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REVIEW

Advancing hybrid rice cultivation in Indonesia's tidal swamp areas: Challenges and innovations

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ABSTRACT

Tidal swamp lands offer potential for expanding rice cultivation, but developing hybrid rice (*Oryza sativa* L.) in these areas faces significant challenges. Key obstacles include seed availability, fertilizer requirements, water management infrastructure, capital constraints, farmers' technical skills, pest and disease pressures, consumer preferences, and institutional complexities. Addressing these challenges requires technological interventions and institutional support. Proposed technological solutions cover variety selection, water management, land preparation, seedling practices, amelioration techniques, transplanting methods, fertilization strategies, and pest and disease control measures. These solutions aim to overcome limited seed availability, nutrient deficiencies, suboptimal water management, and pest infestations, maximizing hybrid rice productivity in tidal swamp areas. Institutional strengthening is crucial to tackle systemic barriers like ineffective farmer associations, inadequate extension services, and limited market access. Collaborative efforts involving government agencies, research institutions, farmer groups, and market stakeholders are essential to unlock the full potential of hybrid rice cultivation in tidal swamp lands. By addressing these challenges and implementing targeted interventions, Indonesia can enhance its production sustainably, contributing to national food security and agricultural development goals in line with its vision to become a global food granary by 2045. The development of hybrid rice in swamp areas requires in-depth, on-site research to identify suitable varieties, taking into account soil fertility, hydrological conditions, and seasonal variations. By utilizing local or well-adapted genetic resources, it is possible to ensure the timely and cost-effective production of seeds in large quantities.

Key words: Development, hybrid rice, *Oryza sativa*, technology, tidal swamp land, wetland.

INTRODUCTION

The demand for rice (*Oryza sativa* L.) in Indonesia is steadily increasing, driven by population growth, rising energy needs of individuals, and the Indonesian government's commitment to becoming a global food granary by 2045 (Sutardi et al., 2022). This growing demand is further fueled by the reliance of a large portion of the Indonesian population on it as their primary source of carbohydrates, along with low consumption efficiency.

Land is a critical factor in the rice production system. In Indonesia, the capacity for its production is affected by various factors, including land use conversion, availability of arable land, reduction in cultivated areas, competition for non-paddy land use, and soil fertility degradation. Additional challenges include a decreasing number of farmers, declining interest in agriculture among the youth, production disruptions, lack of agricultural spatial planning, and suboptimal implementation of production technologies.

Issues related to land availability for rice production can be addressed by utilizing tidal swamp land. Indonesia has an estimated 2.80 million hectares of tidal swamp land suitable for its cultivation, with 2.63 million hectares of mineral soil and 0.82 million hectares of peat soil (Sari et al., 2023). However, both soil types have limitations as growing mediums, including water dynamics (Sulaeman et al., 2022), saltwater intrusion (Nguyen et al., 2024), soil and water acidity (Abduh and Annisa, 2017), the presence of toxic substances, and low and variable soil fertility (Girsang and Raharjo, 2021; Sulaeman et al., 2024). Therefore, effective utilization of tidal swamp land for rice cultivation requires environmental improvements.

Rice productivity can also be enhanced through the cultivation of hybrid rice. It grown in irrigated paddy fields has shown a productivity increase of approximately 15%-20% compared to inbred (Satoto and Widyastuti, 2021). In tidal swamp areas, hybrid rice productivity can increase by 16%-36% (Gribaldi and Nurlaili, 2019). This paper aims to highlight the challenges and cultivation technologies associated with it, providing insights for its development in tidal swamp areas.

PROBLEMS IN DEVELOPING HYBRID RICE IN TIDAL SWAMP LAND

Hybrid rice is the F_1 generation resulting from the crossbreeding of a male sterile line (as the female parent) and a fertility restorer line (as the male parent) (Ashraf et al., 2024). Its performance is significantly influenced by the characteristics of both parent lines, with optimal results achieved when both parents exhibit high genetic diversity, enabling a heterotic combination.

Farmers have widely adopted hybrid rice cultivation due to its numerous advantages, including (a) higher yields, (b) enhanced vigor, making it more competitive against weeds, (c) greater root activity and photosynthesis, lower respiration intensity, and improved assimilate translocation, and (d) morphological benefits such as stronger roots, more tillers, more grains per panicle, and a heavier 1000-grain weight (Kartina et al., 2016; Satoto and Widyastuti, 2021). In other words, hybrid rice excels in physiological, morphological, vigor, and productivity aspects.

Although hybrid rice offers several advantages over inbred, its development faces significant challenges (Pervez et al., 2022). Farmers in tidal swamp areas often prefer planting local varieties due to their favorable taste, which aligns with the preferences of the local community (Mursyidin et al., 2017; Khairullah et al., 2021). Some of the key challenges in developing hybrid rice in these areas include (1) seed availability, (2) fertilizer requirements, (3) water management infrastructure, (4) access to capital, (5) farmers' skills, (6) pest and disease management, (7) consumer preferences, and (8) institutional issues.

Seed availability

Seeds are a critical factor for farmers aiming to achieve maximum production (Firdaus et al., 2020). Consequently, the availability of seeds is vital for the successful development of hybrid rice (Satoto and Widyastuti, 2021). Since its seeds can only be used for one planting season, they must be produced anew each season using complex technology that is not yet readily accessible to farmers.

Moreover, the seed production capacity for hybrid is significantly lower than that for inbred. While inbred seed producers can yield up to 6.0 t ha^{-1}, hybrid seed producers typically achieve only about 25% of that amount, with some cases yielding as little as 1.0 t ha^{-1} (Wang et al., 2018). Consequently, producing an equivalent amount of hybrid seeds requires 4-6 times more land compared to inbred. Additionally, hybrid seed production demands higher capital investment due to the need for more intensive care. This contributes to the high cost and deters many farmers from becoming seed producers.

The limited number of seed producers results in a constrained supply of hybrid seeds, with only a few private producers capable of producing up to 1000 tons per season (Dey et al., 2022). Overall, the production capacity of hybrid rice seeds in Indonesia is under 5000 tons per season. This limited capacity naturally restricts the scale of its cultivation, and the transportation of seeds to tidal swamp areas often encounters logistical challenges.

To address these issues, specific incentives are needed to encourage the development of seed production in tidal swamp areas.

The high targets for seed production are impeded by costly land rentals, high maintenance expenses, and low production capacity. As a result, producers often resort to producing B-grade quality hybrid rice seeds, which leads to reduced productivity (Vernooy et al., 2022).

Fertilizer needs

Hybrid rice is known to respond strongly to N fertilization (Jiang et al., 2015; Amanullah and Hidayatullah, 2016). The increase its productivity necessitates higher fertilizer inputs (Nagabovanalli Basavarajappa et al., 2021; Masganti et al., 2023). This requirement leads to elevated farming costs, particularly in tidal swamp areas where fertilizer availability is often a significant constraint. Not only do farmers face higher expenses, but fertilizers are also frequently unavailable when needed. As a result, farmers may use whatever fertilizers are available, both in terms of dosage and type, which can lead to suboptimal productivity.

Fertilizing hybrid rice plants involves the use of both inorganic and organic fertilizers. Research suggests that the addition of organic amendments can improve plant growth and enhance the productivity of it (Amanullah and Hidayatullah, 2016; Moe et al., 2017). This is particularly important because soil fertility and organic C levels are often low, especially when rice straw is not returned to the soil. To address these soil fertility issues, additional capital is required to purchase organic fertilizers from outside the cultivation area.

Water management infrastructure

Water management is a significant challenge in hybrid rice cultivation in tidal swamp areas (Paiman et al., 2020; Hairani et al., 2023; Sari et al., 2023). Effective water management is essential for successful its cultivation, as it ensures that water is available according to the plant's needs at each growth stage. Proper management is crucial for achieving optimal production.

In addition to satisfying the water needs of the plants, water management must also address several other factors. It should maintain aeration conditions for microorganisms (Kou et al., 2023), control soil chemical reactions and plant root development (Horel, 2024), regulate greenhouse gas emissions (Toma et al., 2019; Islam et al., 2020), enhance fertilizer efficiency (Wang et al., 2021), suppress weed growth (Kaya-Altop et al., 2019; Winkler et al., 2023), and wash away toxic substances (Rodríguez et al., 2014; Feng et al., 2020).

Field observations reveal that water management infrastructure in tidal swamp areas can be categorized into three types: (a) Areas without any water management infrastructure, (b) areas with infrastructure that is either not functioning optimally or not functioning at all, and (c) areas with functional water management infrastructure. However, the proportion of areas with fully functional infrastructure is estimated to be very low, around 5%-10%. Therefore, an inventory and characterization of the existing water management network are essential to determine the optimal steps for its optimization and revitalization (Mardiatno et al., 2023).

Optimization of the water management network can be achieved through several measures: (a) Using pumps, (b) constructing and utilizing long-term storage, (c) utilizing higher-quality water sources, and (d) strengthening the institutional capacity of Farmer Water User Associations. Revitalization efforts should focus on (1) normalizing channels and sluice gates and (2) installing control sluice gates. For the successful development of hybrid rice in tidal swamp areas, addressing water management infrastructure should be a top priority (Tirtalistyani et al., 2022).

Capital

Capital is a critical factor in the development of hybrid rice (Krishnamurti and Biru, 2019). The high costs, along with increased expenses for fertilization, amelioration, and maintenance, lead to greater capital requirements for its cultivation (Yan et al., 2022). The suboptimal performance of its technology can be attributed not only to the limited skills of farmers but also to their inability to apply productivity-enhancing technologies effectively. While farmers are aware of the benefits of recommended technologies, they often lack sufficient financial resources (Agussabti et al., 2022). Additionally, agricultural expenses, such as purchasing fertilizers, insecticides, and herbicides, frequently compete with family obligations like tuition fees. As a result, farmers may use whatever fertilizers are available based on their financial capacity. To improve hybrid rice productivity in tidal swamp areas, financial support from both local governments and the private sector is essential. This support should be provided gradually to prevent misuse (Um and Ridyanto, 2019). Furthermore, limited capital reduces farmers' working capacity, even when there is excess family labor. This can lead to the expansion of unproductive land, which may become a source of wildfires during the dry season and a breeding ground for rodents, ultimately reducing productivity.

Farmer's skill

The cultivation of hybrid rice is still relatively new for many farmers (Sivagnanam and Murugan, 2020), especially in tidal swamp areas. This lack of experience can result in farmers being unable to achieve higher yields compared to inbred. Therefore, extension services play a crucial role, and extension workers should be equipped with educational materials to effectively communicate with farmers (Sarma et al., 2022). Additionally, farmers often lack the new skills required for adapting to evolving agricultural environments (Dhillon and Moncur, 2023). To enhance farmers' skills, various activities can be implemented, including (1) demonstration plots and field meetings focused on hybrid rice cultivation technology, (2) study tours for farmers to regions that are established centers for its cultivation, and (3) technology meetings organized by Agricultural Extension Centers, involving competent researchers in it.

Pest and disease

The development of hybrid rice in tidal swamp areas is also hindered by pest and disease infestations. The less-than-ideal growing conditions increase the susceptibility to pests and diseases. The low yields in some regions are often attributed to infestations by brown planthoppers, stem rot, and bacterial leaf blight (Krishnamurti and Biru, 2019; Zheng et al., 2023). This issue leads to reduced farmer enthusiasm for hybrid rice cultivation, as its productivity does not significantly surpass that of inbred. To address this, the development of it should be supported by breeding programs aimed at producing cultivar resistant to major pests and diseases, particularly in areas not endemic to pests like brown planthoppers, tungro, and gall midge.

Effective pest control is essential in hybrid rice cultivation in tidal swamp areas. Major pests in these regions include rats, white stem borers, leaf folders, brown planthoppers, and rice bugs (Ikhsan and Oktavia, 2023). The primary diseases include blast, tungro, brown spot, brown streak, bacterial leaf blight, and leaf sheath blight.

Consumer preference

Milling plays a crucial role in determining rice quality and value (Lu et al., 2022). Hybrid rice often has a low milling recovery rate, which results in a lower selling price and diminishes farmers' interest in cultivating it. The selling price is primarily set by rice milling companies, which tends to disadvantage farmers. Additionally, some hybrid rice cultivars exhibit lower quality compared to the best inbred cultivars available in the market (Bao, 2019).

In Indonesia, rice preference typically leans towards a sticky texture, which ranges between sticky and loose, varying by region, area, and ethnicity. The texture is largely determined by its amylose content (Mohidem et al., 2022). Higher amylose content results in a firmer texture, while lower amylose content produces a softer texture. According to Setyowati and Kurniawati (2015), hybrid rice producers often focus on consumers in Java, where the preference for sticky rice is prevalent due to the island's larger population. In contrast, regions such as North Sumatra, West Sumatra, Riau, South Kalimantan, and West Kalimantan generally prefer rice with a firmer texture (Rina and Koesrini, 2018). Therefore, farmers in the area cross-breed local rice varieties with high-yield cultivars to preserve the desired texture of the rice. For instance, the *O. sativa* 'Margasari' is a hybrid between *O. sativa* vars. Siam Unus and Cisokan (Khairullah et al., 2024). This regional variation in preference contributes to farmers' lower interest in developing hybrid rice in tidal swamp areas.

Institutional issues

Institutional structure is a crucial component of the rice farming system, including in tidal swamp areas (Khumairoh et al., 2024). One notable shortcoming within this system is the Farmer Water User Associations (FWUA). Farmers often lack cohesion in planning and implementing efficient water use for rice cultivation. Even when plans are agreed upon, they are frequently not executed due to various factors. Additionally, farmers may lack skills in administrative management. To support the development of hybrid rice in tidal swamp areas, it is essential to strengthen the FWUA institutions by enhancing management skills among executives and increasing awareness among members (Safira et al., 2019).

Institutional support is equally crucial for seed producers (Bahtiar et al., 2021). To address the reliance on external seed supplies, it is essential to establish local seed producers. This can be achieved by empowering Farmer Group Associations, which will support the development of hybrid rice by ensuring a more reliable and self-sufficient seed supply (Wardana et al., 2023). Extension services are another key institution that needs capacity enhancement to effectively transfer knowledge to farmers. Addressing the inadequacy of supporting facilities demonstration plots is a priority. Extension workers should acquire new technology before farmers and demonstrate its performance through well-managed demonstration plots.

The development of hybrid rice in tidal swamp areas also requires robust support from marketing institutions. One common challenge is overproduction, which often results in low prices. Additionally, with its comparatively lower quality, necessitates more effort to market effectively (Hermawan et al., 2017). Markets are another essential institution for supporting the development of hybrid rice in tidal swamp areas. Many markets in these regions are regular, operating only on specific days, such as Wednesday markets that only function on Wednesdays. However, continuous markets are crucial for the sustained development of it. They provide farmers with a reliable outlet to sell their produce, which in turn encourages continued production and efforts to increase yields (Satoto and Widyastuti, 2021).

The development of hybrid rice in tidal swamp areas must also consider the availability of family labor. In regions with a crop index exceeding 100%, the use of agricultural machinery and equipment becomes essential. Key machinery includes soil processing tools such as two-wheel (TR-2) and four-wheel tractors (TR-4), planting tools (transplanters), and harvesting tools (combine harvesters). These tools are critical because soil processing, planting, and harvesting are time-consuming and often need to be performed simultaneously. In soil processing, 85% of farmers use TR-2 tractors due to their mobility, lower cost, suitability for smaller fields, and the farmers’ familiarity with operating them.

Farmers often prefer small combine harvesters due to their (1) easier mobility and operational ease, (2) lower risk of damage, and (3) better performance. Beyond choosing the appropriate type and size of machinery, optimization can be achieved by establishing procurement centers in each sub-district, based on their potential usage. Additionally, the availability of machinery workshops that provide spare parts and maintenance is crucial. Training for farmers and operators of Agricultural Machinery Service Businesses (AMSB) is also essential to enhance the efficiency of machinery use and to prevent breakdowns caused by inadequate troubleshooting knowledge among AMSB personnel.

Another critical institution in the development of hybrid rice in tidal swamp areas is agricultural supply shops. These shops are not only limited in number but also often unable to provide the full range of agricultural supplies needed by farmers. This limitation reduces the potential for its production. To address this, it is essential to strengthen farmer institutions such as Farmer Groups and Cooperatives by providing technical guidance on cultivation, processing, packaging, marketing, and professional management to enhance their self-reliance. Additionally, agricultural institutions such as extension services, supply shops, and funding sources need to be fortified to support the successful development of hybrid rice.

HYBRID RICE CULTIVATION TECHNOLOGY

The success of cultivating hybrid rice in tidal swamp areas heavily relies on technological support. Proper technology is essential, as neglecting the specific environmental needs of hybrid rice can result in lower productivity compared to inbred. Key components of hybrid rice production technology that are crucial for achieving maximum productivity include the following:

Cultivar selection

Similar to inbred rice, the productivity of hybrid in tidal swamp areas is significantly influenced by the selected cultivar (Paiman et al., 2020). Key considerations for its selection include (a) productivity, (b) consumer preferences, and (c) resistance to major pests and diseases (Krishnamurti and Biru, 2019). Table 1 lists several proposed hybrid rice cultivars with productivity exceeding 7.5 t ha^{-1}. Current hybrid rice cultivars for tidal swamp areas include *O. sativa* ‘Hipa-5 Cepa’ (Gribaldi and Nurlaili, 2019), ‘Supadio 56’, ‘Supadio 59’, ‘Mapan 02’, ‘Mapan 03’, ‘Sembada 626’ (Darsani et al., 2020), and ‘Intani 602’ (Sari et al., 2023), all of which have productivity above 6.0 t ha^{-1}. The resistance of these seven cultivars to major pests and diseases is also detailed in Table 1.

Table 1. Productivity and resistance of hybrid rice cultivars to major pests/diseases (Krishnamurti and Biru, 2019).

Cultivar	Productivity (t ha^{-1})	Resistance to major pests/diseases		
		Brown planthopper	Bacterial leaf blight	Blast
Hifa 12 SBU	7.70	Slightly-resistant	Slightly-resistant	Less-resistant
Hifa 18	7.80	Slightly-resistant	Slightly-resistant	Less-resistant
Hifa 19	7.80	Resistant	Less-resistant	Resistant
Hifa 9	8.10	Less-resistant	Slightly-resistant	Less-resistant
Hifa 14 SBU	8.40	Less-resistant	Less-resistant	Less-resistant
Hifa 21	8.99	Resistant	Resistant	Less-resistant
Hifa 20	9.54	Resistant	Resistant	Less-resistant

Those hybrid rice cultivars that suitable for tidal swamp area have adaptation to abiotic stress includes internal (tolerance) and external (avoidance) mechanisms. Internal tolerance mechanisms include metal detoxification through chelation/binding in the cytosol or compartmentalization to the vacuole. The vacuole is a cell organelle that occupies 80%-90% of the cell volume and functions as a central storage compartment for compounds. Excess Fe elements in plants are stored in the apoplast and vacuole. The concentration of cytosolic free Fe will be very low, but can increase to micromolar which indicates the efficiency of metal compartmentation in the vacuole. The Fe compartmentation has two functions, namely as a place to store toxic Fe and to carry it to the place where the Fe is synthesized. The number of Fe atoms that can be stored as organic complexes that form non-toxic compounds and in biologically available forms can reach 4500 atoms. In addition to vacuoles, other cell organelles that are the place of Fe compartmentation are chloroplasts, mitochondria, and vesicles (Soepandi, 2013).

Water management

Water management is crucial for providing an adequate quantity and quality of water throughout the various growth phases of hybrid rice. As a guideline, water should be drained as soon as the plants have developed 12 leaves. Drying or creating intermittent water conditions should be done with each fertilization to prevent prolonged waterlogging, which can minimize Fe toxicity (Ullah et al., 2023). Effective water management is also necessary in seedbeds to maintain proper moisture levels. In tidal swamp areas, the water management system is influenced by the type of water overflow, utilizing tides and gravity for water movement. Consequently, the design of the water management network must consider factors such as topography, hydrotopography, water sources, and seasonal variations. Table 2 outlines the types of water overflow and the corresponding water management systems in tidal swamp areas.

Table 2. Types of water overflow and water management systems for cultivating hybrid rice in tidal swamp land based on season (Nazemi et al., 2012; Noor, 2014).

Nr	Types of water overflow	Seasons and water management systems	
		Rainy Season	Dry Season
1	A	One way, stop lock in let	One way
2	B	One way	One way and dam over flow
3	C	Dam over flow	Dam over flow, water pump

Land preparation

A crucial aspect of hybrid rice cultivation is land preparation, which involves modifying the environment to create an optimal physical growing condition for the plants. Effective soil processing is essential to achieve thorough and good tillage (Abduh et al., 2022). In tidal swamp areas, a significant challenge is the presence of pyrite/sulfide (FeS_2) layers in relatively shallow soil layers (25-50 cm), particularly in acid sulfate soils. This pyrite layer can impact the land preparation process; therefore, land preparation should adhere to the principles of land resource conservation (Sulaeman et al., 2024).

Initial land processing is performed using a single plow with a working depth of 10-25 cm. It is important to avoid excessive depth to prevent reaching the pyrite layer, which can increase soil acidity. Soil processing should ideally be conducted when the land is flooded or in a reduced state to minimize the oxidation of pyrite. After initial processing, the soil is left for about a week before being reflooded to a depth of approximately 5 cm. Subsequently, to achieve thorough and effective tillage, a second soil processing is carried out using a rotary plow.

Cultivation system

Lesson learned from the Banjar tribe who cultivate rice in swamp area, they are capable to thrive local rice varieties by improving soil properties during the growing season. In this system, the cultivation schedule is tailored to the land's hydrological conditions, using local rice varieties. Key practices in Banjarese-local rice cultivation include land preparation with a *tajak* tool, organic matter management through the *tapulikampar* method, and maintaining flooded fields during rice growth stages. These practices help control iron solubility, regulate soil pH, and enhance nutrient availability in the soil (Fahmi et al., 2024).

Seedling

Seed quality is a crucial technological component that significantly impacts the growth and productivity of hybrid rice (Ma and Yuan, 2015). High-quality seeds contribute to better plant growth, more productive tillers, longer panicles, more grains per panicle, and heavier 1000-grain weight. The seed requirement per hectare for hybrid rice is lower than for inbred, ranging from 12-15 kg (Krishnamurti and Biru, 2019). Land preparation for seedbeds is done concurrently with the initial land preparation. The area required for seedbeds is about 4% of the planned planting area, which equates to 400 m^2 for a 1 ha planting area. Before sowing, seeds are soaked in a 3% salt solution (30 g table salt per liter of water) for 24 h, and any floating seeds are discarded. The soaked seeds are then drained for 48 h. Germinated seeds are evenly spread on the soil surface of the seedbeds using wet seeding. The seedbeds are lightly covered with soil or humus. To prevent waterlogging, drainage ditches, approximately 10 cm deep, are constructed around the seedbed plot. Fertilization is carried out with organic fertilizer and NPK fertilizer at rates of 2 kg m^2 and 10 g m^2, respectively (Abduh et al., 2022).

Amelioration

Two key nutrients often deficient in tidal swamp land are Ca and organic C (Abduh et al., 2022). Consequently, amelioration is essential for cultivating hybrid rice in these areas to improve soil quality and enhance productivity (Saputra and Sari, 2021). Amelioration can be achieved using lime at a dosage of 1500-3000 kg ha^{-1}, depending on the Ca availability in the soil and the type of water overflow. Organic fertilizers (Masganti et al., 2023) and biochar (Wang et al., 2022) are also effective for soil improvement. The common practice of not returning straw to the field results in a deficiency of organic C. To achieve high productivity, organic fertilization is required at a rate of 1500-3000 kg ha^{-1}, as detailed in Table 3 (Pandey et al., 2014; Amanullah and Hidayatullah, 2016), depending on the water overflow type.

Table 3. Recommendations for the type and dose of ameliorant in cultivating hybrid rice in tidal swamp land based on the type of water overflow.

Nr	Types of water overflow	Types and dosage of ameliorant (kg ha^{-1})			
		$CaCO_3$	(Ca, Mg) $(CO_3)_2$	Straw compost	Manure
1	A	1000-1500	1500-2000	1500-2000	1500-2000
2	B	1500-2000	2.000-3000	2000-2500	2000-2500
3	C	> 2000	> 3000	> 2.500	> 2500

Transplanting

Planting is performed using the brick-planting system with distances of 20 × 20, 22 × 22, or 25 × 25 cm, depending on soil fertility. Alternatively, the Jarwo planting system can be utilized, with configurations such as Jarwo 2:1 (10.0 × 20.0 or 12.5 × 25.0 cm), Jarwo 3:1 (10.0 × 20.0 or 12.5 × 25.0 cm), and Jarwo 4:1 (10.0 × 20.0 or 12.5 × 25.0 cm). However, Sari et al. (2023) recommend using a planting distance of 20 x 20 cm with the square planting system, or (20 × 40) × 10 cm with the Jarwo 2:1 system, as these configurations result in higher productivity.

The hybrid rice seedlings used are 10-21 d old after sowing. Two seedlings are planted in each hole according to the predetermined planting distance. One week after planting, thinning is performed, leaving only one plant per hole. Any seedlings that do not grow normally are replaced with the remaining available seedlings (Abduh et al., 2022).

Fertilization

Fertilization is essential for supporting the healthy growth and high productivity of hybrid rice. It can increase the number of productive tillers, elongate panicles, enhance the number of filled grains per panicle, and boost the weight of 1000 filled grains (Zhuang et al., 2022). The recommended fertilization schedule in tidal swamp areas is detailed in Table 4. Fertilization is performed in three stages: First, at 7-10 d after planting (DAP), where all NPK and SP-36 fertilizers, ¼ dose of urea, and ½ dose of KCl are applied. The second application occurs at 21 DAP with ½ dose of urea. The final fertilization takes place at 42 DAP, with ½ dose of KCl and ¼ dose of urea.

Table 4. Recommendations for fertilizing hybrid rice in tidal swamp land based on the type of water overflow.

Nr	Types of water overflow	Dosage of fertilizer (kg ha^{-1})			
		NPK	Urea	SP-36	KCl
1	A	250-300	250-300	100-150	100-150
2	B	300-350	300-350	150-200	150-200
3	C	350-400	350-400	200-250	200-250

Control of plant pest organisms

Plant pests are a significant concern in hybrid rice cultivation in tidal swamp areas, as they can drastically reduce production. According to Krishnamurti and Biru (2019), pest and disease infestations notably diminish the productivity and yield. Major pests in tidal swamp rice fields include rats, white stem borers, leaf folders, brown planthoppers, and water spiders. Key diseases affecting the crop are blast, tungro, brown spot, brown streaked spot, bacterial leaf blight, and leaf blight (Gnanamanickam, 2009). To sustain the productivity, an integrated pest management approach is essential (Hajjar et al., 2023).

Weed control in hybrid rice cultivation involves the use of pre-emergence herbicides and manual weeding performed twice. Rat pests are managed through baiting with rodenticides, trapping using ratels, and implementing a trap barrier system. Other major pests are controlled with insecticides, while major rice diseases are managed using fungicides (Ilham et al., 2023).

CONCLUSIONS

The development of hybrid rice in tidal swamp areas presents promising opportunities to enhance rice productivity in Indonesia. However, overcoming the challenges associated with seed availability, fertilizer needs, water management infrastructure, capital requirements, farmers' skills, pest and disease management, consumer preferences, and institutional issues is imperative. Technological solutions, including variety selection, optimized water management, proper land preparation, amelioration techniques, transplanting methods, fertilization strategies, and pest and disease control measures are essential for maximizing hybrid rice productivity in tidal swamp areas. Furthermore, strengthening institutional support, improving farmer skills through extension services, and addressing consumer preferences are critical for the successful development of hybrid rice in these challenging environments. Collaborative efforts between government agencies, research institutions, farmers, and other stakeholders are needed to address these challenges and unlock the full potential of hybrid rice cultivation in tidal swamp areas, contributing to the sustainable food security of Indonesia.

Author contribution

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