

# Biochar Application for Rice Cultivation in Salt-Affected Soils

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## Research

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# Abstract

In many areas, soil salinization is a major threat to ecosystems, agriculture, and food security. Human activities and climate change contribute to its increasing prevalence. In Thailand, Nakhon Ratchasima is the most severely affected province in the country's Northeast region, and was selected for this study. The underlying geology and human activities both contribute to the problem in this area. The roots of field crops bring saline groundwater up into the rhizosphere. Evaporation at the soil surface leads to salinization, reducing crop growth, and, ultimately, rendering the soil barren. This research aimed to improve the quality of saline soil using rice husk biochar (RHB) to enable rice cultivation and limit evaporation. The study examined the effect of RHB incorporation on improving the soil properties. Jasmine rice variety KDML 105 was planted in cement rings (80 cm diameter) filled with saline sodic soil at pH 10.6, with a total sodium content of 0.83%, electrical conductivity (EC) of 68.6 dS/m, and sodium adsorption ratio (SAR) of 11707. The results indicated that RHB can significantly reduce the soil salinity, EC, Na<sup>+</sup> content, and SAR value, while elevating the levels of available macronutrients, such as nitrogen, calcium, and magnesium. In addition, the study found that incorporation of RHB at a rate of 1.5 kg/cement ring was optimal for growing Jasmine Rice (KDML105) under these conditions.

## 1. Introduction

Salinization currently affects approximately 10 million km<sup>2</sup> of soils worldwide. While the geological conditions are the underlying cause [1], it is exacerbated by land use (farming and deforestation) and poor water management. Climate change further aggravates the impacts through changing rainfall frequency and intensity, droughts, and higher temperatures and evaporation rates. As a consequence, salt-affected areas around the world are expanding [2]. Saline soil impacts on ecosystems and land use and reduces agricultural productivity [3, 4]. Soil salinization, therefore, represents a serious threat to global food and nutritional security.

The Northeast region of Thailand is the country's most severely saline soil affected region, with Nakhon Ratchasima (14° 58' 16" N, 102° 5' 59" E) the most severely impacted province. Of its total area of approximately 20,494 km<sup>2</sup>, about 4,810 km<sup>2</sup> (23.47%) is affected by soil salinization, which is distributed across the lowlands (53.33%), plateau (46.66%), and salt farming areas (0.02%). Approximately 3.75% of these saline soils cannot be cultivated and are abandoned [5]. Kham Thale So District (15° 2' 11" N, 101° 55' 54" E) is a salt-affected critical area of Nakhon Ratchasima Province. Approximately 214 km<sup>2</sup> or 71.47% of the district area is salinized [6] (Fig. 1).

Salt-affected area in Kham Thale So comprises lowland area (29.15%) and high land area (69.15%). The salt-affected area in the province resulted from the layers of rock salt underneath the land that contributes directly to the saline soil on the top surface. High land (69.15%) with a rock salt layer underneath which has the high salinity distribution potential [5, 7]. Four different concentration levels of salt-affected area were found scattered in the lowland area: 10.75% of the total area is heavy level (more than 50%), 5.08% is high level (10–50%), 4.75% is moderate level (1–10%), and 8.57% is low level (less than 1% of salt stains) [7]. Several areas of Kham Thale So District suffer from low agricultural productivity with some areas that are no longer cultivable (Fig. 2).

Three practical methods of desalinization are available. The first is remediation with physical methods, such as salt washing, drainage, etc. [8, 9]. The second is remediation with chemical methods, such as adding gypsum, calcium chloride, etc. [3, 10], while the third is remediation with biological methods, such as planting salt-tolerant varieties, or adding organic matter (OM), such biomass, organic fertilizer, rice husk, and biochar [5, 11–14]. Desalinization by biological methods is considered an efficient and appropriate treatment, since OM is easy to find and the operation

is not complicated. In addition, farmers can do this at the same time as cultivation, which reduces the labor and costs [14, 15].

Biochar is a form of charcoal produced from biomass through pyrolysis, a controlled combustion process conducted under limited oxygen conditions at a controlled temperature [14, 16, 17]. The high carbon (C) content and persistence of biochar offers an opportunity for the long-term storage of C through soil sequestration to mitigate greenhouse gas emissions from agriculture [18, 19]. The porosity, vast internal surface area, and negatively charged ions at the surface, make biochar useful as a soil amendment to improve the soil quality and boost crop yields and quality [15, 20–22], and restoration of contaminated soil [23]. Biochar also helps plant nutrients remain in the soil for a long time [24–27]. Moreover, biochar makes plants have more roots, the roots are deep and more growth [28, 29].

A number of studies have indicated that mixing biochar with soil can effectively improve the soil's physical and chemical properties [30–33], with biochar also improving the drainage, aeration, and water retention in clay [34], sandy [35, 36], hard and compact [17], acidic [28, 37], alkaline [38, 39], and saline soils [4, 40–42]. Biochar can increase the nutrient uptake ability of plant roots [43–46].

The efficiency of biochar in this aspect depends on the feedstock characteristics and pyrolysis conditions [16, 47, 48], and also on the soil type. Saline soils are of particular interest [15, 49]. According to Wijitkosum [5], although rice husk biochar (RHB) was found to improve the properties of saline soils and to render them more suitable for rice cultivation, the upward migration of saline groundwater to the soil surface poses an important challenge for remediation.

To address this challenge, this study investigated the extent to which the migration of saline groundwater to the surface might be mitigated by planting rice in cement rings and limiting the amount of water provided. In addition, the study aimed to investigate the effects of RHB on the soil quality and on the growth and yield of Jasmine Rice (KDML105) cultivated in these soils. The study aimed to improve the properties of saline soils that are no longer able to support crop growth by applying RHB, which is not only derived from an abundant agricultural waste and is easily available in the local area, but also the production of RHB is not complicated and has a low production cost, but results in a high-quality biochar. Thus, this study aimed to evaluate RHB as a model for solving the problem of saline soil in saline crisis areas to allow sustainable agriculture and so lead to increased food security in agricultural countries.

## 2. Materials And Methods

### 2.1. Materials preparation

In this study, RHB was produced by drying rice husk for 1–2 d and then placed into the “Controlled Temperature Rice Husk Biochar 4 × 200 liters Retort for Slow Pyrolysis Process” (patent number: 1601001281). This is an appropriate technology as it is small-scale, affordable, and utilizes locally available materials, with a controlled-temperature pyrolysis between 400–500 °C [5, 15].

The organic fertilizer was produced from cow manure, which are raised by local farmers, and had the following properties: pH 8.9, cation exchange capacity (CEC) of 61.33 cmol/kg, electrical conductivity (EC) of 13.21 dS/m, 35.45 wt.% OM, 1.94 wt.% total nitrogen (N), 1.84 wt.% total phosphorus (P), 5.22 wt.% total potassium (K), 2.44 wt.% calcium (Ca<sup>2+</sup>), 0.91 wt.% magnesium (Mg<sup>2+</sup>), and a 10.60 C/N ratio.

Saline soils were collected from Nong Suang, Kham Thale So, Nakhon Ratchasima, Thailand (15° 04' 51.3" N, 101° 54' 17.2" E) (Fig. 1), and had a loamy sandy texture (Fig. 2). The saline soil was sampled by a simple random sampling method, collecting the soil at a depth of 0–30 cm from the soil surface, to a total amount of 1,000 kg. The soil was poured onto a plastic sheet, spread and sun/air dried for 2–3 d. The dried soil was then sifted through a 2-mm sieve to remove unwanted plants or gravel, and were then homogenized by thorough mixing.

## 2.2. Experiment

The experiment was performed at Pong Daeng, Kham Thale So, Nakhon Ratchasima, Thailand (14° 57' 46.2" N 101° 56' 14.9" E), at an altitude of 200–209 meters above sea level, which has an average annual precipitation of 1,000–1,050 mm/y (Fig. 1). The rice cultivation was conducted in-season between August–December 2019.

This study was a completely randomized design (CRD) with four replicates of each of four treatments, totaling 16 experimental units. The planting materials (saline soil, dried cow manure as an OM fertilizer, and RHB) were mixed together at four different levels of RHB: at 0%wt (RHB-0) which was similar to normal rice cultivation of local farmers, at 1%wt (RHB-1), 1.5%wt (RHB-1.5), and 2%wt (RHB-2). Dried cow manure (500 g) was applied before planting (mixed with soil and RHB) and re-applied during the tillering stage (500 g). All the planting materials were thoroughly mixed in cement rings (80 cm diameter x 40 cm depth with bottom cover) and were incubated for 14 d. The rice was cultivated under the transplantation pattern and wet-dry water management technique [50]. This began with the cultivation of rice seeds in fertile soil, as the rice seeds do not grow well in extremely saline soil [5]. For all treatments, rice plants were transplanted as 45-d-old seedlings with 3 seedlings per hill or 15 seedlings per cement ring. The water depth was controlled at 1–2 cm above the soil surface during the seedling stage and at 8–10 cm thereafter. The growth of rice in each cement ring was measured four times, namely at the tillering stage, panicle initiation, booting stage, and maturation stage. The growth and yield data were evaluated in terms of the height, tiller number per hill, panicle number per hill, number of grains per panicle, and grain weight. To characterize the properties of the planting materials, RHB and organic fertilizer were analyzed before planting and the soil was analyzed before mixing, 14 days after mixing with all planting materials, and after rice cultivation.

## 2.3. Method of characterization of plant materials

Analysis methods and parameters studied for the RHB [5] were based on the Standardized Product Definition and Product Testing Guidelines for Biochar that is used in Soil [51], and are as follows: pH [pH meter with 1:2 (v/v) char: water], EC [electrical conductivity meter measuring a 1:5 (v/v) char: water suspension], CEC (leaching method), total N (Kjeldahl method), P content ( $P_2O_5$ ; Vanadomolybdophosphoric acid colorimetric method), K content [ $K_2O$ ; by atomic absorbance spectrometry (AAS)], total C (Shimadzu TOC Tvch), OM, (Walkley and Black method), and porosity and surface area (Brunauer-Emmett-Teller method).

Analysis methods and parameters studied for the organic fertilizer were according to the Thai Land Development Department [52] and were as follows: pH [pH meter with 1:2 (v/v) fertilizer: water], EC (electrical conductivity meter), CEC (ammonium acetate method), total N (Kjeldahl method), P content ( $P_2O_5$ ; Vanadomolybdophosphoric acid colorimetric method), K content ( $K_2O$ ; AAS), Mg and Ca content (AAS), and OM (Walkley and Black method).

Analysis methods and parameters studied for the saline soil were according to the Thai Land Development Department [53] and were as follows: pH [pH meter with 1:1 (v/v) soil: water], EC (electrical conductivity meter), CEC (ammonium acetate method), total N Kjeldahl method), available P (Bray II modified method), exchangeable K,  $Ca^{2+}$ , and total  $Na^+$  (ammonium acetate method),  $Mg^{2+}$  content (saturation water extract), soil texture (hydrometer), and OM (Walkley and Black method).

## 2.4. Data analysis

The characteristic of the mixed soil before and after cultivation and the growth and yield of rice were analyzed for statistical differences using Analysis of Variance (ANOVA) and Duncan's New Multiple Range Test (DMRT) in the Statistical Package for the Social Sciences (SPSS) software and accepting significance at the  $p < 0.05$  level).

## 3. Results And Discussion

### 3.1. Properties of planting materials

The characteristics of the RHB were pH 7.90, EC of 0.35 dS/m, CEC of 17.34 cmol/kg, OM of 13.06%, 0.51% total N, 0.29%  $P_2O_5$ , 1.02%  $K_2O$ , Ca content of 0.10%, Mg content of 0.07%, C content of 45.68%, 9.10 C/N ratio, specific surface area of 41.43  $m^2/g$ , and porosity of 0.03  $cm^3/g$  [5]. The saline soil was characterized as a loamy sandy soil (81% sand, 14% silt, and 5% clay), pH 10.60, CEC of 2.4 cmol/kg, EC of 68.6 dS/m, OM of 0.19%, total N of 203.0 mg/kg, available P of 13.9 mg/kg, exchangeable  $K^+$  of 70.2 mg/kg, exchangeable  $Ca^{2+}$  of 540 mg/kg, exchangeable  $Mg^{2+}$  of 1.14 mg/kg, total  $Na^+$  of 0.83%, and sodium adsorption ratio (SAR) of 11,707. According to the USSS Staff classification [54], the soil was characterized as saline sodic soil.

### 3.2. Effects of RHB on the physiochemical properties of the soil mixture

After mixing all three materials (saline soil, organic fertilizer, and RHB), with the RHB at 0%wt (RHB-0), 1%wt (RHB-1), 1.5%wt (RHB-1.5), and 2.0%wt (RHB-2), respectively, samples were left for 14 d and then analyzed for their pre-cultivation chemical and physical properties. After 120 d of rice cultivation, the post-cultivation soil samples were collected for analysis.

#### 3.2.1. Soil pH value

The pre-cultivation soil mixture pH across the four treatments ranged from 9.82–10.02, increasing slightly (numerically but not significantly) with increasing RHB levels. However, while it was significantly increased in the post-cultivation soil, ranging from pH 0.16–10.48. However, the pH values between the four treatments (RHB-0, RHB-1, RHB-1.5, and RHB-2) were not significantly different. The change in soil pH has been shown to depend on the initial pH of the biochar and the original soil [30–32]. Previous studies reported that the pH of saline sodic and sodic soils decreased after applying biochar [5, 31, 40, 55, 56], which might have resulted from the high amount of  $Ca^{2+}$  and  $Mg^{2+}$  in the biochar that replaced and released  $H^+$  [40], or the result of the high CEC value of biochar promoting the plants to uptake nutrients, such as  $K^+$ ,  $Ca^{2+}$ , and  $Mg^{2+}$ , and to release  $H^+$  from its roots to maintain the soil balance [29].

Liu and Zhang [32] reported that carboxylic acids ( $-COOH$ ) were released from the slow oxidation of biochar. In addition, different soil levels have different pH values. The topsoil had a higher pH than the lower soil layers, due to water evaporation that leaves the ions in the topsoil. On the other hand, many studies have reported that adding biochar to the soil increased the soil pH, which was attributed to  $Na^+$  being washed away from the soil, and depended on the biochar pH and the amount of added biochar [13, 22, 37, 55]. Regardless, the pH is an important parameter that is related to ion precipitation, ion release (e.g., heavy metals and nutrients), controlling soil buffer, CEC values, and soil microbial activity [11, 33].

## 3.2.2. Soil EC

The EC of the pre-cultivation soil mixture varied between treatments and ranged from 61.4 dS/m for RHB-2 to 90.4 dS/m for RHB-1.5, but the EC values decreased significantly in every post-cultivation treatment, ranging from 13.33–29.2 dS/m. However, these numerical differences in the EC between the four treatments were not significant. This result is similar to most previous studies that reported applying biochar to salt-affected soil decreased the EC. The possible mechanisms are reducing the soil density, which causes a greater water flow and Na<sup>+</sup> leaching [12, 13], as the biochar at the soil surface reducing water evaporation, and biochar's high adsorption capacity for salt ions [41, 49], such that various ions are absorbed by the surface functional groups of the biochar [5]. However, the change in the EC of saline soil have been reported to depend on the properties of biochar, the amount of added biochar, mixing time, salinity, and leaching [11, 56].

## 3.2.3. Soil OM

The OM of the pre-cultivation soil mixture in each treatment was in the range of 0.20–0.27%, while in the post-cultivation soil mixture it was in the range of 0.12–0.26%. The OM in the pre-/post-cultivation and between the four treatments were not significantly different. Biochar's porous surface is able to absorb slowly leaching nutrients from the OM and so limit their diffusion resulting in reduced amounts of available nutrients in the short term [26, 27]. Furthermore, biochar can absorb organic compounds and promote polymerization of smaller molecules into larger molecules [23, 24]. However, in order to increase the amount of OM and the plant's uptake, increasing the amount of added fertilizer should be considered.

## 3.2.4. Soil CEC

The CEC of the pre-cultivation soil mixture varied in each treatment and ranged from 1.15–4.32 cmol/kg, while it was lower in the post-cultivation soil mixture (except for RHB-1.5) and ranged from 0.52–2.12 cmol/kg. Thus, the CEC decreased in the post-cultivation period in every treatment except for RHB-1.5, where it increased. However, these numerical differences between the pre-/post-cultivation and between the four treatments were not significantly different.

Previous studies reported that adding biochar to the soil increased the soil CEC in proportion to the amount of added biochar, and also depended on the mixing time of the biochar and soil, due to oxidation of the OM adding -COOH groups to the aromatic carbon in biochar [22, 33]. However, in this study only the RHB-1.5 treatment showed a slight but not significant increase in the CEC value after cultivation, while the CEC decreased in the other treatments. This might be caused by the lower content of negative ions, such as sulfate (SO<sub>4</sub><sup>2-</sup>) or chloride ions (Cl<sup>-</sup>). Besides, the increased pH and decreased OM in every treatment might be the reasons for the reduced CEC [38].

# 3.3. Effects of RHB on nutrients of soil mixture

## 3.3.1. Total N

The total N of the pre-cultivation soil mixture in each treatment ranged from 87.5–175.0 mg/kg, while that in the post-cultivation soil mixture ranged from 43.8–219.0 mg/kg. The total-N of the post-cultivation soil mixture was higher than the pre-cultivation soil in every treatment except for RHB-0, where it decreased. However, these numerical differences between both the pre-/post-cultivation and between the four treatments were not significantly different.

Applying biochar to the soil increases the efficiency of N adsorption and N utilization of plant roots and so can improve plant growth [28]. In addition, the total N content was reported to remain in biochar-treated soil more than in

non-biochar treated soil [16, 48]. The N content in biochar has a strong effect on the soil microbial activity, and affects the soil nitrogen cycle, both nitrification and denitrification [19]. Gunarathne et al. [45] indicated that nitrification results in less N and more  $K^+$  uptake by plants due to the competition of these two ions. Saifullah et al. [11] proposed that low-pH biochar is effective in soil N retention and reduces ammonia evaporation in saline sodic and sodic soils.

### **3.3.2. Available P**

The available P in the pre-cultivation soil mixture increased with increasing RHB levels, ranging from 15.0–28.4 mg/kg, while it decreased in the post-cultivation soil mixture in every treatment, ranging from 9.1–18.3 mg/kg. The available P in RHB-2 was significantly higher than in RHB-0, but the available P of the pre-/post-cultivation by precipitation [25], in which the soil pH is a key factor in the precipitation of P as phosphate. Both P adsorption and precipitation occur when the biochar and phosphorus fertilizer are added to a saline sodic soil, where a pH range between 5.5–7 is optimal for P release and a pH above 7 will decrease the available P [57]. In addition, the large content of calcium in soil at pH 8.00 leads to calcium and phosphate quickly binding and precipitating, resulting in a decreased available P level [4, 39]. Therefore, biochar can directly affect the soil pH, as well as the available P. Biochar with a high amount of  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Al^{3+}$ , and  $Fe^{3+}$  is able to absorb P as well [20, 58].

### **3.3.3. Exchangeable K**

The exchangeable K level of the pre-cultivation soil mixture increased with increasing RHB addition, ranging from 75.4 mg/kg in RHB-0 to 206.0 mg/kg in RHB-2, while it decreased in the post-cultivation soil mixture in all treatments except for RBH-1, and ranged from 67.2–166.0 mg/kg, and was significantly higher in RHB-2 than in RHB-0.

Due to the high amount of K in biochar, the K content depended on the amount of added biochar into soil [44]. Previous research indicated that biochar increases the amount of exchangeable K because of increasing the soil CEC [35, 45]. However, in this study, the amount of exchangeable K was reduced (except for RHB-1), presumably as the biochar increased the uptake of K by the plants [43, 46].

### **3.3.4. Exchangeable $Ca^{2+}$ and $Mg^{2+}$**

The exchangeable  $Ca^{2+}$  in the pre-cultivation soil mixture slightly decreased with increasing RHB levels, ranging from 417–512 mg/kg, and increased significantly in the post-cultivation soil in every treatment, ranging from 633–837 mg/kg. However, these numerical differences were not significant. The exchangeable  $Mg^{2+}$  in the pre-cultivation soil mixtures ranged from 0.53–1.28 mg/kg, and increased in the post-cultivation soil mixtures in each treatment to range from 1.18–1.78 mg/kg. However, these numerical differences were not significant.

Because biochar contains a high amount of K,  $Ca^{2+}$ , and  $Mg^{2+}$ , its addition to the soil leads to a direct increase in the content of these ions, as already mentioned and previously reported [5, 13]. Moreover, the surface area of biochar is able to exchange between  $Na^+$  and  $Ca^{2+}$  or  $Mg^{2+}$ , resulting in increased exchangeable  $Ca^{2+}$  and  $Mg^{2+}$  concentrations, while the  $Na^+$  content decreased [42].

## **3.4. Impacts of RHB for reduce soil salinity**

### **3.4.1. Soluble $Na^+$ and Total $Na^+$**

The soluble  $Na^+$  level in the pre-cultivation soil mixture in each treatment ranged from 630.2–1,327.4 mmol/l, while it significantly decreased in the post-cultivation soil mixture to a range of 65–358.1 mmol/l. However, soluble the

soluble  $\text{Na}^+$  level between the four treatments was not significantly different.

The total  $\text{Na}^+$  content of the pre-cultivation soil mixture in each treatment ranged from 0.74–0.91%, but decreased significantly to 0.18–0.36% in the post-cultivation soils. However, the total  $\text{Na}^+$  level between the four treatments were not significantly different.

Previous research reported that biochar can bind  $\text{Na}^+$  in the soil solution and increase the efficiency of the plant's K uptake, resulting in a decreased soluble  $\text{Na}^+$  and total  $\text{Na}^+$  content over time [5, 56]. Akhtar et al. [41] proposed the  $\text{Na}^+$  adsorption mechanism of biochar, which is temporary since  $\text{Na}^+$  is not as strongly adsorbed to the negatively charged surfaces of biochar compared to other divalent cations, causing a lower  $\text{Na}^+$  uptake by plants or a reduced by-pass flow. Another possible mechanism is, because biochar has a high content of exchangeable  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ , the exchange between these cations and  $\text{Na}^+$  in the soil leads to a reduction in the proportion of  $\text{Na}^+$  [13, 56]. In addition, sodium content in soil decreased as the amount of added biochar increased [22].

### 3.4.2. Soil SAR

The SAR of the pre-cultivation soil mixture in each treatment ranged from 9,355–15,713, while in the post-cultivation soil mixture it ranged from 4,602–37,014. The SAR of post-cultivation RHB-0 and RHB-1 soils were increased compared to pre-cultivation, but the SAR of post-cultivation RHB-2 and RHB-3 soils were decreased. However, these numerical differences were not significantly different.

The SAR refers to the exchangeable  $\text{Na}^+$  in the soil solution, which is the ratio between  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$  [59], in which the concentration of ions depends on the type and amount of added biochar [40, 60]. In other words, decreasing the amount of  $\text{Na}^+$  or increasing the amount of  $\text{Ca}^{2+}$  results in a decreased SAR value. However, the SAR values can be reduced by adding organic or chemical fertilizers to replace  $\text{Na}^+$  with other ions [11]. Similar results, that the SAR values of saline soils decreased significantly after rice cultivation, have been reported [5, 13, 56].

## 3.5. Effects of RHB as soil amendment on rice growth in cement rings

The first crop of rice cultivation in cement rings, in which the amount of water was controlled, did not show any significant difference in the height of rice at each developmental stage or between treatments (Fig. 3). The average number of grains per spike (Fig. 4) of RHB-1.5 was the highest (17.20), followed by RHB-0 (14.90), RHB-2 (7.80), and RHB-1 (4.30). Similar trends in the results were seen for the grain weight (Fig. 5), where RHB-1.5 had the highest average seed weight (18.67 g), followed by RHB-0 (15.55 g), RHB-2 (5.63 g), and RHB-1 (0.93 g). The grain weight in RHB-1 was significantly lower than in other treatments. Thus, the rice growth and yield were highest in RHB-1.5, followed by RHB-0, RHB-2, and RHB-1 respectively.

A similar result was also found by Wijitkosum [5], in that the effect of biochar was not related to the amount added in a dose-dependent manner. However, growing rice in cement rings with a wet-dry water management method decreased the amount of water for rice cultivation compared to cultivation in paddy fields, which is essential for agricultural areas with water resource problems, such as Nakhon Ratchasima. Nevertheless, the difference in rice growth between cement rings and paddy fields is not clear. The rice grown in paddy fields had the highest rice growth in RHB at 2.0  $\text{kg}/\text{m}^2$ , followed by that in 4.0  $\text{kg}/\text{m}^2$  and 3.0  $\text{kg}/\text{m}^2$  [5], whereas in this study the rice growth was best in RHB at 1.5%wt, followed by that in 0, 2, and 1%wt, respectively, yet in both studies these differences in rice growth were not significant. Moreover, one crop of rice cultivating (120 d) might not be able to give clear results,

since changing soil properties to be more suitable for rice growth likely requires more time. Nevertheless, consistent results from this research and the previous research by Wijitkosum [5] can conclude that biochar is able to decrease the salinity of salt-affected soil within only 120 d.

## 4. Conclusions

This research studied the effect of RHB as a soil amendment at addition levels of 0, 1, 1.5, and 2%wt into saline soil. The result demonstrated that RHB at 1.5%wt gave the highest rice yield, and so was suitable for growing Jasmine 105 rice (KDML105) in saline soil in a cement ring. In support, RHB at 1.5%wt was the only treatment that increased the CEC value, while decreasing the salinity parameters (EC, soluble Na<sup>+</sup>, total Na<sup>+</sup>, and SAR). In conclusion, the addition of RHB was able to reduce the salinity and improve the soil properties to be more suitable for cultivation. However, for applying biochar as a soil amendment, the type and amount of added biochar, the type and characteristics of the soil, and the type of plant all need to be considered since biochar has specific properties and its mechanisms are still unclear.

## Declarations

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### Availability of data and materials

All data generated or analyzed during this study are included within the article.

### Competing interests

The authors declare they have no competing interests.

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### Authors' contributions

All the authors have contributed to the structure, content, and writing of the paper. All authors read and approved the final manuscript.

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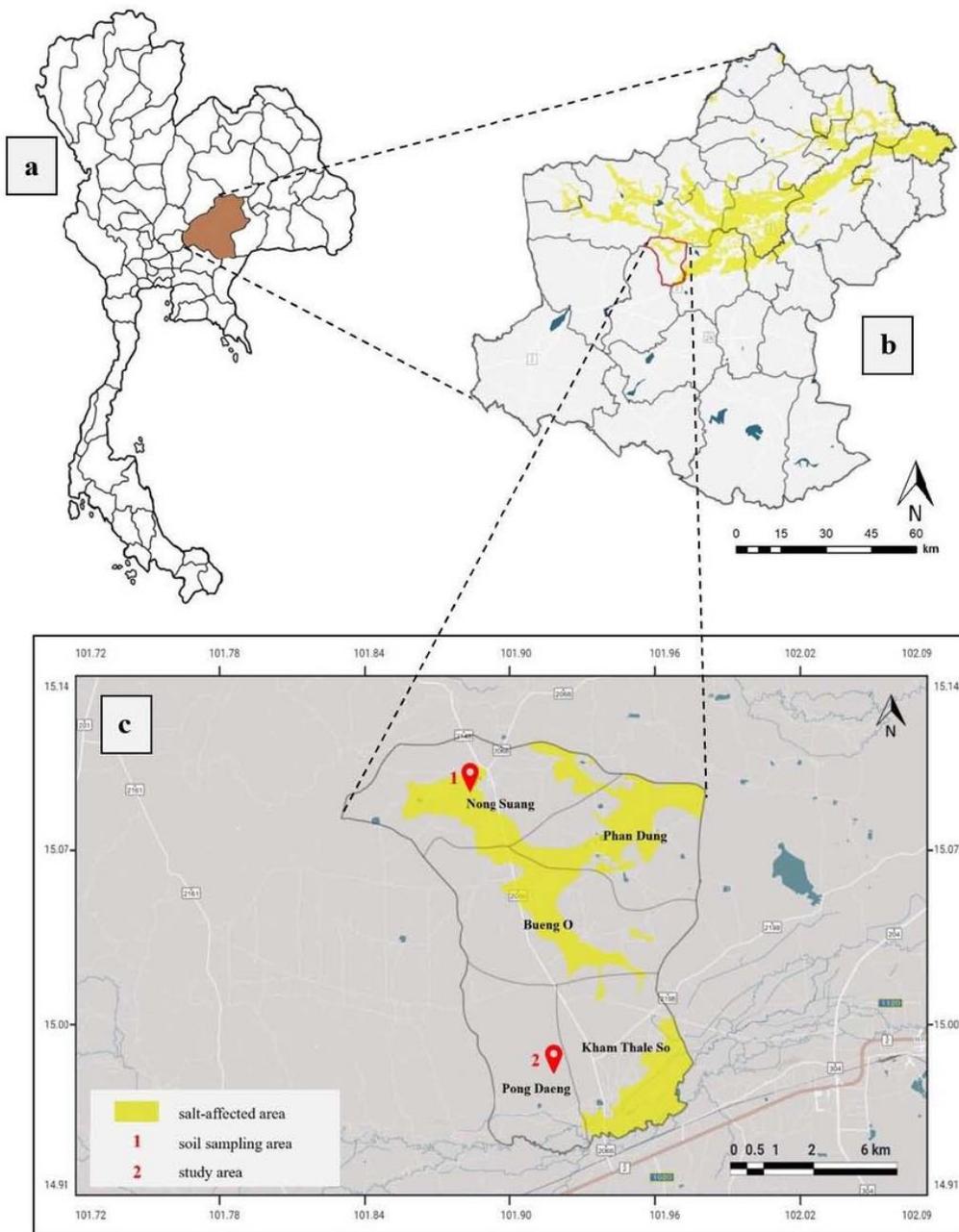
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## Table

Table 1  
Characteristics of each soil mixture at pre- and post-cultivation

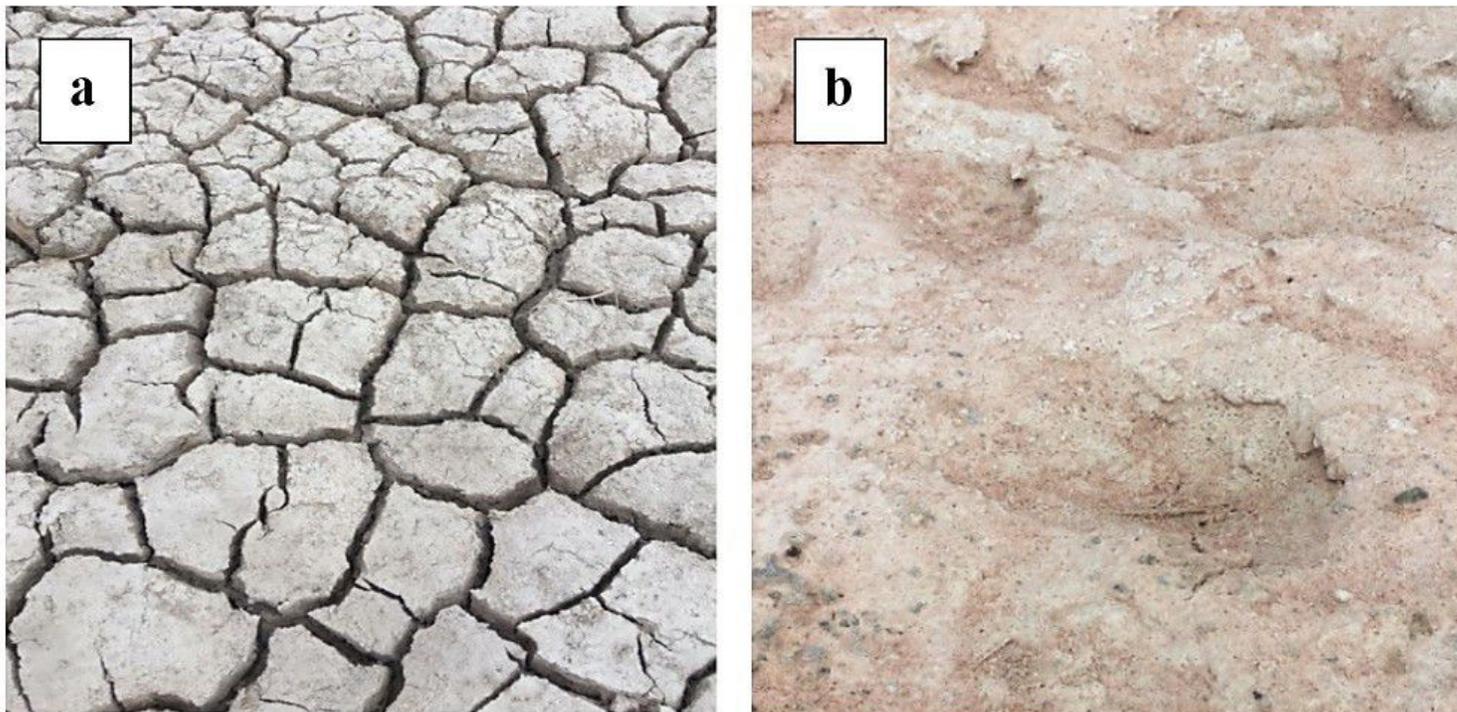
Parameter	Units	Soil mixture of pre-cultivation				Soil mixture of post-cultivation			
		RHB-0	RHB-1	RHB-1.5	RHB-2	RHB-0	RHB-1	RHB-1.5	RHB-2
pH	-	9.82 <sup>a,*</sup>	9.85 <sup>a,*</sup>	9.89 <sup>a,*</sup>	10.02 <sup>a,*</sup>	10.19 <sup>a,*</sup>	10.16 <sup>a,*</sup>	10.48 <sup>a,*</sup>	10.45 <sup>a,*</sup>
ECe	dS/m	74.5 <sup>a,*</sup>	77.7 <sup>a,*</sup>	90.4 <sup>a,*</sup>	61.4 <sup>a,*</sup>	29.2 <sup>a,*</sup>	24.7 <sup>a,*</sup>	13.33 <sup>a,*</sup>	25.6 <sup>a,*</sup>
OM	%	0.22 <sup>a</sup>	0.22 <sup>a</sup>	0.20 <sup>a</sup>	0.27 <sup>a</sup>	0.12 <sup>a</sup>	0.26 <sup>a</sup>	0.21 <sup>a</sup>	0.25 <sup>a</sup>
CEC	cmol/kg	1.93 <sup>a</sup>	4.32 <sup>a</sup>	1.15 <sup>a</sup>	2.78 <sup>a</sup>	1.88 <sup>a</sup>	0.52 <sup>a</sup>	2.12 <sup>a</sup>	1.99 <sup>a</sup>
total N	mg/kg	131.0 <sup>a</sup>	87.5 <sup>a</sup>	175.0 <sup>a</sup>	87.5 <sup>a</sup>	43.8 <sup>a</sup>	131.0 <sup>a</sup>	219.0 <sup>a</sup>	175.0 <sup>a</sup>
Avail. P	mg/kg	15.0 <sup>a</sup>	18.7 <sup>ab</sup>	22.8 <sup>ab</sup>	28.4 <sup>b</sup>	9.1 <sup>a</sup>	18.1 <sup>ab</sup>	14.1 <sup>ab</sup>	18.3 <sup>b</sup>
Exc. K	mg/kg	75.4 <sup>a</sup>	122.0 <sup>ab</sup>	179.0 <sup>ab</sup>	206.0 <sup>b</sup>	67.2 <sup>a</sup>	159.0 <sup>ab</sup>	96.4 <sup>ab</sup>	166.0 <sup>b</sup>
Exc. Ca	mg/kg	509 <sup>a,*</sup>	512 <sup>a,*</sup>	430 <sup>a,*</sup>	417 <sup>a,*</sup>	642 <sup>a,*</sup>	837 <sup>a,*</sup>	725 <sup>a,*</sup>	633 <sup>a,*</sup>
Exc. Mg	mg/kg	0.78 <sup>a</sup>	0.58 <sup>a</sup>	0.53 <sup>a</sup>	1.28 <sup>a</sup>	1.18 <sup>a</sup>	1.68 <sup>a</sup>	1.78 <sup>a</sup>	1.38 <sup>a</sup>
Sol. Na	mmol/l	878.4 <sup>a,*</sup>	936.9 <sup>a,*</sup>	1327.4 <sup>a,*</sup>	630.2 <sup>a,*</sup>	358.1 <sup>a,*</sup>	208.2 <sup>a,*</sup>	65.0 <sup>a,*</sup>	215.1 <sup>a,*</sup>
total Na	%	0.88 <sup>a,*</sup>	0.77 <sup>a,*</sup>	0.91 <sup>a,*</sup>	0.74 <sup>a,*</sup>	0.28 <sup>a,*</sup>	0.30 <sup>a,*</sup>	0.18 <sup>a,*</sup>	0.36 <sup>a,*</sup>
SAR	-	10,921 <sup>a</sup>	9,355 <sup>a</sup>	15,713 <sup>a</sup>	11,240 <sup>a</sup>	37,014 <sup>a</sup>	11,294 <sup>a</sup>	4,602 <sup>a</sup>	6,061 <sup>a</sup>
Data are shown as the mean, derived from 2 independent repeats.									
a, b, ab Significantly different between the four treatments at the p < 0.05 level.									
* Significantly different between pre- and post-cultivation at the p < 0.05 level.									

## Figures



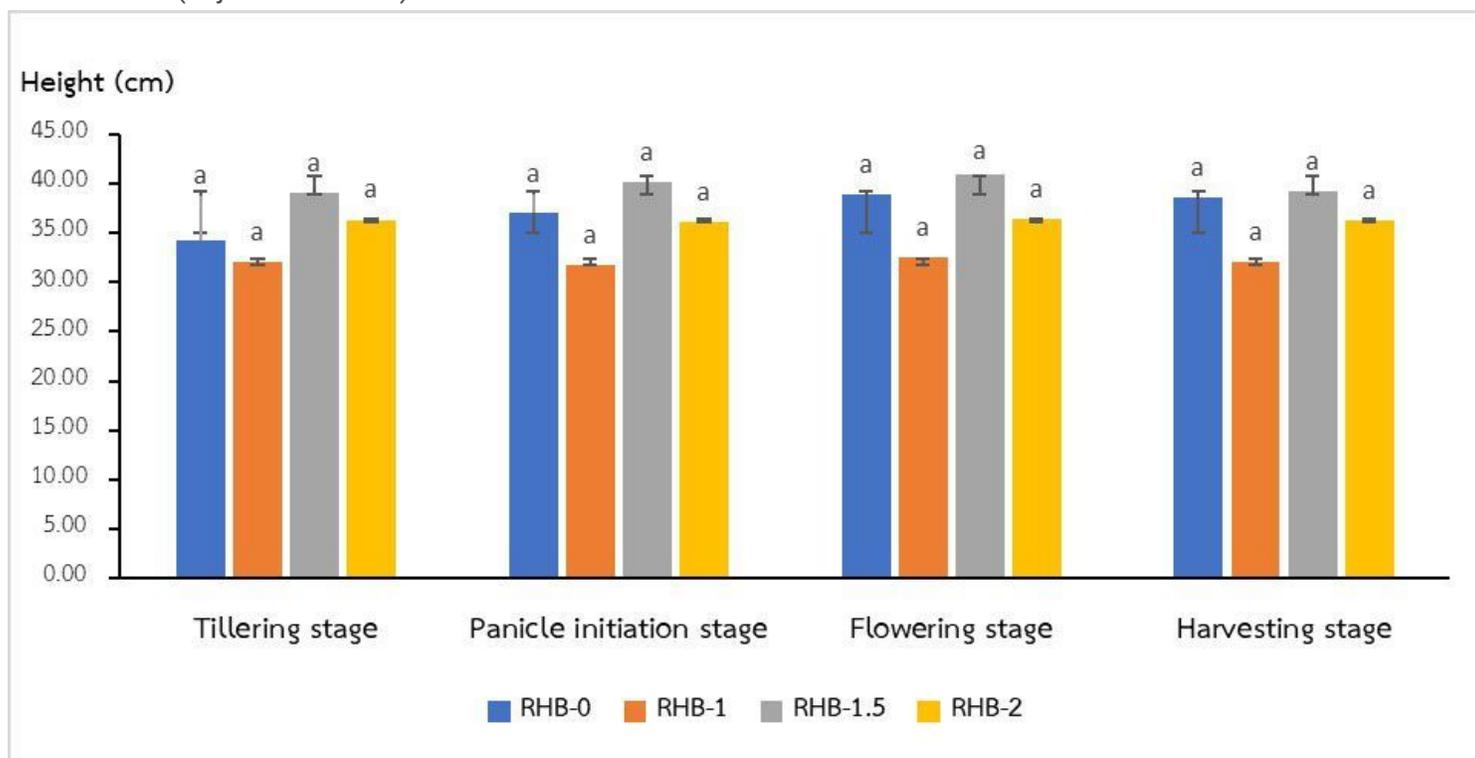
**Figure 1**

Map of Thailand showing Nakhon Ratchasima province (a). Map of salt-affected area in Nakhon Ratchasima (b) and Kham Thale So district (c). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



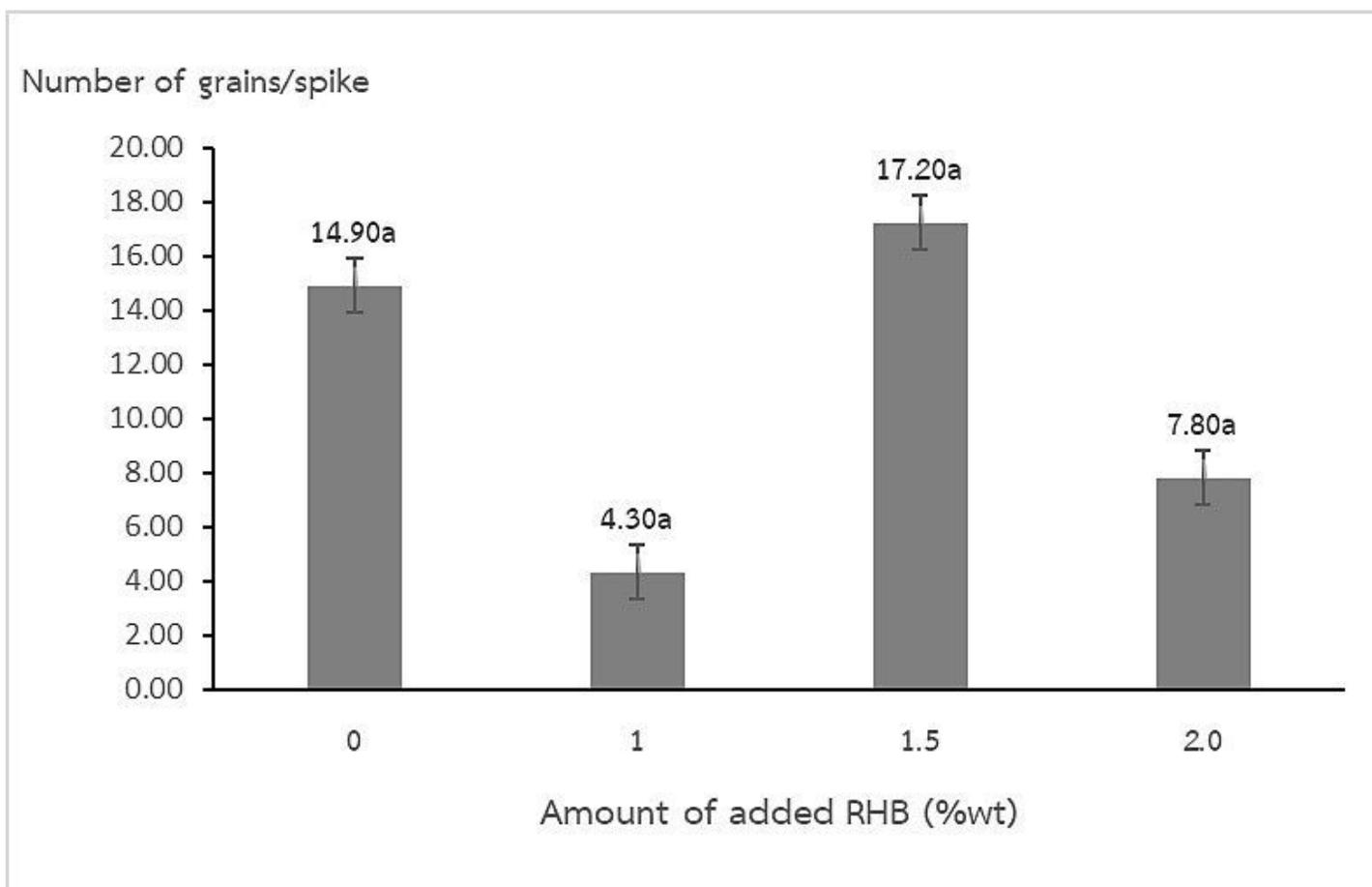
**Figure 2**

Pictures of saline sodic soil surface cracks from evaporation (a) and surface texture (b) in Kham Thale So, Nakhon Ratchasima. (Wijitkosum 2020)



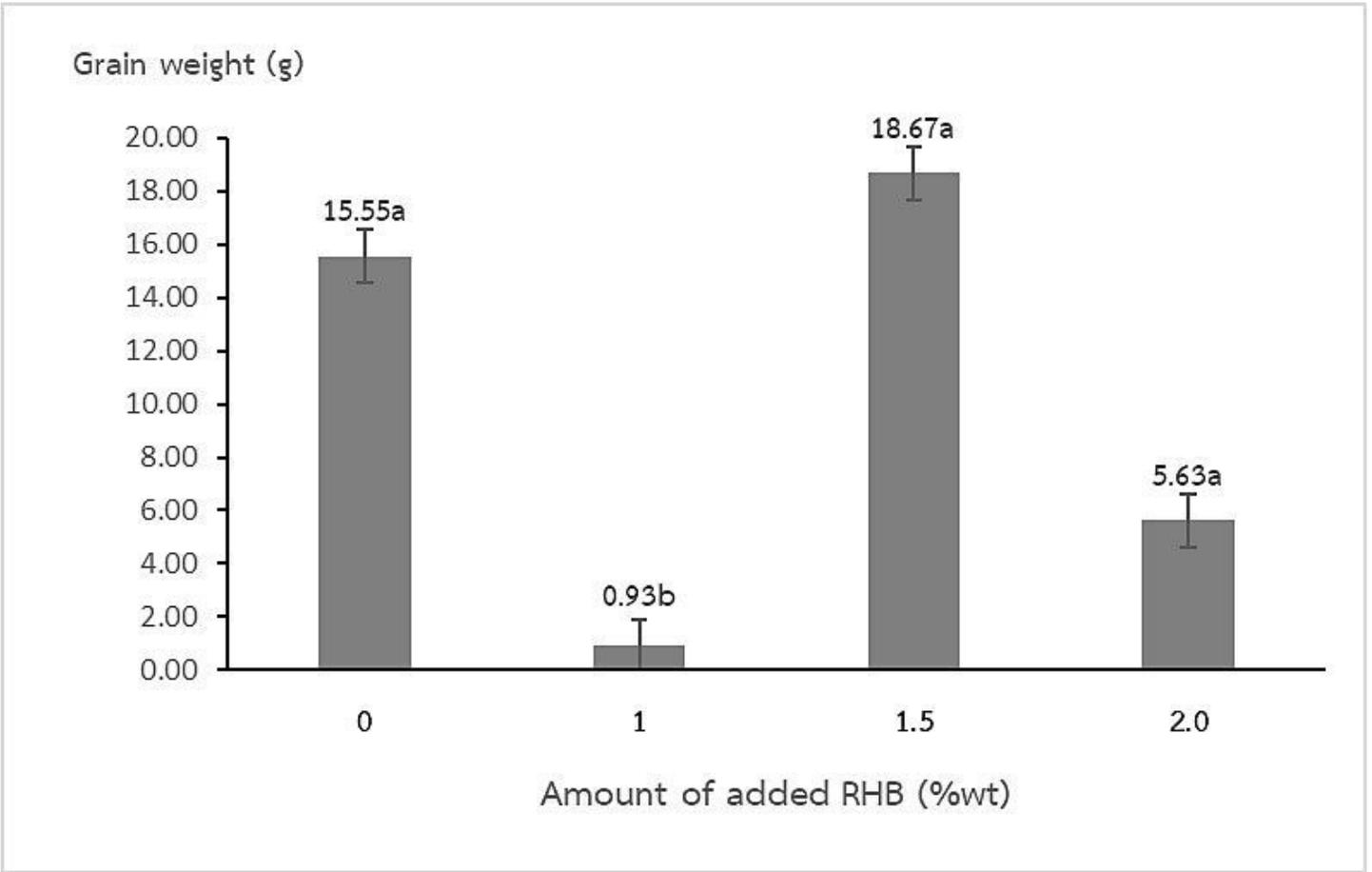
**Figure 3**

Height of rice in each treatment at different growth stages. Data are shown as the mean  $\pm$  1SD, derived from 20 independent repeats. No significant differences between means was observed.



**Figure 4**

Number of rice grains per spike in each treatment. Data are shown as the mean  $\pm$  1SD, derived from 20 independent repeats. No significant differences between means was observed.



**Figure 5**

The yield (weight) of rice grains in each treatment. Data are shown as the mean  $\pm$  1SD, derived from 4 independent repeats. Means with a different letter are significantly different.