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Research Article

Efficacy of Various Disease Management Options and Evaluation of Farmers' Fields for Major Diseases of Rice in Sierra Leone

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Abstract

This study assessed the efficacy of various disease management options of rice and status of farmers' fields for major rice diseases of Sierra Leone. The field experiment was laid out in a randomized complete block design in three replicates at the School Agriculture and Food Sciences, Njala University, Njala, Southern Sierra Leone during the 2022 cropping season. For the on-farm study, a total of 90 farms were assessed in three districts (Kambia, Kenema and Moyamba) during the same year. At each farm, 30 plants were evaluated with 15 plants randomly selected along each diagonal. Findings revealed that treatments Mancozan 80WP and Copper hydroxide effective in reducing disease incidence and severity. Disease treatments significantly influenced grain yield and yield components, with Neem leaf extract, Neem seed powder, Mancozan, and Metarhizium enhancing panicle length, spikelet number, grain yield, and 1000-grain weight. Mancozan 80WP exhibited the highest grain yield, 1000-grain weight, grain number, and seed dry matter. The on-farm study revealed that the incidence and severity of leaf blast and bacteria leaf blight were high in Kambia, while Moyamba exhibited a higher proportion of moderately susceptible farms to yellow mottle virus disease and panicle blast. Findings indicate the potential of the tested treatments in improving rice production, disease management, and crop productivity. They provide valuable insights for the development of sustainable and eco-friendly disease management approaches, contributing to food security in Sierra Leone. Results also suggest that Participatory Rural Appraisal (PRA), participatory disease assessment and participatory plant breeding techniques should be explored to promote collaborations among stakeholders, researchers and scientists for development of new rice varieties with desired traits including resistance to major biotic constraints such as diseases and pests, while improving grain yield, and other desired key traits.

Keywords: *Rice, Disease infection, Management options, Geospatial analysis, Farmers' fields.*

Introduction

The cultivation of rice in Sub-Saharan Africa (SSA) dates back to the 12th century, but in the last two decades, rice production in the region has doubled (Zenna, *et al.*, 2017; Mutiga, *et al.*,2021). This increase is attributed to favorable government policies, expanded cultivation, and intensification. Additionally, improvements in rice cultivars, focusing on traits preferred by farmers and consumers, have contributed to this growth (Zenna, *et al.*, 2017; Mutiga, *et al.*, 2021). According to FAO (2020), of the total global rice production of 499.6 million ton in 2020, SSA contributed about 3%. Of the rice produced in SSA, more than 80% was from eight countries (Nigeria, Madagascar, Ivory Coast, Tanzania, Mali,

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Guinea, Sierra Leone and Senegal; with Nigeria and Madagascar accounting for one-third of the rice production in the subregion (FAO, 2020).

Rice is the main staple crop in Sierra Leone and provides 80% of its caloric intake (Vangahun, 2019). A steady increase in rice cultivation has occurred over the years, but not sufficient to meet basic requirement of demand, hence a deficit in the country's rice supply chain. Consumption of rice, however, exceeds production in the country. Sierra Leone produces 712,092 metric tons of rice while it consumes 1,094 million metric tons of rice annually (USDA, 2018).

Rice cultivation in Sierra Leone is primarily undertaken by smallholder farmers who produce barely enough for home consumption with little or none for the market across both upland and diverse lowland ecologies. Moreover, the country has long struggled to meet its local rice consumption demands. Between 1960 and 1975, there was a boost in rice production due to the expansion of cultivated land and, to some extent, an increase in yield. In 1975, Sierra Leone was reported to have achieved self-sufficiency in rice, with records indicating over 600,000 tons of paddy at the end of the 1970s (GOSL, 2018). During the 2004/05 cropping season 56 percent of the households cultivated less than 1 ha of farmland, while only 44 percent cultivated at least 1 ha. Rice field area per household ranged from 0.25 ha to 5.5 ha with an average of 1.06 ha (GOSL, 2018). The smallholder farmers in Sierra Leone are generally resource poor with only the hoe, axe and cutlass as the main implements, while labor is mainly supplied by family members thereby severely limiting their scale of production (GOSL, 2018).

Rice is attacked by several diseases, some of which cause serious economic losses, while others are of minor importance (MSU, 2001). The diseases are caused by various pathogens such as viruses, bacteria, fungi, nematodes (Safdar, *et al*., 1993). These pathogens may appear at any growth stage and or on part of the plant, including the seed, root system, foliage, stalk, leaf sheath, inflorescence and the grain (Government of Sindh Agriculture Department, 2004; Adur-Okello, *et al*., 2020). Sierra Leone, like other rice growing countries, has developed the adoption of disease resistant rice variety like NERICA. However, the impact of diseases on rice production has increased over time,this is because there are limitations in the usage of only resistant varieties to manage rice diseases. Most improved varieties exude appreciable resistance to a few major diseases that are the subject of intensive breeding (Youyong, 2006). Diseases have become more important in rice production, due to expanded acreage, prolonged re-cropping of fields and limited land for long rotations in most rice growing countries (MSU, 2001). According to Youyong (2006), diseases have been a major cause of yield loss and lower profits in rice production, with annual estimated yield and quality losses of 8-10% in rice growing countries. Rice diseases caused by fungi are among key biotic constraints that limit rice production in terms of both qualitative and quantitative losses (Nalley, *et al*., 2016; Law, *et al*., 2017). For instance, rice blast disease caused by *Pyricularia oryzae* (*Magnaporthe grisea*), which has been opined as the most significant disease, cause yield losses of up to 50% (Nalley, *et al*., 2016). This fungus infects rice at all growth stages, spanning from the seedling to reproductive stage, thereby causing severe damage to rice leaves. It can cause yield losses of up to 80% under favorable conditions (25–30 °C and 80–95% humidity) in susceptible rice cultivars (Kongcharoen, *et al*., 2020).

In Sierra Leone, pest and disease attacks are amongmajor factors limiting the production and high yield in rice. However, little is known about disease management options and current status of farmers' fields regardingyield loss caused by major rice diseases of Sierra Leone. This makes a study in this area very necessary because every successful breeding program should be based on distinct identification of farmers' constraints and preferences of end users. Moreover, adequate disease diagnosis is imperative for economic justification for treatment and protection against crop failure. Proper identification of diseasesis the first step in managing rice diseases. Some diseases can be managed by adopting or altering new cultural practices or by selecting a resistant variety (Mwalyego and Kayeke, 2011). Rice diseases are mainly identified by symptom expressions since each disease has unique characteristics that distinguish it from the other diseases (Adur-Okello, *et al.*, 2020).

Notwithstanding, farmers are mostly reluctant to accept technologies which are not in line with their preference and consumer expectation (Placide, *et al.*, 2015). This necessitates their inclusion in technology and innovation activities. One of such techniques is known as participatory rural appraisal (PRA). The PRA technique allows the inclusion of farmers in research decision making, in planning the generation of new technologies, and also serves as a non-formal approach to collect detailed data as well as other relevant information of a system (Uddin, 2013). In this study, PRA was used as a platform that enhances interaction among farmers, researchers and scientists as a more effective way to get a detailed insight into the farming system in that ecology. Therefore, the aim of this study was to evaluatethe efficacy of various disease management options and assess status of farmers' fields for major rice diseases of Sierra Leone.

Materials and Methods

Description of Study Area

The field experiment was conducted in June 2022 in the upland ecology of the experimental site of Crop Protection Department, School of Agriculture and Food Sciences, Njala University, Njala Campus in the Kori Chiefdom, Moyamba District, South of Sierra Leone. School of Agriculture and Food Sciences is located on an elevation of 5m above sea level on latitude 8°6N and longitude 12°6W of the equator. Njala University, Njala Campus is located at a distance of about 114 miles from the Capital city, Freetown and approximately 7 miles off the Bo-Freetown highway. The mean monthly air temperature ranges from 21°C to 23°C for greater part of the day and night especially during the rainy season. Predominantly, the land scape of Njala University, Njala Campus is covered with secondary bush and consists of well-balanced mixture of sand, clay, and humus. The experimental location is presented in Figure 1.

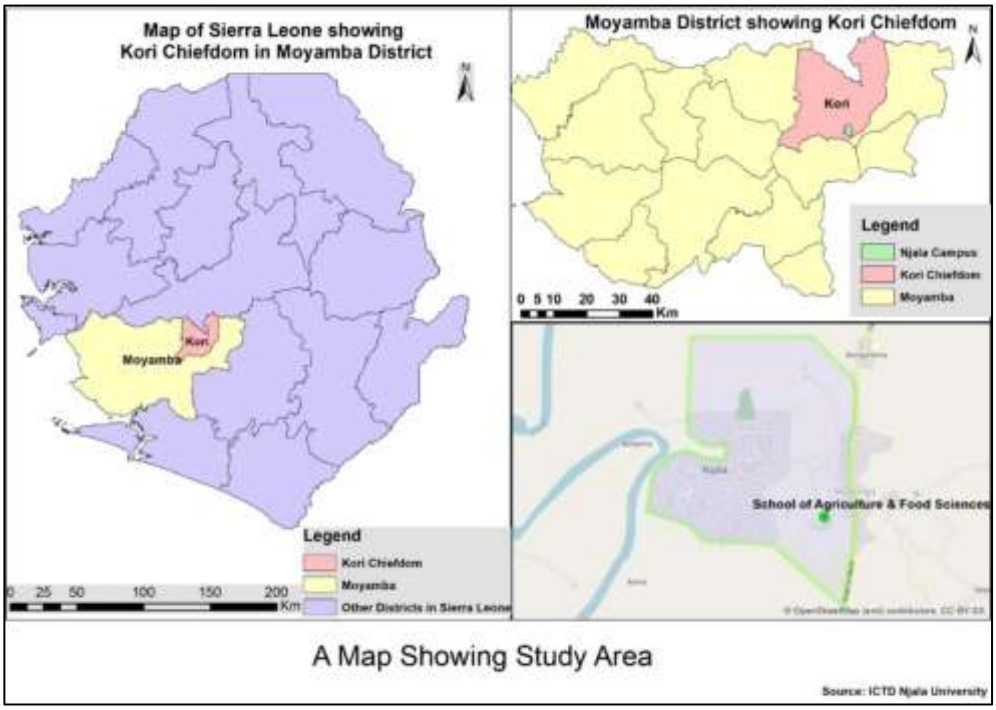

Figure 1: Map showing the study area

Treatments, Experimental Layout and Design

A total of 15 treatments including (i) copper hydroxide at 2.02 g/L, (ii) mancozan at 2.25 g/L, (iii) mancozanat 3.37 g/L, (iv) mancozanat 1.25 g/L, (v) metarhizium at 10 g/L, (vi) Metarhizium at 15 g/L, (vii) metarhizium at 5g/L, (viii) control, (ix) ginger at 100 g/L, (x) Neem seed powder at 10 g/L, (xi) Neem seed powder at 20 g/L, (xii) neem seed powder at 30 g/L, (xiii) neem leaf extract 500 g/L, (xiv) neem leaf extract 1000 g/L, and (xv) neem leaf extract 1500 g/L were utilized.

Neem extracts (seed and leaf) were collected from the neem plants in the School of Agriculture and Food Sciences. The seeds were sun dried prior to grindinginto powder, whereas the leaf was collected wet and ground using a mortar and pestle. The neem seed powder was measured at 10g, 20 g, and 30 g, while the ground neem leaves was measured at 500 g, 1000 g and 1500 g using sensitive electronic scale. Each of the neem samples was dissolved in 1 L of water and saba soap and filtered a day before application. The ginger sample was prepared by properly washing, weighing a 10 g sample per replication, grinding the sample using a blender, mixing with 1 L of water and filtering one day before application. The inorganic extracts were prepared after the dilution on the day of application and applied using knapsack sprayer as follows. Copper hydroxide was weighed at 2.02 g/ L of water, mancozan was weighed at 3.37 g/L of water (0.5 above recommended rate), 1.125 g/L of water (0.5 below recommended rate) and 2.25 g/L of water (recommended rate). Metarhizium was also weighed at 10 g/L of water (recommended rate), 15 g/L of water (0.5 above recommended rate) and at 5 g/L of water (0.5 below recommended rate).

The experiment was laid out in a randomized complete block design replicated three times. The experimental area measured 33 m × 17 m (561 m^2), and each plot measured 3 m × 3 m (9 m^2). There were 15 plots, each separated by 0.5 m and 1.0 m, within plots and between replications, respectively. The experimental field was prepared by ploughing the soil to a depth of 30 cm and harrowing manually. The rice variety was obtained from Crop Science Department and was directly sowed at 20 cm × 20 cm with 10 plants in each row and column giving a total of 100 plants per plot. The application of the various treatmentsto the plots started at three weeks after planting (WAP).

Evaluation of Farmers' Fields for Major Diseases of Rice in Sierra Leone

A survey was conducted in September 2022 in three major rice growing districts (Kambia, Kenema and Moyamba) of Sierra Leone to assess major diseases of rice on farmers' fields**.** The survey was conducted by three trained enumerators that are knowledgeable enough in diseases assessment. A total of 90 farms were sampled; of which, 30 farms per district were assessed. The fields surveyed were separated on average by 10 km, the diagonal (×) method was used in this study to assess the plants and a total of 30 plants were evaluated in each field, with 15 plants randomly selected along each diagonal. A tablet which has Kobo application and GPS facility that made it possible to identify the geographical coordinates (longitude, latitude, altitude) in each field was used to collect for data collection in each field.

Data Collection

In each plot, 20 plants were tagged for growth (plant height, number of leaves and number tillers), and harvest (panicle length, number of grains, yield grainweight, 1000-grain yield weight and yield dry matter) data collection.

The disease incidence was calculated as a percentage of the total plants infected over the total number of plants assessed.

$$\text{Mean incidence (\%)} = \frac{\sum \text{Infected plants}}{\sum \text{plants}} \times 100$$

The severity of major diseases of rice was scored in each plot based on visual assessment according to the standard scoring system for leaf blast based on the dominant type of infection (the standard scoring system for leaf blast based on the dominant type of infection (0-9) (IRRI, 2014).

Table 1: Standard scoring system (IRRI, 2014)

Disease incidence	Description	Reaction
0	No disease observed	Resistant (R)
1	Less than 5%	Resistant (R)
3	5-10%	Resistant (R)
5	11-25%	Moderately Resistant (MR)
7	26-50%	Susceptible (S)
9	More than 50%	Susceptible (S)

Data Analysis

An analysis of variance with one classification criterion (ANOVA) was carried out to determine the distribution of the incidence and severity of symptoms. The differences between the means were compared by using Fisher's LSD test to distinguish homogeneous groups at the significance level P = 0.05. The data were analyzed using RStudio software.

Results and Discussion

Growth Responses to Different Control Options

The F-test showed significant differences ($P \leq 0.05$) among treatments and the control. Plant height increased over time. At 30, 45, and 60 days after sowing (DAS), there was a significant difference ($P \leq 0.05$) in plant heights between the treatment plots and the control. Mancozan 80WP at 3.37 g/L and 2.25 g/L had the highest plant height, except for Mancozan 80WP at 1.25 g/L, which was lower than Metarhizium at 15 g/L with no significant difference at 30, 60, and 90 DAS. The increase in plant height with Mancozan 80WP at 3.37 g/L is due to a higher dose reducing disease expression and promoting growth. Neem kernel powder at 30 g/L and Metarhizium at 10 g/L also resulted in high plant heights. The lowest plant heights were in the control plot.

The number of tillers per hill was generally higher in copper hydroxide at 2.02 g/L treated plots at 30, 60, and 90 DAS, followed by Mancozan 80WP at 3.37 g/L. Metarhizium at 10 g/L and 15 g/L, as well as Ginger at 100 g/L, Neem kernel extract at 30 g/L and 20 g/L, and Neem leaf extract at various concentrations also showed significant differences in the number of tillers. The control plot had the lowest number of tillers.

Table-2: Growth response to different major diseases of rice control option during 2023 cropping season

Treatment	Plant height (cm)			Number of tillers^{-1}		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Copper hydroxide (2.02g/L)	18.5±0.9^{b}	39.7±2.0^{ab}	73.0±1.9^{ab}	3.1±0.2^{a}	7.5±0.30^{a}	15.1±0.7^{a}
Mancozan 80WP (2.25g/L)	22.3±0.7^{a}	46.1±0.4^{a}	78.1±3.1^{a}	2.9±0.1^{a}	7.3±0.2^{a}	13.9±0.4^{a}
Mancozan 80WP (3.37g/L)	23.0±1.4^{a}	46.2±0.4^{a}	78.2±3.7^{a}	3.0±0.1^{a}	7.4±0.3^{a}	14.0±0.5^{a}
Mancozan 80WP (1.25g/L)	18.2±0.3^{b}	36.5±0.6^{b}	69.8±1.7^{b}	2.4±0.1^{a}	7.1±0.5^{a}	12.2±0.1^{ab}
Metarhizium (10g/L)	18.5±0.1^{b}	34.8±2.5^{c}	70.3±2.0^{b}	3.0±0.0^{a}	6.8±0.1^{a}	13.2±0.2^{ab}
Metarhizium (15g/L)	20.6±0.2^{b}	37.4±3.7^{b}	71.8±0.6^{b}	2.6±0.2^{a}	6.9±0.2^{a}	13.6±0.3^{ab}
Metarhizium (5g/L)	16.6±0.2^{c}	31.7±0.9^{d}	68.8±1.1^{c}	2.2±0.2^{a}	6.6±0.5^{a}	13.2±0.1^{ab}
Ginger (100g/L)	16.9±0.8^{c}	32.0±0.6^{d}	67.4±2.2^{c}	2.3±0.1^{a}	6.4±0.4^{a}	12.1±0.7^{ab}
Neem kernel extract (10g/L)	15.9±1.4^{c}	31.9±1.9^{d}	67.6±1.0^{c}	2.1±0.1^{a}	5.0±0.0^{b}	10.7±0.3^{b}
Neem kernel extract (20g/L)	17.0±0.6^{c}	32.4±±0.7^{d}	65.5±3.5^{d}	2.3±0.1^{a}	5.4±0.1^{b}	11.5±0.2^{b}
Neem kernel extract (30g/L)	19.6±0.3^{b}	35.2±1.7^{b}	66.5±2.3^{d}	2.5±0.1^{a}	5.9±0.5^{ab}	13.4±0.2^{ab}
Neem leaf extract (0.5kg/L)	17.0±0.1^{c}	30.7±0.3^{d}	65.2±2.9^{d}	2.1±0.1^{a}	4.8±0.9^{c}	10.7±0.3^{b}
Neem leaf extract (1kg/L)	17.8±0.4^{c}	33.7±0.3^{c}	64.3±3.0^{d}	2.3±0.2^{a}	5.2±0.2^{b}	10.7±0.1^{b}

Neem leaf extract at 1.5kg/L	18.9±1.2[b]	37.6±0.1[b]	68.1±3.0[c]	2.5±0.1[a]	6.2±0.1[a]	11.2±0.4[b]
Control	15.4±1.3[c]	28.9±0.6[d]	57.7±1.7[e]	2.0±0.1[a]	4.0±0.3[c]	7.0±1.0[c]
Pr> F	0.04	0.028	<.001	NS	0.051	<.001
CV(%)	12.3	17.8	16.0	17.0	12.0	10.0

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Duncan multiple range- test

Effects of Disease Management Options on the Incidence of Major Diseases of Rice at the Vegetative Stage

The statistical analyses indicated significant differences (P ≤ 0.05) in the incidence of the major diseases of rice identified in the field at vegetative growth (30 and 60 days after sowing). In general, all treatments used significantly reduced the incidence of the diseases identified in the field (Table 3). The incidence of leaf blast disease after sowing was lowest in the plot treated with Mancozan 80WP at 3.37 g/L, with percentages of 25.4% at 30 days and 10.0% at 60 days. The next lowest incidence was observed in the plot treated with Mancozan 80WP at 2.25g/L, with percentages of 28.0% at 30 days and 11.3% at 60 days. Copper hydroxide at 2.02g/L treatment resulted in an incidence of 28.3% at 30 days and 15.0% at 60 days. Neem kernel extract at 30 g/L treatment had an incidence of 28.3% at 30 days and 19.9% at 60 days. Metarhizium at 15 g/L treatment had an incidence of 33.3% at 30 days and 18.3% at 60 days. Treatment Ginger at 100 g/L had an incidence of 35.6% at 30 days and 19.3% at 60 days after planting. The other treatments and control had higher incidences of leaf blast disease.

For bacteria blight disease after planting, the lowest incidence was observed in the plot treated with Mancozan 80WP at 3.37g/L, with percentages of 5% at 30 days and 0.0% at 60 days. The next lowest incidence was observed in the plot treated with Mancozan 80WP at 2.25 g/L, with percentages of 5.3% at 30 days and 0.0% at 60 days. Mancozan 80WP at 1.25 g/L treatment resulted in an incidence of 5.3% at 30 days and 0.0% at 60 days. Other treatments and control had higher incidences of bacteria blight disease.

For brown leaf spot disease after planting, the lowest incidence was observed in the plot treated with Mancozan 80WP at 3.37 g/L, with percentages of 5.0% at 30 days and 0.0% at 60 days. The next lowest incidence was observed in the plot treated with Mancozan 80WP at 2.25 g/L, with percentages of 8.0% at 30 days and 0.0% at 60 days. Copper hydroxide at 2.02 g/L treatment resulted in an incidence of 10.0% at 30 days and 0.0% at 60 days. Other treatments and control had higher incidences of brown leaf spot disease.

The incidence of yellow mottle virus disease was very low in most treatments, with the lowest incidences observed in the plots treated with Neem kernel extract at 30 g/L and Neem leaf extract at 1.5 kg/L, both at 5.0% at 30 days and 0.0% at 60 days. Other treatments and control had higher incidences of yellow mottle virus disease.

For bacteria strike disease after sowing, there was no incidence in the plots treated with Copper hydroxide at 2.02 g/L, Mancozan 80WP at 2.25 g/L (recommended rate), and Mancozan 80WP at 3.37 g/L (0.5 g above recommended rate), as well as Neem kernel extract at 30 g/L. The incidence was very low in plots treated with Mancozan 80WP at 1.25 g/L (0.5 g less than recommended rate), Metarhizium at 5 g/L, Ginger at 100 g/L, and Neem kernel extract at 20 g/L. Other treatments and control had higher incidences of bacteria strike disease (Table 3).

During this study, leaf blast, bacteria leaf blight, brown spot, bacteria leaf strikeand rice yellow mottle virus diseases were observed at the vegetative stage of the rice, whereas panicle and neck blast were the only diseases identified at heading stage (Table 4).

Table-3: Effects on different disease management options on the incidence of major diseases of rice at vegetative stage during the 2022 cropping season

Treatment	Leaf blast		Bacteria blight		Brown spot		RYMV		Bacteria strike	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Copper hydroxide (2.02g/L)	28.3±1.6^{e}	15.0±2.5^{d}	8.3±4.4^{c}	8.0±0.01^{c}	10.1±0.0^{c}	0.0±0.0^{d}	16.6±1.5^{e}	10.0±1.0^{b}	0.0±0.0^{d}	0.0±0.0^{d}
Mancozan 80WP (2.25g/L)	28.0±4.6^{c}	11.3±1.6^{f}	5.3±0.8^{e}	0.0±0.0^{e}	8.8±0.5^{d}	0.0±0.0^{d}	16.6±1.3^{e}	10.0±1.2^{b}	0.0±0.0^{d}	0.0±0.0^{d}
Mancozan 80WP(3.37g /L)	25.4±5.2^{d}	10.0±0.0^{f}	5.0±0.3^{d}	0.0±0.0^{e}	5.0±0.0^{d}	0.0±0.0^{d}	16.6±1.3^{e}	10.0±1.0^{b}	0.0±0.0^{d}	0.0±0.0^{d}
Mancozan 80WP (1.25g/L)	33.3±4.1^{b}	18.3±1.6^{c}	5.3±0.7^{e}	0.0±0.0^{e}	10.0±0.0^{c}	10.0±0.0^{c}	16.6±1.0^{e}	10.0±1.3^{b}	10.1±0.0^{c}	10.0±0.0^{b}
Metarhizium (10g/L)	33.6±4.5^{b}	20.0±0.0^{b}	6.6±1.2^{d}	5.0±1.3^{d}	13.4±1.7^{b}	11.6±1.6^{b}	16.6±1.4^{e}	10.0±1.1^{b}	11.6±1.6^{b}	10.0±0.0^{b}
Metarhizium (15g/L)	33.3±2.8^{b}	18.3±1.6^{c}	10.0±0.0^{b}	5.0±1.2^{d}	13.3±1.6^{b}	11.6±1.6^{b}	13.5±1.7^{b}	10.0±1.0^{b}	11.6±1.6^{b}	7.2±0.2^{c}
Metarhizium at 5g/L	35.2±2.9^{a}	21.6±3.3^{b}	11.6±1.6^{b}	6.6±1.3^{d}	14.1±2.8^{b}	10.0±0.0^{c}	10.4±0.2^{c}	10.0±0.6^{b}	10.2±0.0^{c}	10.0±0.0^{b}
Ginger (100g/L)	35.6±3.8^{a}	19.3±0.6^{b}	10.0±0.0^{b}	10.0±1.9^{b}	16.6±3.3^{ab}	10.0±0.0^{c}	8.3±1.6^{d}	8.0±1.0^{b}	10.2±0.0^{c}	10.0±0.0^{b}
Neem kernel extract (10g/L)	34.3±2.8^{ab}	20.0±0.0^{b}	11.6±1.6^{b}	11.0±1.7^{b}	13.3±1.6^{b}	13.3±3.3^{ab}	10.2±0.0^{f}	0.6±0.0^{c}	13.3±3.3^{ab}	10.0±0.0^{b}
Neem kernel extract (20g/L)	35.0±4.4^{a}	20.4±0.2^{b}	11.7±3.3^{a}	10.8±1.7^{b}	12.1±1.0^{bc}	10.0±0.0^{c}	10.±0.1^{c}	0.6±0.0^{c}	10.2±0.0^{c}	10.2±0.2^{b}
Neem kernel extract (30g/L)	28.3±2.9^{e}	19.9±1.6^{b}	11.6±0.0^{b}	10.6±1.6^{b}	10.0±0.0^{c}	0.0±0.0^{d}	5.0±0.0^{c}	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{b}
Neem leaf extract (0.5kg/L)	35.6±1.6^{a}	20.0±0.0^{b}	11.0±0.0^{b}	11.0±0.5^{c}	10.0±0.0^{c}	10.0±0.0^{c}	6.5±0.0^{f}	0.5±0.0^{c}	10.3±0.0^{c}	10.1±0.1^{b}
Neem leaf extract (1kg/L)	31.6±1.6^{c}	19.7±2.4^{b}	11.7±1.6^{b}	11.0±1.5^{b}	10.0±0.0^{c}	10.0±0.0^{c}	6.0±0.0^{c}	0.0±0.0^{c}	10.5±0.0^{c}	10.3±0.3^{b}
Neem leaf extract (1.5kg/L)	33.3±3.3^{b}	13.3±1.6^{e}	11.6±1.6^{b}	10.0±1.0^{b}	10.0±0.0^{c}	10.0±0.0^{c}	5.0±0.0^{f}	0.0±0.0^{c}	10.5±0.0^{c}	10.0±0.0^{b}
Control	30.6±3.4^{a}	40.0±6.0^{a}	15.3±3.3^{a}	30.0±3.0^{a}	20.0±3.3^{a}	20.0±3.3^{a}	30.0±3.3^{a}	20.0±2.9^{a}	15.0±3.3^{a}	15.3±3.3^{a}
Pr> F	0.05	<.001	0.02	<.001	<.001	0.02	<.001	<.001	0.03	<.001
CV(%)	20.5	16.7	12.0	10.5	10.1	15.0	12.3	10.2	14.6	11.0

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Duncan multiple range- test; RYMV=Yellow mottle virus disease; DAS=days after sowing

Table 4: Major diseases of rice identified in the experimental field in 2022 cropping season

Diseases identified	Causative agent	Growth stage	Type of disease
Leaf blast	*Magnaporthe oryzae*	Vegetative	Fungus
Bacterial leaf blight	*Xanthomonas oryzae*pv. Oryzae	Vegetative	Bacteria
Brown spot	*Cochliobolus miyabeanus*	Vegetative	Bacteria
Rice yellow mottle disease	Rice yellow mottle virus	Vegetative	Virus
Bacteria leaf streak	*Xanthomonas oryzae*pv. Oryzicola	Vegetative	Bacteria
Panicle blast	*Magnaporthe oryzae*	Heading	Fungus
Neck blast	*Magnaporthe oryzae*	Heading	Fungus

Effects of Disease Management Options on the Incidence of Major Diseases of Rice at Heading Stage

Incidence of panicle blast and neck blastdiseases of rice assessed at heading stagesignificantly (P ≤ 0.05) differed among disease management treatments (Table 5). Among treated plots, Mancozan 80WP at 3.37 g/L exhibited the lowest panicle blast incidence (20.4%), and Mancozan 80WP at 3.37 g/L also showed the lowest neck blast incidence (10.0%). Recommended rate treatments and other substances displayed varying incidence rates, with the control plot recording the highest panicle blast (40.0%) and neck blast (25.0%) incidences.

Table-5: Effects of different management options on the incidence of major diseases of rice at heading stage during 2023 cropping season

Treatment	Panicle blast	Neck blast
Copper hydroxide at 2.02g/L	28.33±1.67[c]	18.50±1.83[c]
Mancozan 80WP at 2.25g/L	23.60±1.80[d]	13.17±1.83[d]
Mancozan 80WPat 3.37g/L	20.4±1.73[d]	10.00±0.00[e]
Mancozan 80WP at 1.25g/L	28.33±1.76[c]	18.33±1.66[c]
Metarhizium at 10g/L	33.33±1.66[b]	20.33±0.16[b]
Metarhizium at 15g/L	33.73±1.86[b]	20.33±0.16[b]
Metarhizium at 5g/L	28.33±1.66[c]	18.50±1.75
Ginger at 100g/L	38.33±1.66[ab]	18.50±1.76
Neem kernel extract at 10g/L	33.46±1.73[b]	18.50±1.75
Neem kernel extract at 20g/L	28.46±1.73[c]	20.16±0.16[b]
Neem kernel extract at 30g/L	32.33±1.16[b]	20.16±0.16[b]
Neem leaf extract at 0.5kg/L	28.33±1.67[c]	20.00±0.16[b]
Neem leaf extract at 1kg/L	28.33±1.67[c]	20.00±0.16[b]
Neem leaf extract at 1.5kg/L	28.33±1.66[c]	20.0±0.01[b]
Control	40.00±4.00[a]	25.00±0.01[a]
Pr> F	<.001	0.05
CV(%)	16.5	12.0

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Duncan multiple range- test; CV=coefficient of variation

Effects of Various Disease Management Options on the Severity of Major Diseases of Rice at Vegetative Stage

Statistical analyses indicated significant differences (P ≤ 0.05) in disease severity between treated and control plots. For bacterial blight, treated plots, especially those with Mancozan 80WP at 3.37 g/L, displayed low severity (classified as resistant) at 30 and 60 days after planting. Neem kernel extract at 30 g/L, Copper hydroxide at 2.02 g/L, Ginger at 100 g/L, Neem leaf extract at 1 kg/L, and Neem leaf extract at 1.5 kg/L also demonstrated resistance. Control plots had the highest severity, classified as highly susceptible. In the case of brown spot disease, all treated plots showed a significant reduction in severity. Mancozan 80WP at 3.37 g/L, Mancozan 80WP at 2.25 g/L, and Copper hydroxide at 2.02 g/L treatments exhibited resistance. Neem leaf extract at 1.5 kg/L was also classified as resistant, while other treatments showed varying degrees of susceptibility. Control plots recorded the highest severity. Yellow mottle virus severity was reduced in all treated plots. Neem leaf extract at 1.5 kg/L exhibited the lowest severity, classified as resistant, followed by other treatments. Control plots had the highest severity, classified as very susceptible. Bacterial leaf streak severity was significantly low (resistant) in copper hydroxide at 2.02 g/L, Mancozan 80WP at 3.37 g/L, and Mancozan 80WP at 2.25 g/L treated plots at

30 and 60 days after planting. Other treatments showed varying degrees of resistance or susceptibility, while control plots had the highest severity, classified as very susceptible and moderately susceptible at 30 and 60 days after planting.

Effects of Different Control Options on the Severity of Major Diseases of Rice at Heading Stage

The statistical analysis revealed a significant difference ($P \leq 0.05$) in disease severity between treated and control plots for panicle blast and neck blast, the major diseases in the rice field (Table 7). All treatments significantly reduced panicle blast severity, with Mancozan 80WP at 3.37 g/L and Mancozan 80WP at 2.25 g/L exhibiting the lowest severity (1.5 and 1.6), classified as resistant. Neck blast severity was also significantly reduced by all treatments, with Mancozan 80WP at 3.37 g/L, Mancozan 80WP at 2.25 g/L, and Mancozan 80WP at 1.25 g/L showing highly resistant severity (1.0). Control plots consistently recorded the highest severity scores for both panicle and neck blast diseases.

Table-6: Effects of different control options on the severity of major diseases of rice identified during the vegetative stage of 2022 cropping season

Treatment	Leaf blast		Bacteria blight		Brown Spot		Yellow mottle virus disease		Bacteria strike	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Copper hydroxide (2.02g/L)	5.1 ± 0.0^{b}	3.1 ± 0.0^{b}	3.1 ± 0.1^{b}	3.0 ± 0.1^{b}	3.0 ± 0.1^{b}	1.0 ± 0.0^{c}	3.7 ± 0.2^{b}	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	1.0 ± 0.0^{c}
Mancozan 80WP (2.25g/L)	5.0 ± 0.0^{b}	1.0 ± 0.0^{c}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	3.2 ± 0.2^{b}	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	1.0 ± 0.0^{c}
Mancozan 80WP(3.37g/L)	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	3.2 ± 0.2^{b}	3.1 ± 0.1^{b}	1.0 ± 0.0^{c}	1.0 ± 0.0^{c}
Mancozan 80WP (1.25g/L)	5.7 ± 0.0^{b}	1.1 ± 0.0^{c}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	3.2 ± 0.1^{b}	3.0 ± 0.2^{b}	3.3 ± 0.1^{b}	3.1 ± 0.1^{b}	3.7 ± 0.3^{ab}	3.0 ± 0.0^{c}
Metarhizium (10g/L)	5.5 ± 0.0^{b}	3.3 ± 0.0^{b}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	5.5 ± 0.1^{b}	5.0 ± 0.1^{b}	3.3 ± 0.0^{b}	3.1 ± 0.1^{b}	5.7 ± 0.7^{ab}	3.0 ± 0.0^{c}
Metarhizium (15g/L)	7.1 ± 0.0^{ab}	3.0 ± 0.0^{b}	3.0 ± 0.0^{b}	1.0 ± 0.0^{c}	5.9 ± 0.1^{b}	5.7 ± 0.0	5.5 ± 0.0^{b}	3.1 ± 0.0^{b}	5.0 ± 0.0^{ab}	3.0 ± 0.0^{c}
Metarhizium (5g/L)	5.1 ± 0.1^{b}	1.3 ± 0.0^{c}	5.0 ± 0.0^{b}	3.0 ± 0.0^{c}	5.6 ± 0.1^{b}	3.1 ± 0.0^{b}	3.0 ± 0.0^{b}	3.0 ± 0.0^{b}	3.7 ± 0.7^{ab}	3.0 ± 0.0^{c}
Ginger (100g/L)	5.5 ± 0.1^{b}	3.1 ± 0.0^{b}	3.3 ± 0.1^{b}	3.0 ± 0.1^{c}	5.7 ± 0.1^{b}	3.0 ± 0.0^{b}	3.0 ± 0.0^{c}	3.0 ± 0.0^{c}	3.1 ± 0.1^{c}	3.0 ± 0.0^{c}
Neem kernel extract (10g/L)	7.6 ± 0.0^{ab}	1.6 ± 0.4^{c}	5.3 ± 0.2^{b}	3.0 ± 0.2^{b}	5.9 ± 0.1^{b}	5.1 ± 0.0^{b}	3.0 ± 0.0^{b}	1.5 ± 0.0^{b}	5.8 ± 0.2^{c}	3.3 ± 0.3^{b}
Neem kernel extract (20g/L)	5.2 ± 0.0^{b}	1.7 ± 0.3^{c}	5.1 ± 0.1^{b}	3.0 ± 0.1^{b}	5.0 ± 0.0^{b}	5.0 ± 0.0^{b}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	3.8 ± 0.2^{c}	3.0 ± 0.0^{c}
Neem kernel extract (30g/L)	5.2 ± 0.03^{b}	3.1 ± 0.0^{b}	3.0 ± 0.0^{c}	3.0 ± 0.0^{c}	5.0 ± 0.0^{b}	3.0 ± 0.0^{c}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	1.0 ± 0.00^{c}	3.0 ± 0.00^{c}
Neem leaf extract (0.5kg/L)	5.9 ± 0.3^{b}	1.7 ± 0.2^{c}	5.3 ± 0.2^{b}	3.3 ± 0.2^{c}	5.5 ± 0.0^{b}	3.5 ± 0.0^{b}	3.0 ± 0.0^{b}	1.6 ± 0.0^{b}	3.1 ± 0.1^{c}	3.3 ± 0.3^{b}
Neem leaf extract (1kg/L)	5.9 ± 0.0^{b}	3.2 ± 0.1^{b}	3.8 ± 0.2^{b}	3.0 ± 0.2^{c}	5.0 ± 0.0^{b}	3.0 ± 0.0^{b}	3.0 ± 0.0^{c}	1.0 ± 0.0^{c}	3.0 ± 0.0^{c}	3.0 ± 0.0^{c}
Neem leaf extract (1.5kg/L)	7.4 ± 0.0^{ab}	3.0 ± 0.0^{b}	3.9 ± 0.3^{b}	3.0 ± 0.3^{c}	3.8 ± 0.2^{c}	3.5 ± 0.0^{b}	1.6 ± 0.0^{c}	1.0 ± 0.0^{c}	5.0 ± 0.0^{c}	3.0 ± 0.0^{c}

Control	9.3±0.4[a]	7.7±0.3[a]	7.0±0.0[a]	7.0±0.0[a]	7.0±0.0[a]	7.0±0.0[a]	7.0±0.1[a]	7.0±0.3[a]	7.0±2.2[a]	5.67±0.3[a]
Pr> F	0.050	<.001	0.021	<.001	<.001	0.023	0.04	0.05	0.05	0.05
CV(%)	13.8	10.0	15.8	10.0	11.4	10.0	14.8	13.0	11.0	9.0

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Ducan multiple range-test; CV=coefficient of variation; DAS=days after sowing

Table-7: Severity of major diseases assessed at heading stage (90 days after sowing) in rice grown under different disease control options

Treatment	Panicle blast severity score	Neck blast severity score
Copper hydroxide at 2.02g/L	5.33±0.16[ab]	3±0.00[b]
Mancozan 80WP at 2.25g/L	1.60±0.00[b]	1.0±0.00[b]
Mancozan 80WPat 3.37g/L	1.50±0.00[b]	1.00±0.00[b]
Mancozan 80WP at 1.25g/L	3.66±0.33[a]	1.00±0.00[b]
Metarhizium at 10g/L	7.86±0.43[a]	3.63±0.06[b]
Metarhizium at 15g/L	5.93±0.00[a]	3.56±0.03[b]
Metarhizium at 5g/L	7.50±0.46[ab]	3.63±0.03[b]
Ginger at 100g/L	7.80±0.40[a]	5.70±0.06[b]
Neem kernel extract at 10g/L	7.80±0.00[a]	5.56±0.10[b]
Neem kernel extract at 20g/L	7.00±0.43[a]	5.10±0.03[b]
Neem kernel extract at 30g/L	7.86±0.00[a]	5.70±0.00[b]
Neem leaf extract at 0.5kg/L	7.80±0.00[a]	5.50±0.00[b]
Neem leaf extract at 1kg/L	7.00±0.00[a]	5.20±0.00[b]
Neem leaf extract at 1.5kg/L	7.00±0.00[a]	5.20±0.00[b]
Control	9.0±0.70[a]	7.66±0.16[a]
Pr> F	0.04	0.05
CV%	18.7	13.3

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Duncan multiple- test

Yield and Yield Component Responses to Different Control Options of Major Rice and Diseases

The application of various treatments significantly ($P \leq 0.05$) influenced rice yield and its components, including panicle length, number of spikelets, number of grains per panicle, grain yield, 1000-grain weight, dry matter yield, and straw yield. Panicle length ranged from 17.0 cm to 22.3 cm, with the highest length observed in Neem leaf extract at 1.5 g/L treated plots. Treatments showed a significant difference in the number of spikelets, with the highest (11.5) in Neem leaf extract at 1.0 kg/L. The number of grains per panicle varied significantly, with the highest (96.8) in Mancozan at 3.37 g/L treated plots. Grain yield was significantly influenced by treatments, with the highest (4.2 t/ha) obtained in plots amended with Mancozan 80WP at 3.37 g/L. The 1000-grain yield weight ranged from 13.7 g to 26.7 g, with the highest obtained in Mancozan 80WP at 3.37 g/L treated plots. Dry grain yield varied significantly, with the highest (2.6 t/ha) obtained in plots amended with Mancozan 80WP at 3.37 g/L. Control plots consistently recorded the lowest values for most yield components.

Table-8: Effects of different control options of major diseases of rice on the yield and yield components of rice during the 2023 cropping season

Treatments	Panicle length (cm)	Number of spikelet plant^{-1}	Number of grains plant^{-1}	Grain yield (t/ha)*	Weight of 1000-grain weight (g)	Dry grain yield (t/ha)**
Copper hydroxide at 2.02 g/L	18.3±1.5	9.7±0.1^{b}	72.6±1.2^{ab}	3.6±0.2^{ab}	22.9±0.1^{b}	1.6±0.1^{b}
Mancozan 80WP at 2.25 g/L	19.6±0.0^{ab}	9.1±0.3^{b}	73.9±0.6^{ab}	3.1±0.2^{b}	26.6±0.2^{a}	1.3±0.1^{b}
Mancozan 80WP (3.37 g/L)	21.1±0.6^{a}	10.3±0.3^{a}	96.9±0.1^{a}	4.2±0.3^{a}	26.7±0.1^{a}	2.6±0.2^{a}
Mancozan 80WP at 1.25 g/L	18.7±1.7^{b}	11.4±0.3^{a}	69.3±0.6^{b}	2.7±0.2^{c}	18.3±0.1^{d}	1.0±0.0^{b}
Metarhizium at 10 g/L	21.0±0.5^{a}	10.5±0.3	65.4±0.8^{c}	3.1±0.3^{b}	20.9±0.0^{c}	1.2±0.1^{b}
Metarhizium at 15 g/L	20.5±0.2^{ab}	10.4±0.3^{a}	73.7±0.7^{ab}	3.5±0.2^{ab}	25.6±0.2^{a}	1.5±0.1^{b}
Metarhizium at 5 g/L	18.1±1.5^{b}	9.9±0.0^{b}	53.67±2.2^{f}	2.6±0.1^{c}	21.7±0.1^{b}	1.2±0.1^{b}
Ginger at 100 g/L	19.9±0.0^{ab}	10.7±0.1^{a}	69.2±0.4^{b}	3.3±0.3^{b}	20.9±0.1^{c}	1.5±0.1^{b}
Neem kernel extract at 10 g/L	20.1±0.0^{ab}	9.6±0.2^{b}	45.9±7.0	2.5±0.1^{c}	25.6±0.2^{a}	1.1±0.1^{bc}
Neem kernel extract at 20 g/L	21.8±0.0^{a}	9.6±0.2^{b}	69.7±0.1^{b}	2.6±0.2^{c}	20.9±0.1^{c}	1.5±0.1^{b}
Neem kernel extract at 30 g/L	19.0±0.0^{b}	10.3±0.1^{a}	62.9±0.5^{d}	3.2±0.3^{b}	25.5±0.2^{a}	1.5±0.1^{b}
Neem leaf extract at 0.5 kg/L	20.0±0.0^{ab}	9.3±0.3^{b}	70.1±0.0^{b}	2.5±0.2^{c}	24.5±0.2^{ab}	1.1±0.0^{b}
Neem leaf extract at 1.0 kg/L	21.0±0.0^{a}	11.5±0.2^{a}	60.0±0.0^{e}	2.8±0.2^{bc}	21.7±0.1^{b}	1.3±0.0^{b}
Neem leaf extract at 1.5 kg/L	22.3±0.0^{a}	8.7±0.1^{b}	56.1±1.9^{e}	3.1±0.3^{b}	20.9±0.1^{c}	1.5±0.1^{b}
Control	17.0±0.0^{c}	6.4±0.3^{c}	26.9±2.6^{g}	1.5±0.0^{d}	13.7±0.6^{e}	0.6±0.0^{c}
Pr> F	0.006	<.001	<.001	<.001	0.04	<.001
CV(%)	11.2	15.6	16.7	11.20	20.1	10.3

Means with the same superscripts in column are not significantly different (P>0.05) as indicated by Duncan multiple range- test; CV=coefficient of variation; *=fresh grain yield at harvest; **=dry grain yield at 10% moisture content

Assessment of Incidence and Severity of Major Diseases of Rice on Farmers' Fields Across Three Agro-Ecologies of Sierra Leone

A field assessment across 90 farms in three agro-ecologies identified major rice diseases at the vegetative stage, including leaf blast, leaf brown spot, bacterial leaf blight, yellow mottle viruses' disease, and bacterial leaf streak disease. Leaf blast incidence was highest in Kambia district (65.3%), followed by Kenema district (58.0%), with Moyamba district recording 55.7% (Figure 1A). Brown spot incidence was highest in Kambia district

(46.7%), followed by Kenema district (40.5%), and lowest in Moyamba district (35.4%). Bacterial blight incidence was highest in Kambia district (35.8%), followed by Moyamba district (30.4%), and lowest in Kenema district (25.7%). Rice yellow mottle virus disease incidence was highest in Kenema district (30.5%), followed by Moyamba district (25.4%), with Kambia district recording the lowest (23.4%). Bacterial leaf streak disease incidence was low across all farms, with Kenema and Kambia districts recording the highest (15.0%) and Moyamba district the lowest (10.0%).

Panicle and neck blast diseases were identified as major issues. Moyamba district had the highest mean incidence of panicle blast (56.7%), followed by Kenema district (55.5%), while Kambia district recorded a lower mean incidence of 54.3% (Figure 1B). The mean incidence of neck blast was low in all districts, with Kenema and Kambia districts recording the highest (40.5%) and Moyamba district the lowest (33.4%).

The mean severity of leaf blast disease was consistently high across all three districts, with Kambia district recording the highest severity (7.1), followed by Kenema district (7.0), and Moyamba district showing a slightly lower mean severity. Brown spot disease had a high mean severity in Kambia (7.1) and Moyamba (7.0) districts, while Kenema district exhibited a moderately high severity (5.5) (Figure 1C). Bacterial blight's mean severity was moderately high in Kambia and Moyamba (5.0) districts and low in Kenema district (3.0). Yellow mottle virus disease had a moderately high mean severity in Moyamba district (5.0) and low in Kenema (3.1) and Kambia (3.0) districts. Bacterial leaf streak had a low mean severity in all three districts, with Moyamba district recording the highest mean severity (3.5).For panicle blast disease, the mean severity was generally high in all three districts, with Kambia district having the highest severity (7.3), followed by Kenema (7.0) and Moyamba (7.0) districts (Figure 1D). Neck blast disease showed high mean severity only in Kambia district (7.0), moderately high in Moyamba district (5.0), and low in Kenema district (3.0).

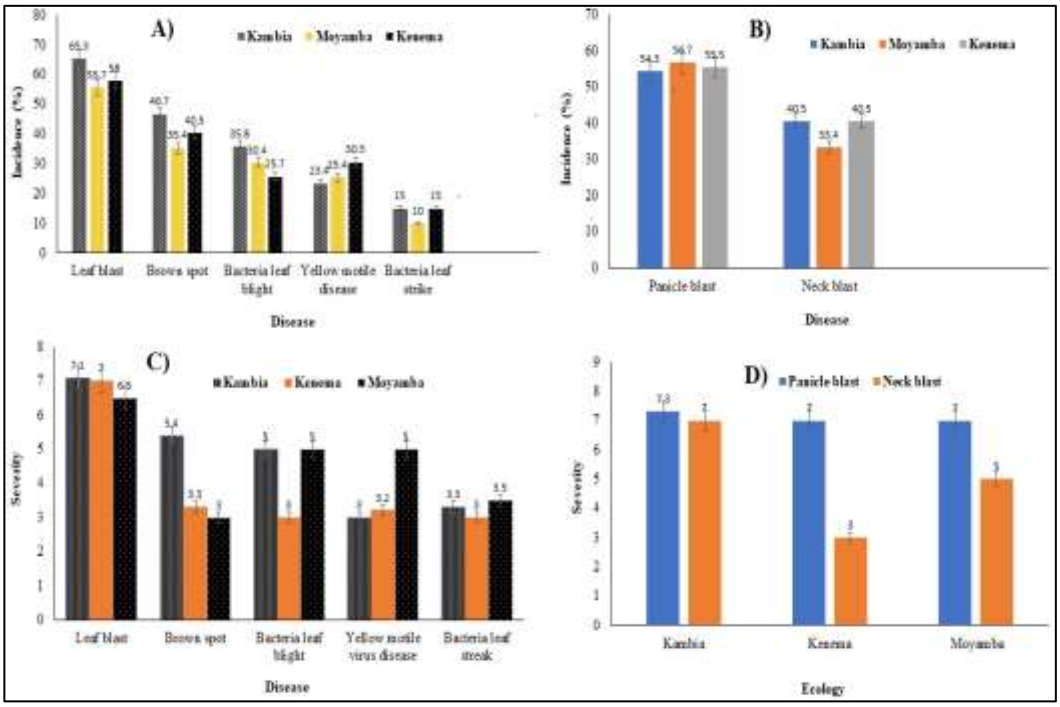

Figure 1: Incidence of major diseases of rice identified at (A) vegetative stage; (B) heading; (C) severity of diseases at vegetative stage; (D) severity of disease at heading across the three agro-ecologies

Distribution Maps of Major Diseases of Rice in Kambia, Kenema and Moyamba Districts

Leaf blast disease incidence and severity were observed in all fields assessed across three major rice-growing districts (Figure 2A and B). The distribution map revealed a high susceptibility to leaf blast in Kambia district, while Moyamba district had mostly resistant farms, and Kenema districtshowed moderate susceptibility. Overall, the incidence of leaf blast was widespread and severe in Kambia district, with most farms highly susceptible. In contrast, Moyamba district had a lower severity score, indicating resistance, while Kenemadistrict had a mix of moderately susceptible and healthy farms. No healthy farms were identified in Kambia district. The distribution map of panicle blast disease across three districts indicated a widespread incidence in the majority of assessed farms (Figure 2C and D). In Moyamba district, most farms were highly susceptible to the disease, while those in Kambia and Kenema districts were susceptible and moderately susceptible, respectively. Few healthy farms were identified across all districts, with Kenema district having the highest number of healthy farms, followed by Kambia, and Moyamba districts recording the least. The severity distribution map of panicle blast revealed widespread infection in all three districts, with most farms in Kambia district being moderately susceptible or susceptible. Kenema had a majority of susceptible farms, with a few healthy ones, while Moyamba district had a higher proportion of moderately susceptible farms.

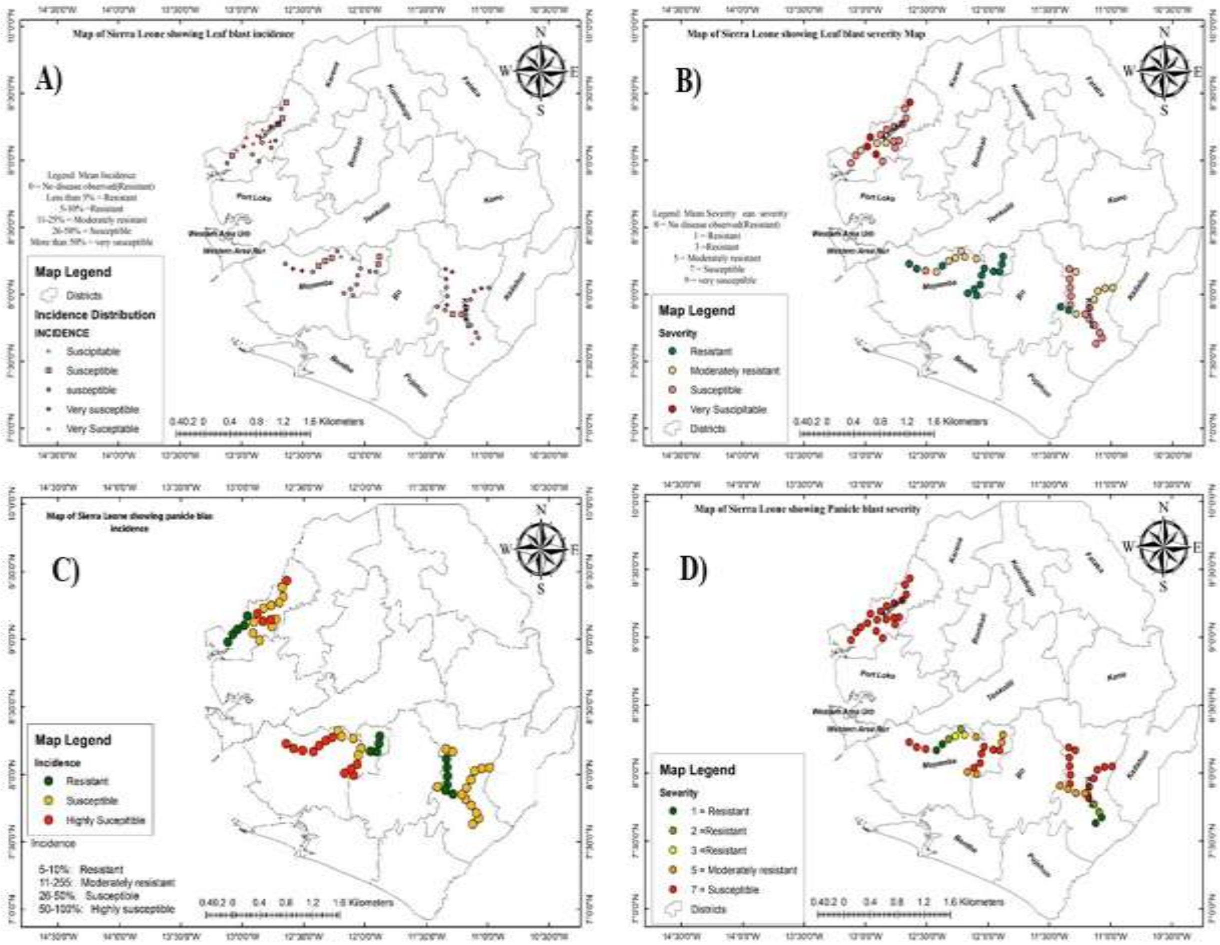

Figure 2: Map of Sierra Leone showing the distribution of (A) leaf blast incidence; (B) leaf blast severity; (C) panicle blast incidence; (D) panicle blast severity in three districts

The distribution map of bacteria leaf blight incidence revealed widespread occurrence of the disease in the majority of farms visited, particularly in Kambia district, where most farms were moderately susceptible or susceptibl9e (Figure 3A and B). In Moyamba district, many farms were also susceptible, with a few showing moderate resistance/ susceptibility. Conversely, most farms assessed in Kenema district were moderately resistant. The severity distribution map showed low infection of the disease across all three districts. In Kambia district, most farms were moderately susceptible, with some being susceptible. Moyamba and Kenema districts showed most resistant farms with relatively low severity scores, while a few healthy farms were identified in Kenema district.

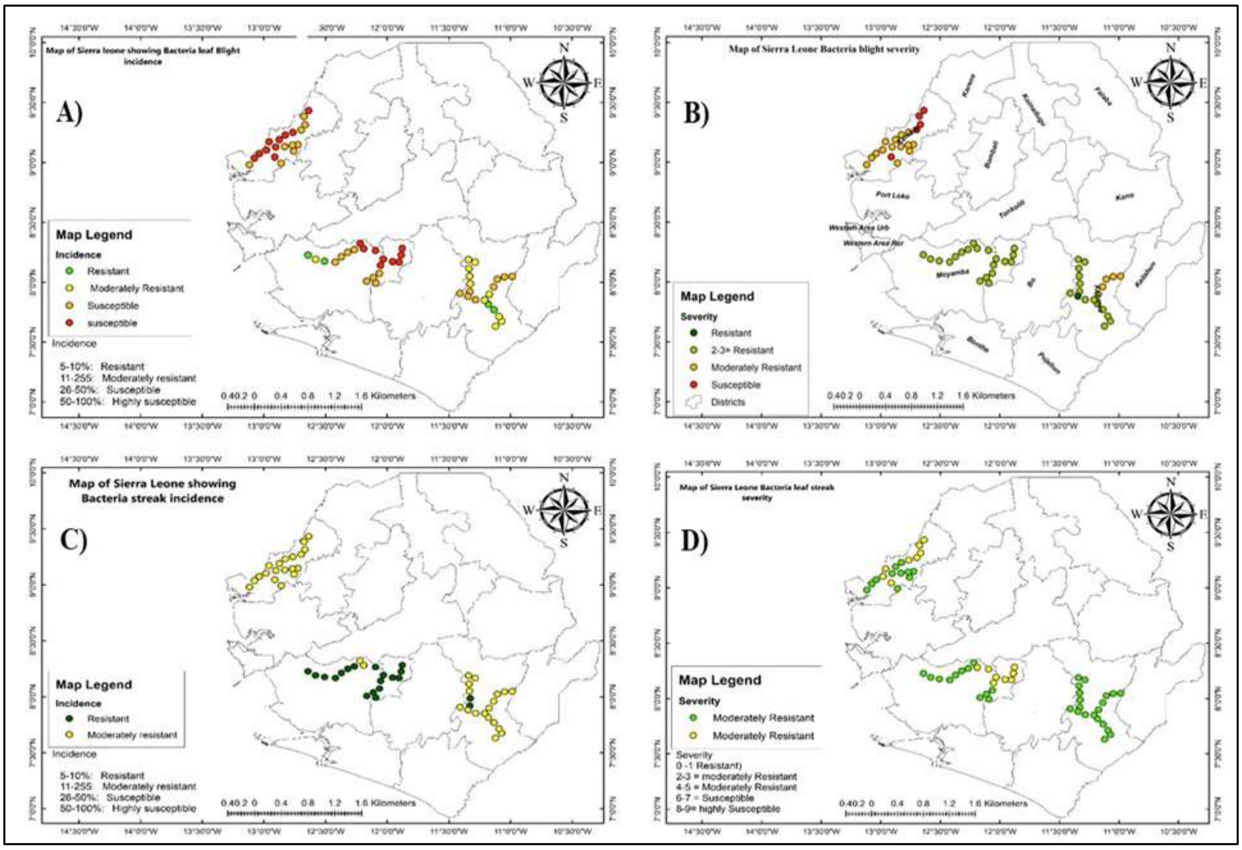

Figure 3: Map of Sierra Leone showing the distribution of (A) bacteria leaf blight incidence; (B) bacteria leaf blight severity; (C) bacteria leaf streak incidence; (D) bacteria leaf streak severity in three districts

The distribution map of bacteria leaf streak incidence indicated a widespread of the disease in majority of the farmsvisited. In Kambia and Kenema districts, most farms showed a moderate resistance to the disease, with few healthy farms in Kenema. Conversely, Moyamba district had mostly healthy farms. The severity distribution map revealed that most farms across all three districts were infected with bacteria leaf streak disease, but with low severity scores. Most farms displayed resistance with low severity in all districts, while a few farms in Kambia and Moyamba districts were moderately resistant. However, all farms in Kenema district were resistant.

The distribution map of the incidence and severity of brown leaf spot showed that brown leaf spot disease was widely spread in most of the farms visited (Figure 4A and B). All the farms assessed in Kambia and Kenema districts were susceptible to brown leaf spot disease. Resistant and moderately resistant farms were only found in Moyamba district. The distribution map of the severity of brown leaf spot showed that susceptible and moderately resistant farms were found in Kambia and Moyamba districts. All farms in Kenema district were resistant with low severity score.

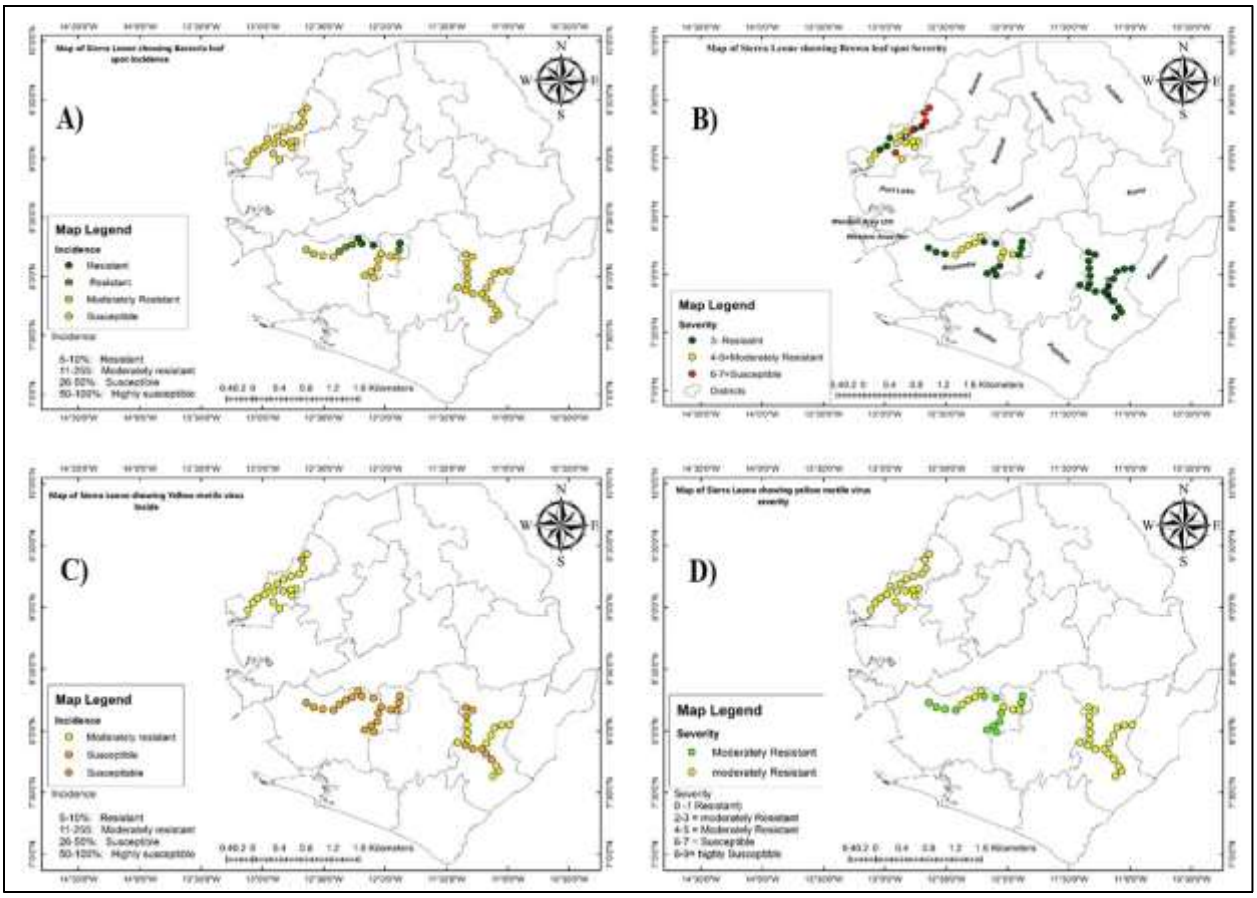

Figure 4: Map of Sierra Leone showing the distribution of (A) brown leaf spot incidence; (B) brown leaf spot severity; (C) rice yellow mottle virus incidence; (D) rice yellow mottle virus severity in three districts

The distribution map of the incidence and severity of rice yellow mottle virus (RYMV) disease showed that RYMV disease was widely spread in all farms visited (Figure 4 C and D). Moderately resistant farms were found in Kambia and Kenema districts and all farms assessed in Moyamba district were susceptible to yellow mottle virus disease. The distribution map of the severity of yellow mottle virus disease showed that susceptible and moderately resistant farms were found more in Kambia and Kenema districts than in Moyamba district. However, few resistant farms with low severity scores were found in Moyamba district.

Discussion

Fungicide application is considered as an effective option for controlling rice diseases. Mancozeb is an effective fungicide that carries out the protective activity of inhibiting spore germination on leaf surfaces (Gullino, *et al*., 2010). The present study explored eco-friendly alternatives, evaluating treatments' impact on growth, disease incidence, and severity. The effects of the tested fungicides in controlling the various rice diseases including fungi (leaf blast, panicle and neck blast) and bacteria (bacteria leaf blight, brown leaf spot, and bacteria leaf streak) and virus (RYMV) indicated that Treatments Mancozan 80WP at 3.37 g/L and Copper hydroxide at 2.02 g/L were effective in promoting growth and reducing disease incidence and severity. These findings concur with Kongcharoen, *et al*. (2020) who reported that fungicidal application is an effective option in controlling rice diseases in Thailand. Moreover, the use of a broad-spectrum fungicide such as Mancozan 80%WP is noted with the best fungicidal activity among fungicides used in inhibiting *P. oryzae* in the laboratory with the lowest EC_{50} value of 0.206 ppm. Mancozan 80%WP was also found with a low-level activity against both rice blast and dirty panicle diseases in field tests compared to the other fungicides. Significant treatment effects were also found for grain yield and yield components (panicle length, spikelet number, and 1000-grain weight) of rice including. Treatments Neem leaf extract at 1.5 g/L and Mancozan 80%WP at 3.37 g/L showcased potential in enhancing panicle length and spikelet number, indicating their role in improving crop productivity and disease management. Tricyclazole and mancozeb were reported to exhibit the greatest and the least levels of fungicide activity against rice blast disease at 67.9% and 5.5%, respectively (Chen, *et al*., 2013). The efficacy of 50% carbendazim in controlling rice blast disease was 59–61% (Chen, *et al*., 2013).

On-farm assessment for major diseases across selected rice growing districts of Sierra Leone revealed widespread prevalence of diseases with varying levels of susceptibility. In the present study, leaf blast, bacteria leaf streak disease, brown leaf spot, rice yellow mottle virus (RYMV), and panicle blast diseases were widely spread in all farms assessed. These findings corroborate with Adur-Okello, *et al*., (2020) who opined that RYMV, leaf blast, brown spot, sheath rot, panicle blast and bacterial leaf blight are the most important disease in rice production in Uganda.Findings also support the view that geospatial analytical technique depicts spatial patterns of disease incidence and severity in farmers' fields suggesting links between disease and potential risk factors of a geographic area (Waller, 2001). The disease mapping or visualization in this study describes geographic patterns of diseases.

Conclusion

This study demonstrates the potential of disease management options in improving rice disease management that could be exploited for increased rice production and productivity. Findings provide valuable insights for the development of sustainable and eco-friendly disease management approaches, contributing to food security in Sierra Leone. Application of Mancozan 80WP at 3.37 g/L and Copper hydroxide at 2.02 g/L were established as effective in controlling diseases and boosting rice production. The study also successfully generated distribution maps of key diseases of rice in Sierra Leone using geospatial analysis technique. Findings established that useful genetic variability exists in the regional distribution of diseases of that provide useful guide for plant breeders, plant scientists, students, lecturers, policymakers, research and development partners. It also provides a data base for policy makers, rice breeders, plant scientists, conservationists, farmers as well as other rice value chain actors to make informed decision for genotypic selection for production, conservation, utilization, and/ or genetic improvement in a rice breeding program based on existing genetic variability in rice germplasm.

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