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Response of rice husk biochar coating on seed quality and productivity of rice in Fogera Plain, Ethiopia

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Abstract
The primary factors contributing to poor seed quality and lower rice yields are largely attributed to inadequate seed quality management strategies. The quality of rice seeds and productivity in the Fogera Plain of Ethiopia suffer from prolonged seedling emergence, and insufficient seedling growth. Coating rice seeds with rice husk biochar (RHB) can significantly enhance seed quality and productivity. However, researchers have not yet investigated the optimal ratio of RHB to rice seeds for effective coating in the region. Therefore, this experiment was conducted both in a greenhouse and laboratory conditions to evaluate seed quality characteristics and the impact of varying concentrations of RHB on rice seed quality and productivity. A completely randomized design was employed with three replications, testing RHB at ratios of 0%, 10%, 20%, 30%, and 40% grams of RHB per kilogram of rice seeds. Accordingly, our findings indicated that a coating of 20% of RHB with rice seeds significantly ($P \leq 0.05$) improved the standard germination percentage, germination speed, and vigor index I compared to the other treatments. Furthermore, this treatment notably increased grain yield, above-ground biomass, and panicle length compared to the control group. In this respect, the results demonstrate that 20% of RHB treated rice seeds yielded higher grain output but also exhibited a more substantial response to biochar seed coating, resulting in a net benefit of 302,800 ETB per hectare, compared to 182,500 ETB per hectare for the control. It is advisable to use a coating concentration of 20% of RHB in proportion with rice seeds as an effective management strategy to promote early germination, enhance vigor, increase grain yield and reduced grain discoloration in Fogera Plain and similar rain-fed rice growing regions.

Keywords Grain discoloration, Rice husk biochar, Rice seed coating, Vigor

1 Introduction

Rice is a staple food crop vital to global food security [9]. Currently, the rising food demand has led to increased pesticide usage in rice cultivation; however, widespread pesticide application poses significant risks to human health and the environment [11]. As global populations grow and environmental pressures intensify, enhancing the resilience and sustainability of rice production becomes increasingly important [4]. Mosaberpanah and Umar [23] demonstrated that approximately 750 million tons of rice are produced annually, resulting in about 160 million tonnes of rice husks. Unfortunately, this waste is improperly managed and discarded, leading to significant environmental issues. In this context, environmentally friendly and sustainable alternatives that reduce harm are highly desirable [5]. Rice breeding techniques, including molecular marker-assisted selection and gene editing, have been streamlined to address costly approaches to improve rice quality, seed security, and the evolving agricultural demand [32]. However, affordable alternatives were studied from rice-husk biochar. Accordingly, Recent studies highlight biochar as an economically important component in seed coating formulations, prized for its porosity, water-holding capacity, and nutrient availability. This has led to a notable increase in interest in biochar-based seed coatings. Additionally, biochar seed coatings promote plant emergence and growth while enhancing nutrition and overall productivity [37]. Karam et al. [15] also identified rice husk biochar as an ideal soil amendment that can enhance soil fertility and improve the effectiveness of other fertilizers. A related study by Olanrewaju et al. [27] demonstrated that rice-husk biochar (RHB) is a silicon-rich soil amendment that holds great potential for improving soil health and supporting sustainable rice production practices.

Utilization of rice-husk biochar could also be used to improve rice quality [10]. Rice-husk biochar coating is indeed a promising technique for improving seed quality and enhancing seedling establishment [35]. Numerous studies, including those by Zhang et al. [36], [37], Singh et al. [31], Zhang et al. [35], and Asadi et al. [3], provide evidence that applying rice husk biochar to seeds before sowing can enhance germination, increase seedling vigor, and enhance productivity per unit area. The possible ways how RHB could enhance rice quality and yield might be better retention in water and nutrients.

Despite the suitability of the Fogera Plain in Ethiopia for rice cultivation, low productivity persists due to inadequate seed quality management strategies. There is limited research in Ethiopia on the effects of optimal rice husk biochar coating to improve seed germination, vigor index, grain discoloration and yield which adversely affects rice seed marketability. Additionally, the effects of different biochar coating concentrations on rice growth under Fogera-specific conditions have not been thoroughly studied. Therefore, this study aims to determine the appropriate amount of rice husk biochar (RHB) coating kg^{-1} of rice seeds (as percentage ratio) to enhance physiological quality and productivity in the improved rice seeds of '*Selam'* variety grown under rain-fed conditions in the Fogera Plain, Northwestern Ethiopia. Therefore, the objective of this study was to evaluate the response of rice seed quality and productivity to different levels of rice husk biochar coating in the Fogera Plain, Ethiopia.

2 Materials and methods

2.1 Study area

The experiment was conducted in a greenhouse and laboratory during the 2024 cropping season at the Fogera National Rice Research and Training Center in the Fogera District, Northwestern Ethiopia. The experimental site is situated at an elevation of 1,815 m above sea level, at coordinates 11°58'00" N latitude and 37°41'00" E longitude (Fig. 1). The predominant soil texture in the research area is clay, characterized by its tendency to swell and crack. The soil's available phosphorus (P) level is 9.85 mg/kg, and

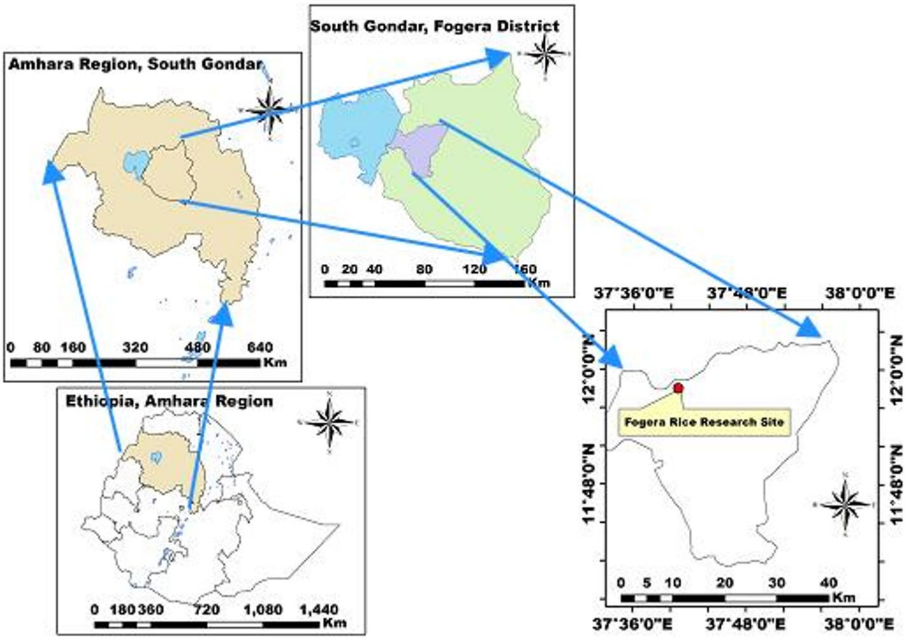

Fig. 1 Location map of the study area

total nitrogen (N) content is 0.21%, both classified as medium. Additionally, the cation exchange capacity of the surface soil is high, measuring 57 meq/100 g of soil (Molla et al. [22]).

2.2 Experimental design and procedures

The popular improved seeds of '*Selam*' rice variety was obtained from Fogera National Rice Research and Training Center. The pot experiment involved five different biochar application rates. Biochar was applied to the seeds in optimized amounts of 0%, 10%, 20%, 30%, and 40% of biochar to rice rice seed ratio, with three replications for each treatment. To produce the rice husk biochar, we used a burner container with air restriction. A potato juice extractor was employed to extract starch from the potatoes, and the collected juice served as an adhesive for applying the biochar to the rice seeds. One kilogram (1 kg) of potato was used for starch extraction for each of the coating treatment. Adherence percentage of 10% of the weight of rice-husk biochar was taken to calculate the amount of starch required and potato required to achieve 10% of starch for respective treatments was calculated. Then, the treatments 10%, 20%, 30%, and 40% of biochar to rice seed ratio. Finally, rice seeds were coated with 2 ml, 4 ml, 6 ml, and 8 ml of potato starch per a single rice seed, respective to each treatment. The coated seeds were then stored in a refrigerator for approximately two weeks before sowing.

Soil samples were collected from the experimental station at a depth of up to 20 cm, specifically from the topsoil designated for planting. These samples were dried, powdered, and sieved through a 2.0 mm mesh. Treatments were set up in 15 plastic pots, each measuring 60 cm in diameter at the top, 30 cm at the base, and 40 cm in height, filled with the prepared soil. The soils were kept moist with water for one week to maintain field capacity.

Each growing pot contained 24 rice seeds arranged in twelve hills, where 12 pots were coated with RHB whereas three pots containing uncoated (control) seeds. After 25 days,

Fig. 2 Rice husk in the stove (**a**), Burning rice husk gasifier stove (**b**), Produced rice husk biochar (**c**)

Fig. 3 Grant Squirrel SQ2020 data logger

thinning was undertaken for the seedlings in each container to achieve an optimal plant population. For data collection, we focused on the rice plants from the central six hills, accounting for any border effects.

2.2.1 Preparation of rice husk biochar

Paralizer was utilized with silicon-enhancing properties to produce rice husk biochar (RHB). As illustrated in Fig. 2, the pyrolysis of rice husk biomass occurred in a gasifier stove designed for restricted oxygen conditions, resulting in the production of gas, tar, and char. The cylindrical reactor of the gasifier stove, shown in Fig. 2b, is constructed from 3 mm mild steel and measures 0.19 m in diameter, 0.665 m in height, and has a volume of 0.019 m^3.

According to Belonio [6], when the fuel is ignited from the top, where a fan supplies limited airflow, the burning layer of rice husks-referred to as the combustion zone-descends through the reactor. Each batch of the gasifier stove consumes approximately 2.51 kg of husk. The silicon component during pyrolysis is effectively utilized at temperatures ranging from 300 to 600 °C without oxygen [31]. Rice husks can be converted into biochar at various pyrolysis temperatures between 150 and 700 °C [28]. For our process, we employed a temperature of 500 °C in the pyrolizer to create biochar. The procedure for converting rice husks into biochar is depicted in Fig. 2a. This process involves igniting a pile of rice husks using the gasifier stove (Fig. 2b) and allowing the 2.51 kg of rice husks to burn gradually.

A temperature-measuring data logger, supplied by an industrial equipment provider in Chesterland, Ohio, USA, was inserted into the reactor chamber, as shown in Fig. 3. This data logger measured the temperature generated by the combustion of rice husks in the stove's reactor, as well as the associated heat production and losses. Squirrel 2020 model data loggers were utilized in this research, which feature high-performance capabilities and PC-linked data acquisition systems. During the experiment, we recorded the time required to produce charcoal. After allowing the reactor to cool to room temperature, we collected the char from the reactor.

Biochar was ground into powder using a locally manufactured pyrolizer, similar to a hammer mill (Fig. 4a). This machine features welded pegs arranged in a chain configuration around a revolving shaft, as illustrated in Fig. 4a. The pyrolizer is equipped with a drive motor, shaft, hopper, power transmission system, and a chain structure with welded pegs. To transfer power from the motor to the shaft, the transmission system employs a pulley and belt. A single-phase, 1.5-kilowatt motor ensures the machine operates efficiently. In this setup, rice husk materials are fed into the machine, where they come into contact with a tapered, rotating peg chain. The high-speed rotation of the peg chain crushes the biochar, and the resulting powder is discharged through the outlet of the machine.

2.2.2 Characteristics of Rice-husk biochar (RHB)

Rice husk biochar (RHB) was produced from Fogera Plain rice-milling by-products via pyrolysis at 400–600 °C for 2 h under limited oxygen, yielding a stable char suitable for soil amendment and briquetting [17]. Characterization included proximate analysis, pH and electrical conductivity, elemental composition (C, H, N), BET surface area, FTIR functional groups, and SEM/XRD structural analysis [21]. RHB typically contains ash 15–30%, fixed carbon 40–60%, pH 7.5–9.5, C: N ratio > 50, and BET surface area 50–350 $m^2\ g^{-1}$, with high silica content, low H/C and O/C ratios, and abundant functional groups that enhance cation exchange and nutrient adsorption [17, 21]. Biochar derived from rice husks is shown to enhance soil characteristics and improve fertilizer efficiency, leading to greater nutrient absorption by plants. The application of 10 g of biochar has resulted in an increase in the macro nutrient content of the soil. In addition to carbon, biochar contains other components including 50% cellulose, 25–30% lignin, 15–20% silica, 10–15% moisture [12, 31].

2.3 Data collection

Data was collected on standard germination, germination speed, plant height, panicle length, above-ground biomass, the number of discolored rice seeds, vigor index I (VI-I), and grain yield. ISTA, [14] procedures were adopted to evaluate the quality of rice seeds.

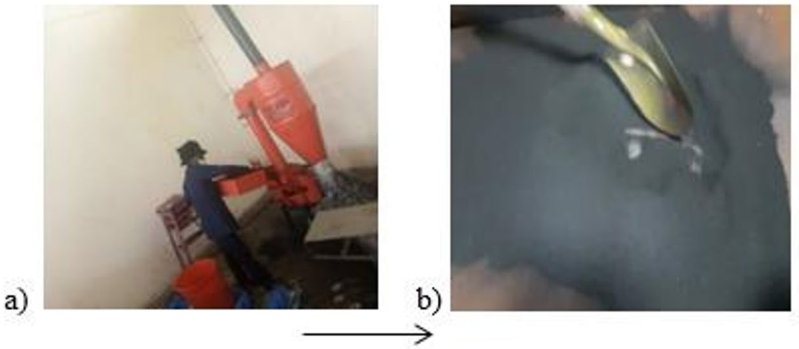

Fig. 4 Biochar miller machine (**a**), Rice husk biochar powder (**b**)

2.3.1 Average percentage of germination

Germination box was utilized to sow 100 rice seeds, with four replications for each trial. Fourteen days after placing the seeds on germination paper, the final germination percentage was recorded. This was calculated using the formula:

$$Standard\ Germination\ Percentage = (Number\ of\ Normally\ Germinated\ Seeds/Total\ Seeds\ Sown) \times 100$$

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2.3.2 Speed of germination

To measure germination speed, 100 seeds were planted in germination boxes, again with four replications. Five days post-seeding, we recorded the number of germinations from each experimental pot. The number of seeds that germinated each day for fourteen days was counted. Speed of germination was calculated by dividing the total number of germinated seeds by the corresponding number of days.

2.3.3 Seedling vigor index I

Seedling vigor index was calculated using the formula from Abdul-Baki and Andersen [1]. This involved multiplying the average sum of the shoot and root lengths by the standard germination percentage.

2.3.4 Plant height

At maturity, plant height was measured the height of five randomly selected plants from each pot using a measuring tape. Measurements were taken in centimeters from the ground to the tip of the panicle, and we calculated the average plant height.

2.3.5 Measurement of panicle length

At maturity, panicle length was determined the average length of five randomly selected panicles from each pot, measuring from the base to the tip.

2.3.6 Unfilled grains count

Unfilled grains were counted the number of unfilled grains per panicle from five randomly selected panicles in the net plot of each treatment and calculated the average.

2.3.7 Discolored rice grains

Discolored rice grains were counted from each experimental units of the rice-husk biochar treatments.

2.3.8 Grain yield and above-ground biomass

After harvesting the entire crop from each pot, grain yield and above-ground biomass yield were measured. Following the recommendations of Mulvaney and Devkota [24] to achieve a grain moisture content of 14%, threshed grains were weighed from each pot and converted this weight into tons per hectare. To calculate the dry matter accumulation of above-ground biomass, the total amount of oven-dried biomass from each pot was weighed. All plant tissues were dried in a forced-draft oven at 70 °C until they reached a constant weight.

2.4 Statistical analysis

For all measured parameters, normality was tested using the Shapiro-Wilk test of normality. Whenever the treatment effects were found significant, treatment means were compared using the least significant difference (LSD) test at 5% [8] and using the Statistix 10 software.

3 Results and discussion

3.1 Standard germination

The effect of rice husk biochar (RHB) coating dose on physiological parameters was presented in Table 1. It was found that the amount of rice husk biochar (RHB) coating was significantly ($P \leq 0.05$) affected by the standard germination percentage, with effects most pronounced at a rate of 20% as depicted in Table 1. Rice seeds coated with 20% of RHB exhibited significant improvement in standard germination percentage compared to non-coated control, with values of 95.33% and 66.67%, respectively. This enhancement might be attributed to rice husk biochar's ability to improve seed coating via water retention capacity and nutrient availability, thereby facilitating easier access to moisture and nutrients for seed imbibition followed by germination. This result was found to be in line with prior research by Zhang et al. [35], who demonstrated that RHB coating enhanced water and nutrient uptake (utilized for imbibition), which is vital for early seedling development. Similarly, Liu et al. [18] demonstrated that coating concentrations (20–40%) were more effective whereas coatings beyond such concentrations showed to inhibit seed germination and related traits probably due to nutrient imbalances. Additional studies by [37] and [16] outlined that coating with rice-husk biochar improved seed germination.

3.2 Speed of germination

The different amount of rice husk biochar coating had a significant ($P \leq 0.05$) influence on the rate of germination. The 20% RHB-coated seeds had the fastest germination rate (86.43%; $p \leq 0.05$), much faster than the non-coated control (55.23%) (Table 1). This enhancement might be attributed to the biochar seed coating's ability to improve moisture and nutrient availability, facilitating quicker and more uniform germination of the rice seeds. These findings were consistent with the study by Zhang et al. [36], who found that seed coating with an appropriate ratio of rice husk biochar significantly increased rice emergence and rapid seedling establishment. Furthermore, Danapriatna et al. [7] demonstrated that an optimal combination of biochar coating with fertilizer applications

Table 1 Effect of RHB coating concentrations on physiological parameters

RHB (%)	SHL(cm)	SPG (%)	SG (%)	VI-I
0	10.95^{c}	55.23^{e}	66.67^{e}	1425.6^{e}
10	13.74^{b}	81.03^{b}	88.00^{b}	2188.6^{b}
20	15.57^{a}	86.43^{a}	95.33^{a}	2546.6^{a}
30	13.47^{b}	78.06^{c}	83.67^{c}	2047.3^{c}
40	13.25^{b}	66.43^{d}	76.00^{d}	1860.60^{d}
LSD 0.05	1.8194	2.582	3.658	71.760
SEM (±)	0.5773965	0.820	1.161	22.773
CV (%)	7.46	1.93	2.45	1.96

RHB Rice Husk Biochar, *SHL* Shoot Length, *SPG* Speed of Germination, *SG* Standard Germination, *VI-I* Vigor index-I, *SEM* standard error of the mean, *CV* coefficient of variation. Means in the Table for the same parameter followed by the same letter(s) are not significantly different from each other at a 5% level of significance resulted in an improved germination speed in lowland rice, further supporting the beneficial role of biochar in promoting rapid seed germination and early growth.

3.3 Shoot length

The amounts of rice husk biochar coating had a significant ($P \leq 0.05$) effect on the length of the shoot. The findings indicated that, at 15.57 cm the rice seeds coated with 20% of RHB ($p \leq 0.05$) had the longest shoot length, much longer than the non-coated control (10.95 cm) (Table 1). This suggests that the 20% RHB coating enhanced the soil's ability to retain water and bioavailability to nutrients to the seeds. The porous structure of biochar likely facilitated the retention of water and nutrients close to the seeds, thereby promoting early seedling growth. Similar study by Pratiwi and Shinogi (2016) demonstrated that the application of rice husk biochar led to improved shoot length. Nevertheless, Zhang et al. [35] found that 30% RHB as an optimal biochar concentration to increase in seed emergence, and shoot length compared to untreated seeds.

3.4 Vigor index-I

Vigor index-I is a composite measure of seedling development, germination and field performance. The different quantities of rice husk biochar coating showed a significant effect on the vigor index-I($P \leq 0.05$). The 20% RHB-coated seeds (2546.6) showed the highest vigor index (VI-I) ($p \leq 0.05$), much higher than the non-coated control (1425.6) (Table 1). This further underscores the beneficial effects of RHB coating on the overall vigor and performance of rice seedlings. In this context, a study by Zhang et al. [35] demonstrated that rice husk biochar-coated rice seeds significantly increased the seedling vigor index-I compared to uncoated seeds. Similarly, Shen et al. [30] found that the seedling vigor index was markedly enhanced by rice husk biochar seed coating when compared to the control group. They suggested that biochar improved the physical properties of the soil and enhanced nutrient retention, thereby promoting the growth and vigor of early seedlings. Parallely, Madsen et al. [19] also demonstrated that extruded pelleting could enhance seedling emergence for low-vigor species.

3.5 Number of discolored rice seeds

The number of discolored rice seeds from each treatment sample was used to quantify the incidence of rice seed discoloration. When 10% and then 20% of biochar concentration were used, the least amount of contaminated rice seeds was discovered. Conversely, using 40% of rice husk biochar-coated rice seeds resulted in the largest number of rice seeds becoming discolored, and similar outcomes were shown with the non-coated control seeds (Fig. 5). This could be a new innovation that the silicon from the biochar made from rice husks allows for a possible decrease in the discoloration of rice seeds. Similar studies demonstrated that the beneficial effects of nutrients in reducing water deficit stress in plants, such as the application of silicon, which has drawn attention by enhancing plant resistance to abiotic stress, especially [20].

3.6 Plant height

The concentrations of the rice husk biochar coating had a significant ($P \leq 0.05$) influence on plant height. Plant height could be an indicative of vigor of a seed, which encompasses all agronomic parameters. The concentrations of the rice husk biochar coating

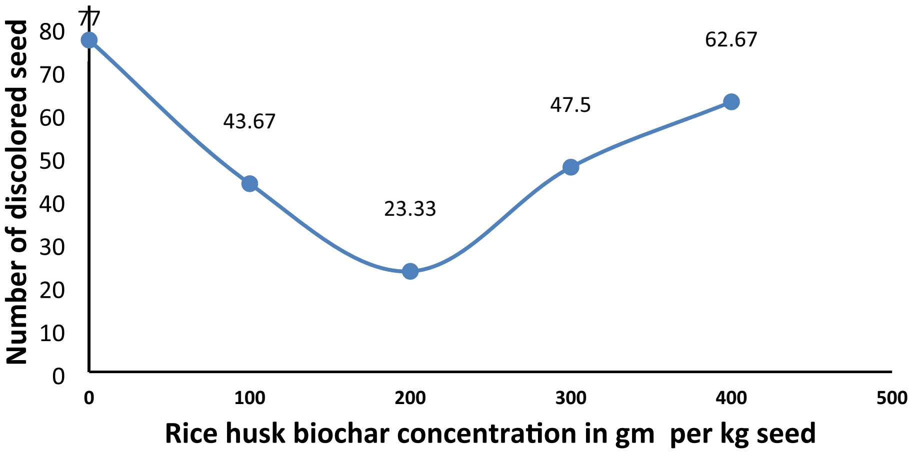

Fig. 5 Incidence of rice seed discoloration among different biochar coating concentrations

Table 2 Effect of RHB coating concentrations on yield-related parameters

RHB (%)	PH (cm)	PL (cm)	AGB (t/ha)	GY (t/ha)
0	68.67^{C}	16.20^{C}	4.3t/ha^{d}	3.61^{d}
10	80.00^{b}	21.32^{a}	5.8t/ha^{b}	5.32^{b}
20	87.33^{a}	22.68^{a}	8.5t/ha^{a}	6.42^{a}
30	78.98^{b}	18.67^{b}	5.7t/ha^{b}	5.31^{b}
40	77.67^{b}	18.67^{b}	5.2t/ha^{c}	4.31^{c}
LSD 0.05	5.5588	2.1151	0.4535	0.4688
CV (%)	2.49	5.96	4.23	5.16
SEM (±)	1.13	0.6712	0.144	0.149

RHB Rice Husk Biochar, *PH* plant height, *PL* panicle length, *AGB* above-ground biomass t/ha, *GY* grain yield t/ha, *SEM* standard error of the mean, *CV* coefficient of variation. Means in the Table for the same parameter followed by the same letter (s) are not significantly different from each other at a 5% level of significance

significantly ($P \le 0.05$) influenced plant height. In comparison to the non-coated control seeds, which measured 68.67 cm, the plant height in the 20% RHB treatment was much higher (87.33 cm). Plant height was statistically equivalent for all other treatments coated with rice husk char (Table 2). This result is in line with Oladele et al. [26] who revealed that applying rice husk biochar in combination with nitrogen fertilizer significantly increased plant height compared to untreated plants. The increased water availability and nutrient retention that biochar offers might be the cause of this increase in plant height.

3.7 Panicle length

Table 2 depicts the significant impact of rice husk biochar coating concentrations on panicle length ($P \le 0.05$). The panicle length of 20% RHB coating resulted in substantially lengthier (22.67 cm) compared to the non-coated control, which was only 15.00 cm (Table 1). This result suggests that coating the 20% of rice seed enhanced the reproductive development of the rice plants, leading to the formation of larger panicles. This might be due to the retention of more plant assimilates. Similarly, Abdillah et al. [2] outlined that a rate of 20 t ha^{-1} application of RHB combined with fertilizer improved panicle length. However, Danapriatna et al. [7] reported no significant effects of biochar on panicle length.

3.8 Number of unfilled grains per panicle

The amounts of rice husk biochar coating significantly ($P \leq 0.05$) impacted the number of unfilled grains per panicle. The 20% of RHB rice seed treatment resulted in a considerably lower number of unfilled grains per panicle compared to the non-coated control, which averaged 14.67 and 33.33, respectively. This finding indicates that the 20% of RHB rice seed treatment reduced the number of unfilled grains in the panicles and improved grain filling (Table 2). This might be due to optimal nutrient availability to the panicles and sufficient photo assimilates, whereas nutrient balance would occur in the subsequent growth stages.

3.9 Above ground biomass

Concentrations of rice husk biochar coating had a significant ($P \leq 0.05$) impact on aboveground biomass (AGB). The above-ground biomass in the 20% RHB treatment measured considerably larger at 8.5 t/ha compared to the non-coated control and 10% RHB of rice seed treatments, which were 4.3 t/ha and 4.5 t/ha, respectively (Table 2). This finding suggests that the 20% RHB of rice seed treatment enhanced the plant's total vegetative growth and dry matter accumulation. A similar study by Oladele et al. [26] demonstrated that the synergistic application of rice husk biochar and nitrogen fertilizer improved the above-ground biomass of rain-fed rice. Yin et al. [34] outlined that applying 4 tones per hectare of nitrogen enriched-biochar enhanced total rice plant biomass.

3.10 Grain yield

In comparison to the treatments of 40%, 30%, 20%, 10%, and non-coated control (which yielded 4.31 t/ha, 5.32 t/ha, 6.42 t/ha, 5.32 t/ha, and 3.61 t/ha, respectively), the grain production in the 20% RHB was significantly ($P \leq 0.05$) higher (6.42 t/ha). This finding indicates that the coating proportion of 20% RHB coating of rice seed most effectively enhanced the overall productivity and grain output of the rice plants (Table 2). These outcomes agree with those of a more recent meta-analysis by Ye et al. [33], which found that the application of biochar generally raised crop yields, including rice yields. Similar research by Huang et al. [13] showed that biochar might be a useful addition to the soil for increased yields. Additionally, Singh et al. [31] showed that when RHB (rice husk biochar) and CSR-BIO (commercialized bio-formulation) treatments were applied to plots, the yield of rice grain was found to be higher than when untreated (control) plots. Furthermore, similar studies by Chen et al. (2023), Munda et al. [25] and Sheikhnazari et al. [29] demonstrated that the application of rice-husk biochar to rice seeds significantly improved the number of effective panicles per plant, associated number of grains per panicle, and greater yield which indicates enhanced nutrient availability and absorption.

3.11 Partial budget analysis

To evaluate the economic viability of the three-year average of the various rice husk biochar seed coating of field price data, a partial budget analysis was carried out. The partial budget analysis results indicated that the application of 20% of rice seed, produced the highest net benefit (302,800ETB ha^{-1}), followed by biochar 10% of rice seed, which produced a medium-level net benefit (NB) (257,140ETB ha^{-1}), and the control treatment, which produced the lowest net benefit (182,500ETB ha^{-1}) (Table 3). The crop cycle must be longer than 4–5 months, and the suggested technique must be new to the farmers, for

Table 3 Partial budget analysis for responses of rice production to rice husk biochar seed coating in Fogera Plain, Ethiopia

Partial budget analysis	**Treatment**				
	T0	**T1**	**T2**	**T3**	**T4**
Rice-husk biochar (kg Qt^{-1})	0	10	20	30	40
Average yield (t/ha)	3.61	5.32	6.42	5.31	4.31
Adjusted grain yield (t/ha)	3.25	4.79	5.8	4.96	3.90
Gross benefit (ETB ha^{-1})	227,500	335,300	406,000	347,200	273,000
Total variable cost (ETB ha^{-1})	45,000	78,160	103,200	128,200	153,200
Net benefit (ETB ha^{-1})	182,500	257,140	302,800	219,000	119,800
Marginal rate of return (MRR) (%)		225.1	182.3	D	D

T0, 0 kg RHB Qt^{-1}; T1,10 kg RHB Qt^{-1}; T2, 20 kg RHB Qt^{-1}; T3, 30 kg RHB Qt^{-1}; T4, 40 kg RHB Qt^{-1}; where Qt, a quintal (100 kg) of selam rice seed; ETB, Ethiopian Birr

a treatment to be considered meaningful to them with 100% of the minimum acceptable rate of return (CIMMYT, 1988). The biochar seed coating treatments weighing 10% of rice seed and 20% of rice seed (recommended for direct seeding a hectare of paddy field) met the requirements. Nevertheless, it was shown that the application of 10% of rice seed had the highest MRR (225.1%), followed by 20% with medium level MRR (182.3%), the least, and 40% with the lowest MRR (130.4%) (Table 3). According to CIMMYT (1988), the suggestion does not always depend on the highest MRR. Farmers should find the net benefits change from one treatment to the next to be appealing as long as the MRR treatments surpass the minimum acceptable rate of return. Therefore, 20% of biochar seed coating is best advised for rice production at Fogera Ethiopia, as Table 3 shows the largest net benefit (302,800ETB ha^{-1}) with an appropriate amount of MRR (182.3%). Additionally, the net benefit of 10% (182,500ETB ha^{-1}) was larger, and MRR treatments might be suggested to nearby farmers as a substitute method (Table 3).

4 Conclusion

The current study concluded that the optimal ratio of rice husk biochar to rice seeds (20% concentration of rice husk biochar) significantly increased the rate of germination, germination percentage, vigor index, above-ground biomass, and grain production while reduced grain discoloration. This optimal treatment also contributed for a significant yield increase (6.42 t/ha) compared to other treatments including the non-primed control. In turn, the seed treatment ensured higher grain yields, indicating economic benefits of optimal rice husk biochar applications. This study showed the promising nature of coating rice seeds with rice husk biochar before sowing for early-generation seed as strategies. In fact, full research consideration on the effects of rice husk biochar coating on various rice varieties and environmental factor considerations would be essential.

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Yilikal Melak Assaye, Dessye Belay Tikuneh and Dr. Tesfaye Molla Desta. The first draft of the manuscript was written by Yilikal Melak Assaye and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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