it to the environmental conditions of different regions. For example, some ecological engineering technologies can be developed to help nutrient circulation and control pests and diseases. You can also try to raise other types of aquatic animals or use more organic fertilizers, which may further improve the yield and quality of rice. It is also necessary to strengthen technical training, provide policy support, and help farmers solve practical difficulties. Researchers, policymakers and farmers should communicate and cooperate more, so that this system can be promoted and play a greater role in improving rice quality and promoting green agricultural development.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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