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Feasibility analysis of rice-crayfish farming in Hainan province based on its development trend in Hubei province over the past 10 years

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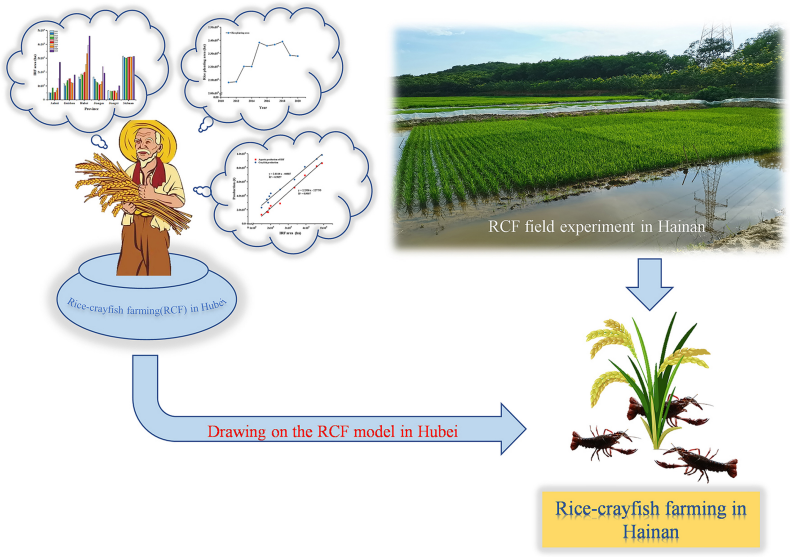
In Brief

This paper systematically analyzes the feasibility of developing RCF in Hainan Province by investigating the changes in RCF development in Hubei Province in recent years, combined with the current state of rice production and RCF trial data in Hainan Province to provide theoretical support for the development of RCF in Hainan Province.

Graphical abstract



Highlights

- Using abandoned land to develop RCF contributes to the total rice production of Hainan Province
- The nitrogen partial factor productivity (NPFP) in the early- and late-season of RCF are significantly higher than those of the RM
- RCF is suitable for promotion in Hainan Province and it can generate large economic benefits

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Feasibility analysis of rice-crayfish farming in Hainan province based on its development trend in Hubei province over the past 10 years

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Abstract

In the face of the current popular crayfish food culture, as well as the strong development trend of rice-crayfish farming (RCF), how to exploit their unique advantages to develop the RCF model is a direction of agricultural development in Hainan province that deserves attention. In this paper, we systematically analyze the feasibility of developing RCF in Hainan province by investigating the changes in RCF development in Hubei province in recent years, combined with the current state of rice production and RCF trial data in Hainan province. The results show that: 1) Using abandoned land to develop RCF contributes to the total rice production of Hainan province. The rice yield of RCF in the late-season is 16.30% higher than that of rice monoculture (RM), but the rice yield of RCF is severely affected by the proportion of culture ditch. 2) Compared to RM, the RCF model can reduce the application of N fertilizer to a certain extent. The nitrogen partial factor productivity (NPFP) in the early- and late-season of RCF are 32.34% and 74.43% higher than those of the RM, respectively. 3) In Hubei, the RCF model has promoted the expansion of rice cultivation area. Therefore, introducing the RCF model in Hainan can help increase the area of the rice cultivation and land utilization while reducing the abandonment of arable land. 4) Drawing on the RCF model in Hubei, Hainan would expect to gain remarkable economic benefits, since anti-seasonal RCF has huge market prospects.

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INTRODUCTION

Continuous reduction in the amount of arable land per capita, the gradually increasing constraints of resources and the environment, and the increasing difficulty of ensuring food security and increasing farmers' income are threatening agricultural development in China[1–3]. With these challenges, it is an inevitable trend to rethink traditional agricultural systems and to develop modern ecological agriculture, thus maintaining the stability of agroecosystems[4]. Rice-crayfish farming (RCF) is one of the integrated rice-animal farming models, which has been considered as a sustainable form of ecological- and circular-agriculture in the past decades, because it produces carbohydrate and protein products using few chemical inputs, and it protects the environment and biodiversity of paddy fields and maximizes the utilization of land and water resources[5–9].

Rice-crayfish (*Procambarus clarkii*) farming has become another 'new favorite' of modern ecological agriculture after rice-fish farming. RCF is an artificial ecosystem centered on rice cultivation, and supplemented by crayfish farming. The interaction between rice and crayfish not only helps to reduce the application of chemical fertilizers and pesticides, but also has the characteristics of increasing food, conserving land, fertilizer and labor[10]. In Hubei, this model fully utilizes the shallow water environment and slack winter season of paddy fields, and organically combines cultivation and aquaculture to achieve the goal of double harvesting rice and crayfish[11]. Because of the strong adaptability, fertility, and return on investment in crayfish farming[12,13], the RCF in Hubei has been able to develop rapidly. In recent years, RCF has been extensively promoted in Anhui, Hunan, Jiangsu, Zhejiang, and other provinces in the middle and lower reaches of the Yangtze River in China[14].

Hainan province has distinct climatic and geographical conditions[15], and is the best potential area for multi-season rice cultivation in China[16]. However, due to market demand from mainland China and relatively low cultivation income for rice, Hainan province has vigorously developed winter melon and vegetable farming in the past two decades, which has resulted in a year-on-year decline in the rice cultivation area. According to reports, the amount of rice sown in Hainan province in 2020 is at an all-time low, which has significantly reduced the incentive for farmers to plant rice due to the pronounced price difference compared to vegetables. Especially, in the rainy season from May to October, most of the arable land is fallow, it not only wastes the productivity of arable land, but also loses the opportunity for drought-water rotation, which could help to improve the soil quality and reduce the pesticide use in the vegetable planting season[17]. Therefore, how to increase farmers' income while simultaneously reactivating the initiative for farmers to cultivate rice is a current issue that needs to be tackled.

As the RCF model and crayfish food culture are accepted by rice farmers and consumers in mainland China, temporal lack of crayfish supply gradually emerges. Due to the impact of

climatic conditions, the market period of adult crayfish is relatively concentrated and short, the development of the crayfish post-production processing and refrigeration industry[18], as well as crayfish farming in different ecological regions[19] has drawn much attention, which is crucial to avoid shortages in the supply chain of the crayfish market. However, Hainan province has preferable temperature and light resources, as well as the climatic conditions, which are just needed by RCF and traditional crayfish farming. Therefore, in this context, the development of RCF in Hainan is worthy of expecting, especially since developing anti-seasonal RCF has incalculable market potential. In this regard, this paper analyzed the feasibility and potential of developing RCF in Hainan province by studying the historical changes in RCF development in Hubei province, and rice planting situation in Hainan province, as well as the field experiment estimation.

MATERIALS AND METHODS

Statistical yearbook sources

Access to data and information was through the Hubei Rural Statistical Yearbook, the China Statistical Yearbook, the Hubei Statistical Yearbook, the Hainan Statistical Yearbook, the China Fishery Statistical Yearbook and the 2020 China Crayfish Industry Development Report.

Site description and experimentation

The field experiment was conducted in the early- and late-season of 2021, and the experimental site was located in Guangji Village, Nanbao Town, Lingao County, Hainan province, China (19°38′ N, 109°37′ E), with an average temperature of 26.8 °C and total rainfall of 1,412.82 mm during the experiment.

The experimental rice cultivar was Yexiangyoulisi, and two treatments were established: rice-monoculture and rice-crayfish co-culture, with four replications for each treatment. A circular farming ditch was employed in the rice-crayfish co-culture, with a percentage of ditch area/total field area of 19.23% (the experimental plots were small, only 1,560 m^2). The experiment was conducted with direct-seeded rice in early April, and juvenile crayfish were released at a rate of 1,500 kg·ha^{-1} at the end of May, followed by the daily feeding and gradual harvesting of adult crayfish and rice in late July. The late-season rice planting was carried out in early August, and the late-season was all rice monoculture. Early- and late-season rice monoculture trial plots were fertilized with 120 kg·ha^{-1} of nitrogen (N), 60 kg·ha^{-1} of phosphorus (P_2O_5), and 100 kg·ha^{-1} of potassium (K_2O) in the early- and late-season, while rice-crayfish co-culture trial plots were fertilized with 80 kg·ha^{-1} of nitrogen (N), 60 kg·ha^{-1} of phosphorus (P_2O_5), 100 kg·ha^{-1} of potassium (K_2O) in both seasons.

Grain yield (Y, kg·ha^{-1}): during the rice maturity period, rice samples were taken from a 3 m^2 area in each plot, threshed, and air-dried after harvesting, and the final yield was calculated with a moisture content of 14%.

Nitrogen partial factor productivity (NPFP, kg·kg^{-1}): NPFP = GY/NF, GY is the grain yield obtained after nitrogen application, and NF is the input amount of nitrogen fertilizer.

Data processing and analysis

Origin2018, Microsoft Excel 2019, and SPSS 25.0 statistical analysis software were used for data processing and statistical analysis, and the one-way ANOVA method was used for significance analysis.

RESULTS AND ANALYSIS

Statistical data analysis

Changes in IRF development in Hubei province over the past 10 years

Integrated rice-animal farming (IRF) models were mainly distributed in the Yangtze River Basin in China. The areas of IRF in Anhui, Guizhou, Hubei, Jiangsu, Jiangxi, and Sichuan provinces were 5.1×10^4, 1.16×10^5, 1.63×10^5, 1.64×10^5, 6.6×10^4, and 3.14×10^5 ha, respectively. With the encouragement and support from national policies and market stimulus, the IRF industry in the last decade has developed rapidly. Sichuan province still maintains a high level of development with an IRF area of 3.13×10^5 ha in 2019, the IRF in Hubei province has increased annually since 2010 to 2019, and its extension area reached 4.6×10^5 ha in 2019, which continuously surpass Sichuan and other provinces since 2017, while the other provinces had the corresponding increase in 2019, with IRF areas of 2.72×10^5, 1.79×10^5, 1.92×10^5, and 1.01×10^5 ha in Anhui, Guizhou, Jiangsu, and Jiangxi provinces, respectively (Fig. 1).

In addition, rice planting area constrains the development of IRF, the proportion of IRF area to total rice planting area in 2019 was 20.11%, 8.80%, 10.84%, 3.02%, 20.11%, 8.12%, 16.73%, 26.98%, and 11.57% in Hubei, Jiangsu, Anhui, Jiangxi, Hunan, Sichuan, Guizhou, and Yunnan, respectively, the IRF area in Hubei province was only slightly lower than that in Guizhou province and much higher than those in other provinces in China (Table 1).

The development of rice cultivation and RCF in Hubei province

In the past decade, the total rice planting area in Hubei province has witnessed a relatively significant growth. The most obvious growth is from 2.09 million ha in 2012 to 2.38 million ha in 2015, increasing the rice planting area by about 3.0×10^5 ha. From 2015 to 2018, the rice planting area changed relatively smoothly, basically maintaining between 2.36–2.39

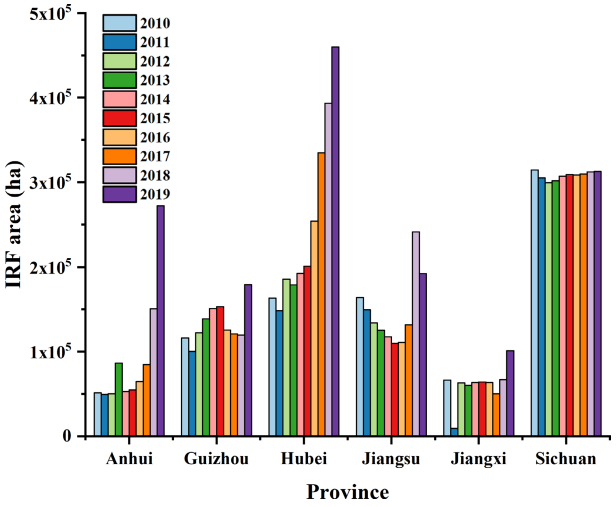

Fig. 1 Development tendency of IRF in eight provinces over the past 10 years (data from the China Fishery Statistical Yearbook (2011–2020)).

Table 1. IRF area/rice planting area in eight provinces in 2019.

Province	Rice planting area (ha)	IRF area (ha)	Proportion of IRF area to rice planting area (%)
Jiangsu	2.18×10^6	1.92×10^5	8.80
Anhui	2.51×10^6	2.72×10^5	10.84
Jiangxi	3.35×10^6	1.01×10^5	3.02
Hubei	2.29×10^6	4.60×10^5	20.11
Hunan	3.86×10^6	3.13×10^5	8.12
Sichuan	1.87×10^6	3.13×10^5	16.73
Guizhou	6.65×10^5	1.79×10^5	26.98
Yunnan	8.42×10^5	9.74×10^4	11.57

million ha, whereas the rice planting area decreased by about 1.0×10^5 ha to 2.28 million ha in Hubei province from 2018 to 2020. In general, the rice planting area in Hubei province increased by about 2.0×10^5 ha from 2010 to 2020 (Fig. 2).

Crayfish production in 2011 was 2.3×10^5 t, which increased 4× by 2020. During this period, aquatic production of IRF in Hubei also showed a sharply increasing trend, from 1.3×10^5 t in 2011 to 8.6×10^5 t in 2020 (Fig. 3). The crayfish production and aquatic production of IRF from 2011 to 2020 increased by 7.5×10^5 and 7.3×10^5 t, respectively. The growth value of crayfish production is similar to that of IRF, which indicated that the development of RCF model had dominated in the past 10 years in Hubei province, and the crayfish production increase from RCF contributed more than 100% to the increase of total aquatic production in IRF.

Changes in the rice cultivation industry in Hainan province in past 10 years

The total crop planting area of Hainan province showed a decreasing trend from 2010 to 2020, with the total crop planting area in Hainan province decreasing from 7.8×10^5 ha in 2010 to 6.9×10^5 ha in 2020, with a decline of approximately 11.6%. The rice planting area is also annually decreasing in the same period, with 2.3×10^5 ha of the rice planting area in 2020, which has decreased by 28.03% compared to 2010 (Fig. 4).

Field trials analysis of RCF in Hainan

Grain yield

The rice yields of rice monoculture (RM) and RCF (including or excluding culture ditch) in the early-season are 7.74, 6.83 and 5.51 t·ha^{-1}. The rice yields of RCF (excluding culture ditch) and RCF (including culture ditches) are 11.76% and 28.81% lower than that of RM with significant difference, respectively. The rice yields of RM and RCF's field (including or excluding culture ditch) in the late-season are 3.45, 4.01 and 3.24 t·ha^{-1}, the rice yield of RCF's field (excluding culture ditch) is 16.30% higher than that of RM with a significant difference, the rice yield of RCF's field (including culture ditch) is 6.07% lower than that of RM with no significant difference (Table 2).

Nitrogen partial factor productivity

Compared with RM, N fertilizer application is reduced by one-third in RCF in both the early- and late-season. The nitrogen partial factor productivity (NPFP) of RM and RCF (including or excluding culture ditch) in the early-season are 64.47, 85.32 and 68.92 kg·kg^{-1}, respectively, the NPFP of RCF (excluding culture ditch) is significantly higher than that of RM, the NPFP of RCF (including or excluding culture ditch) increased by 6.90% and 32.34%, respectively, compared with that of RM. The NPFP of RM and RCF's field (including or

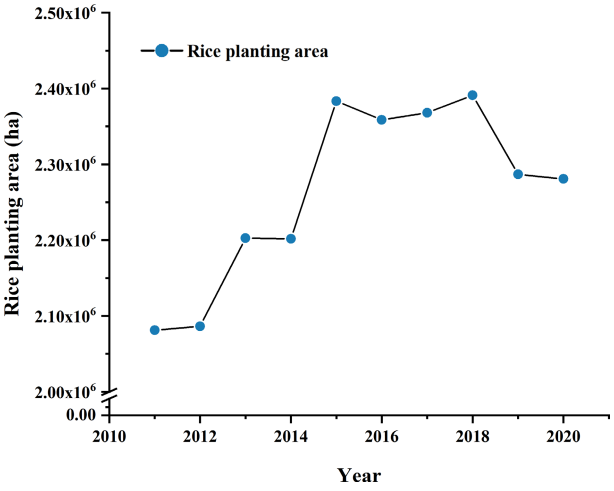

Fig. 2 Change trend of rice planting area in Hubei province over the past 10 years (data from the Hubei Statistical Yearbook (2011-2020)).

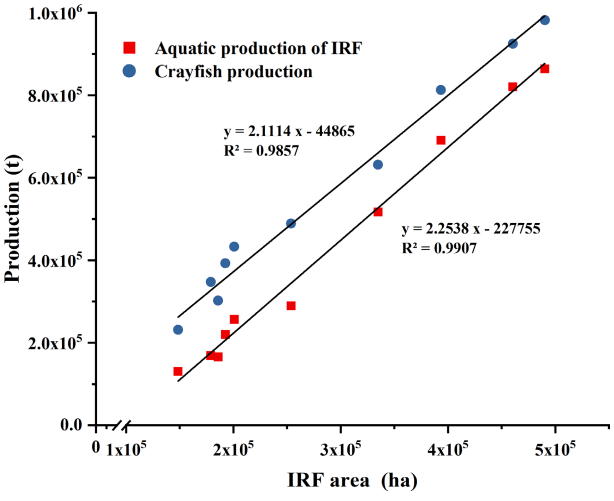

Fig. 3 Relationship between total crayfish production and aquatic production of IRF in Hubei province over the past 10 years (data from the Hubei Rural Statistical Yearbook and the China Fishery Statistical Yearbook (2011-2020)).

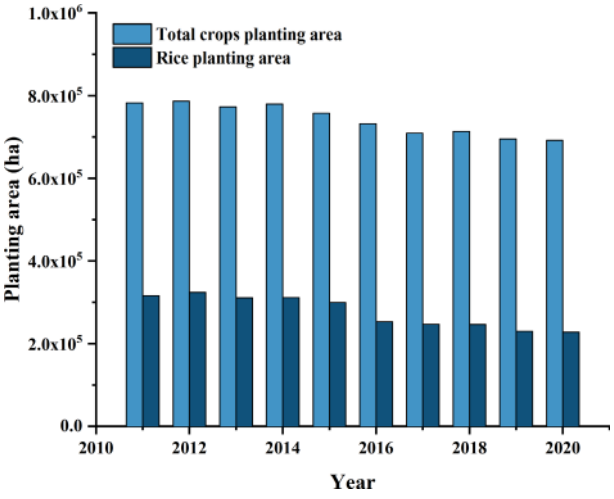

Fig. 4 Change trend of rice planting area in Hainan province over the past 10 years (data from the Hainan Statistical Yearbook (2011-2020)).

Table 2. Comparison of grain yield in field trials.

Seasons	Grain yield (t·ha^{-1})		
	RM	RCF (excluding culture ditch)	RCF (including culture ditch)
Early-season	7.74 a	6.83 b	5.51 b
Late-season	3.45 b	4.01 a	3.24 b

Within a row for each season, means followed by the different letters are significantly different from each other, while the means followed by the same letter are not, according to LSD (0.05).

excluding culture ditch) in the late-season are 28.74, 40.49, 50.13 kg·kg^{-1}, The NPFP of RCF's field (including or excluding culture ditch) in the late-season increased by 40.88% and 74.43%, respectively, compared with that of RM (Table 3).

Economic benefits

The economic income generated by RM and RCF in the early-season is 23208.42 and 91539.73 CNY·ha^{-1}, respectively, and the economic income of RCF was about four times higher than that of traditional RM. The economic income generated by RM and RCF's field in the late-season is 10,345.68 and 9,718.02 CNY·ha^{-1}, respectively, and the return generated by rice planting in RCF's field in the late-season reduced by 6.07% compared to RM (Table 4). Overall, the RCF-RM model increased the annual economic return three times more than the RM-RM model, with higher returns obtained from crayfish farming.

DISCUSSION

Influence of RCF on rice yield

From the rice yield results, it can be found that the rice yield of RCF (excluding culture ditch) was similar to that in RM in the early season, and the rice yield of RCF field (excluding culture ditch) was significantly higher than that in RM in the late-season. This indicates that RCF has a significant impact on rice yield and contributed positively to increase rice yield. The probable reason is that a certain amount of fertility generated by crayfish feeding and the physiological metabolic activity of crayfish in RCF avoids the phenomenon of fertility shortage in the later stages of rice growth, stabilizes the rice yield in the early season, which also plays a role in the improvement of rice yield in the late-season. Peng et al. also concluded that long-term application of the RCF model can significantly increase rice yield because long-term RCF can improve soil basal fertility[20].

In addition, the establishment of the culture ditch occupies a part area of the paddy field. To ensure the stability of grain yield, and to avoid the phenomenon of abandoning rice for crayfish or emphasizing crayfish over rice, the state stipulates the size of the culture ditch in the RCF, and the area of ditch/total paddy field should not exceed 10%[21]. Due to the paddy field in this experiment having a small size, the excavated culture ditch accounted for a higher percentage, about 19.36% of the total area of the paddy field. If the rice yield of the experimental RCF is calculated with the standard ditch proportion of 10%: the rice yield of the RCF in the early-season is 13.56% lower than that of the RM, whereas the rice yield of the RCF field in the late-season is 4.67% higher than that of the RM.

Table 3. Comparison of NPFP in field trials.

Seasons	NPFP (kg·kg^{-1})		
	RM	RCF (excluding culture ditch)	RCF (including culture ditch)
Early-season	64.47 b	85.32 a	68.92 b
Late-season	28.74 c	50.13 a	40.49 b

Within a row for each season, means followed by the different letters are significantly different from each other, while the means followed by the same letter are not, according to LSD (0.05).

Table 4. Economic benefit analysis of field trials.

Seasons	Economic benefits (CNY·ha^{-1})	
	RM	RCF (including culture ditch)
Early-season	23,208.42 b	91,539.73 a
Late-season	10,345.68 b	9,718.02 b

Within a row for each season, means followed by the different letters are significantly different from each other, while the means followed by the same letter are not, according to LSD (0.05). Note: rice price was 3 CNY·kg^{-1}, crayfish price was 50 CNY·kg^{-1}.

RCF helps to improve the efficient utilization of nitrogen fertilizer

Efficient nitrogen utilization is a long-standing and unresolved problem since the development of agriculture. Excessive or insufficient application of nitrogen fertilizer can affect the stability of rice production[22], and to some extent, cause environmental pollution. However, it was found that RCF can reduce the nitrogen fertilizer input during rice cultivation in the case of ensuring a stable rice production[23]. From the data of this experiment, the NPFP of RCF in both seasons of the experiments was significantly higher than that of RM, indicating that RCF helped to improve nitrogen fertilizer utilization and reduce nitrogen fertilizer application significantly. Meanwhile, the co-cultured effect of rice and crayfish also effectively avoided the problem of farming wastewater pollution faced by crayfish monoculture.

RCF helps to restore arable land in Hainan province

Since the mid-1950s, the total arable land in China has been declining[24], mainly due to the large amount of arable land occupied by construction land, the critical contamination of arable land with heavy metals and pesticide residues, as well as soil erosion and soil degradation, which resulted in the abandonment of arable land[25]. However, in the face of these problems, adhering to the red line of 120 million ha of arable land has become an urgent issue to be confronted by the current agricultural development[26].

In 2017, the General Office of the Hainan Provincial Government issued the 'Implementation Plan for Restoring Production on Abandoned Land in Hainan province' (www.gov.cn/xinwen/2017-11/05/content_5237360.htm). The plan was to complete the task of restoring production on 16 × 10^4 ha of abandoned land in the province in three years, starting from 2017. However, there are still large areas of abandoned land that have not yet been restored for use, and even the phenomenon of restored land has been re-abandoned. According to the Hainan statistical yearbook in 2021, the total area of arable land resources in Hainan province is 7.23 × 10^5 ha, and the acreage of commonly used arable land is 4.36 × 10^5 ha, accounting for 60.3% of the total area of arable land resources, while the rest of the arable land is in the condition of uncultivated or abandoned all year round. For this situation,

the rational development and innovative utilization of arable land resources is an effective measure to protect the reduction of arable land[27]. Ni et al. claimed that the development of the RCF model in Hubei could effectively reduce the area of abandoned arable land and improve the utilization rate of cultivated land[28]. Combined with the data from this experiment, we concluded that the development of RCF on abandoned arable land could have effectively increased the total rice production and economy of Hainan province while contributing to the restoration and conservation of cropland in Hainan province. In addition, studies on the salinity tolerance of crayfish showed that crayfish have good tolerance to salinity, and it is feasible to culture crayfish in brackish water with low salinity[29]. And Hainan province has 1.06×10^5 ha of coastal mudflats, so the future development of seawater RCF will have great market prospects.

The economic growth potential of developing the RCF in Hainan province

The 2020 China Crayfish Industry Development Report shows that the total national crayfish farming output in 2019 was about 2.06×10^6 t, with an industry output value of around 71 billion CNY. The production of crayfish farming in Hubei province was about 9.25×10^5 t, accounting for 44.27% of the total national crayfish production. Among them, the production of crayfish from the RCF model in Hubei in 2019 was about 7.89×10^5 t, which was 85.3% of the province's crayfish production. It was estimated that the output value of crayfish farming in Hubei province was about 31.4 billion CNY, which is in the industry's leading position.

However, to improve productivity and farmers' living standards, as well as to alleviate the backwardness of agricultural productivity, the agricultural development of Hainan province urgently needs a comprehensive transformation of the agriculture structure. The RCF developing with higher revenue returns can solve the current problems faced by agricultural development in Hainan province. It is assumed that Hainan province will develop RCF on abandoned arable land. This would not only decrease the area of abandoned arable land but also promote the increase in rice production and the economy in the province. With an area of 2.87×10^5 ha of non-commonly used arable land resources, for example, combined with field trial data, it is estimated that the development of the RCF model in Hainan province will add more than 2.6 million t of grain on top of the original rice production, and the annual revenue from grain production alone can increase by about 7.9 billion CNY, and studies have shown that the quality of rice under RCF is better than that of conventional rice[30–32], and the corresponding rice price is higher than before, results to the total returns of rice will increase accordingly. On this basis, it is further estimated that the economic benefits of RCF in just one season can reach more than 29 billion CNY, and if the RCF-RM model is adopted for development, it could reach about 32 billion CNY for the whole year. Additionally, the Yangtze River basin has a concentrated crayfish marketing period from May to August each year, after which crayfish production declines significantly. The future agricultural economic income of Hainan province will grow exponentially if the province can take advantage of its unique temperature and light resources for anti-seasonal crayfish farming to meet the demand gap in the mainland crayfish market.

SUGGESTIONS FOR THE FUTURE DEVELOPMENT OF RCF IN THE HAINAN PROVINCE

Innovative RCF technology, development of RCF model according to local conditions

Hainan province has huge potential for the development of rice-crayfish farming (RCF), but due to differences in climatic conditions, there are still many specific details to be optimized in order to develop RCF, such as changes in temperature that may lead to differences in fertility cycles of crayfish, and changes in the regulation of feed requirements, thus more experiments are needed to improve the operational protocols of rice-crayfish farming applicable to tropical regions.

Reasonable planning of land to create an RCF industry cluster

To ensure the stability and growth of rice production, the RCF model needs to be promoted and developed in large areas of farmland, thus it is essential to rational plan the land for RCF. In addition, RCF is a 'one-stop' production model, which requires massive land costs for seedling, breeding, fishing, subsequent transportation, and processing. Meanwhile, the government needs to vigorously promote the development of small and medium-sized agricultural cooperatives and the formation of large RCF enterprises while deriving more RCF-related industries and forming RCF-focused clusters, which can preferably improve the capacity and efficiency of RCF and promote the development of the core economy of crayfish.

Strengthen the standardized management to promote the establishment of rice and crayfish brands

With the improvement of social and cultural levels, people are increasingly concerned about a healthy diet and lifestyle. However, green, ecological, healthy, and efficient development is the core intention of the RCF model. We need to strengthen the standardized management of the RCF model, to avoid the use of high-risk, high-residue pesticides, and heavy metal hazards to achieve this purpose. Meanwhile, we need to promote the formation of rice and crayfish brand effect in line with the characteristics of Hainan to increase the total economic output value.

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Conflict of interest

The authors declare that they have no conflict of interest.

Dates

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