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Effects of rice-husk biochar and aluminum sulfate application on rice grain quality in saline-sodic soil of paddy-field

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Abstract

Rice is the second-largest under cultivated crop which is growing globally. However, there is little information about biochar addition particularly in combination with aluminum sulfate on rice grain quality under saline-sodic soil conditions. This study evaluated the effect of rice husk biochar and aluminum sulfate application on rice grain quality in saline-sodic soil. Rice was grown in pots with four treatments viz. "only NPK fertilizer, no biochar and aluminum sulfate (CK+F), aluminum sulfate (0.339g/kg of soil) with NPK fertilizer (A+F), rice husk biochar (30g/kg of soil) with NPK fertilizer (B+F), and biochar (30 g/kg of soil) + aluminum sulfate (0.339g/kg of soil) and NPK fertilizer (B+A+F)". The results indicated that using biochar and aluminum sulfate improved significantly rice grain quality and production. There was observed that (B+A+F) treatment had performed the highest influence in most of the evaluated grain quality traits including amylose content, protein content, taste value, rough rice grain, brown rice rate, white rice rate, whiteness and transmission rate among all the different treatments. Thus, using biochar in combination with aluminum sulfate was revealed an effective and affordable way for improving rice grain quality and soil physicochemical properties in saline-sodic soils of paddy-field.

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Introduction

Rice (*Oryza Sativa L.*) as an important cereal crop, which is cultivated worldwide that consumes as a significant and staple food by 50 % world's population (Kakar *et al.*, 2019). Grain as the main product of rice and the source of nutritional elements, and depending on the type of rice, the grain contains about (85- 90%) carbohydrate, (7-8 %) protein and (2-7 %) fat, and mineral (Brahma, 2017).

Based on the current population growth coupled with the ever-increasing demand, many developing countries are facing challenges for higher rice production under raising stresses (Prasad *et al.*, 2017). Soil degradation due to salinity and sodicity is one of the main abiotic-stress with severe obstacle influences to crop stability and quality in arid and semi-arid climates. These above-mentioned soils create many difficulties including low productivity with poor physicochemical properties that affect the growth of most cultivated crops, particularly rice. Salinity represents one of the biggest barriers to the optimal use of crop resources such as rice, which will be faced with challenges of biological and biochemical processes in growth and resulting in reduced yield and production (Feng *et al.*, 2018). Furthermore, salinity conditions not only negatively affect crop production, especially rice plants but also extremely affect rice grain quality. It has been proven that biochar to be a useful and auxiliary material to reduce salinity, increase rice grain quality and production (Major *et al.*, 2010; Joshi *et al.*, 2015). Numerous update and specifics studies on the effects of biochar addition in rice productivity under salinity condition have found that the biochar amendment improved rice quality and increased rice yield by 13.4 % with decreasing tissues Na-content N/K ratio and increasing K content in the xylem under saline-sodic soil (Feng *et al.*, 2018). A related study by (Ran *et al.*, 2019) showed that biochar adding in saline-sodic soil significantly increased rice yield by 22.45-23.81% while decreasing Na+ (Na+/K+ ratio) and increasing K+ concentration. According to a review conclusion, the biochar amendment is not only effective in soil problems but also an affordable way for the improving physical/chemical and biological properties of salt-affected soils, and rice productivity under salinity problems (Anwari *et al.*, 2020). As well, several studies have been reported that aluminum sulfate as a chemical amendment can promote soil microbial activity and improve the decomposition and synthesis of microorganisms (Zhou *et al.*, 2019). It has been also revealed the role of aluminum sulfate in reducing the pH, carbonate and bicarbonate contents while increasing the content of sulfate ions in soil and plant (Major *et al.*, 2010; Zhang *et al.*, 2010).

Up to date, most of the studies have been paid attention to improving crop production especially rice plants and ameliorating saline soils (Saline-alkaline/sodic soils) through combined application of organic amendments such as solid waste compost, gypsum enriched compost, biomass composts, bio-fertilizer, biochars amendment as well as aluminum sulfate with bio-organic fertilizer (Sadiq *et al.*, 2007; Panhwar *et al.*, 2016; Panhwar *et al.*, 2016; Feng *et al.*, 2018; Ran *et al.*, 2019; Wacal *et al.*, 2019; Zhou *et al.*, 2019; Anwari *et al.*, 2020). Therefore, little focus has been paid about the crucial role of biochar and aluminum sulfate on the rice grain quality. The present study was carried out to acquire further information on the effect of rice husk biochar with aluminum sulfate addition in rice grain quality under saline-sodic soil conditions. In this study, we had hypothesized that biochar and aluminum sulfate applications could directly improve soil physicochemical properties, reduce saline-sodic challenges, which eventually increase rice grain quality and production.

Materials and methods

Experiment site

To investigate the application of biochar and aluminum sulfate on rice productivity and soil quality, a pot experiment has been conducted in 2018 at the Jilin Agricultural University, in the west of Songnen plain of Jilin Province, China (N 45° 35 58″-N 45° 36′ 28″, E 123° 50′ 27″-E 123° 51′ 31″). The most precipitation of this area takes place between

June to September during the rice-growing season. According to the annual details, the average range of temperatures is 4.7 °C, precipitation 413.7 mm, and evaporation 1696.9 mm, respectively, and basically, this region has one rice crop harvested season per year (Ran *et al*., 2019). Based on the classification method of USDA, the soil texture of this region is related to clay-loam and had a four-year history of rice cultivation. The main soil in the experiment is of Solonetz type according to World Reference Base for Soil Resources (IUSS Working Group, 2014).

Soil and biochar properties

Soil samples were taken (0–25 cm) from the saline-sodic paddy field before rice growing in 2018, then air-dried and passed through 2-mm sieve. The soil basic physicochemical characteristics after analysis are as follows, pH 9.64, sand content 22.13%, silt content 39.14%, clay content 35.60%, and with average value of 23.91 EC(usm-2), 352.11 SAR (mmolc L-1)1/2, 73.11 ESP (%), 1.34 bulk density (gcm-1) and organic matter 0.67 (%).

Rice husk biochar used in this study was produced by the company of Jinhefu Agricultural Development Co. Ltd, Liaoning, China. Biochar was pyrolysis at 450°C for 1 to 2 hours. For application to the experiment, biochar was passed through a 2-mm sieve and mixed well as a powder and more uniformly with the soil, then, the amount of biochar and soil needed were weighted. By mixing manually soil and biochar were added into pots 5 days before rice cultivation. The basic rice husk biochar properties and components as described by Lu (2000) are presented in Table 1.

Experimental design and treatments

In this pot experiment, four different blocks based on randomized complete block design were used. The pots dimensions are 35 cm length, 29 cm internal diameter and each pot could hold up 7.5kg of test soil. A total of 100 pots were treated into four treatments including "only NPK fertilizer, no biochar and aluminum sulfate (CK+F), aluminum sulfate (0.339g/kg of soil) with NPK fertilizer (A+F), rice husk biochar (30g/kg of soil) with NPK fertilizer (B+F), and biochar (30 g/kg of soil) + aluminum sulfate (0.339g/kg of soil) and NPK fertilizer (B+A+F)". Rice seeds (from Changbai-9 variety) were selected, then germinated and sown in a nutritional soil in the greenhouse. 40 days old seedlings were pushed out from nursery and then transplanted into plastic pots on 20 May -2018. There were three seedlings per hill and three hills per pot with 15% N, 25% P2O5, and 5% K2O fertilizer of (Sino-Arab Chemical Fertilizers Co. Ltd). Fertilizers were applied three times, in order " first with biochar and aluminum sulfate before transplanting, second during the tillering stage, third in the panicle stage" as a total N, P and K were 175 kg, 75 kg and 62.5 kg ha^{-1}, respectively. Irrigation water used was prepared from underground-water and it was reclaimed through the water purifying. As well as, the paddy pots were kept free of weeds until harvesting on the 10th of October 2018. After maturity, rice was harvested, and milled grain yield was used for quality analysis.

Sampling and analyses

For grain quality analysis, during maturity stages (grain hard, difficult to divide with thumbnail) from 20 representative pots in a treatment, rice plants were harvested. The grains of the representative rice samples were separated and air-dried at room temperature until three months attained.

The aspect parameters such as brown rice rate, white rice rate, brown rice ratio, white rice ratio, milled rice rate, chalky grain percentage, chalkiness ratio, amyloses percentage, protein percentage, and length-width ratio were determined. Subsequently, broken rice and head rice of milled samples were separated, and the end, the milled rice ratio was quantified as a percentage of the total weight of rough rice.

The chalky grain rate percentage, chalkiness ratio, length-width ratio, and amylose content were evaluated according to the National Standard of the People's Republic of China (GB/17891-1999) methods. Overall samples were analyzed twice, and rice protein contents measurements were performed as described by Tan *et al.* (1999) and Lu, (2000).

Data analyses

Whole data came from means of the replicate of four treatments. To be more realizable, data were analyzed using SPSS version 21.0 (SPSS for windows Inc., Chicago, Illinois, USA), and Minitab17.0 statistical software (Minitab Inc. State College, PA, USA). One-way analysis of variance (ANOVA) was run to determine the variability of rice grain quality parameters in the different treatments. Pairwise comparison using Tukey's honestly significance difference (HSD) test ($p < 0.05$) was also performed to compare the different parameters for the different treatments. As well, Pearson correlation coefficients were also calculated to assess the relationship between brown rice grain and milled rice grain, and among the whole physical and chemical properties of rice grain quality.

Results and discussion

Rice husk biochar and aluminum sulfate addition effects on the quality characteristics of milled rice grain

The results of the analysis of variance about rice grain quality indicated that the physicochemical parameters were greatly influenced by rice husk biochar and aluminum sulfate addition (Table 2).

Table 1. Rice husk biochar pH and chemical elemental components.

pH	C (mg•g⁻¹)	N (mg•g⁻¹)	S (mg•g⁻¹)	Mg (mg•g⁻¹)	K (mg•g⁻¹)	Ca (mg•g⁻¹)
7.863	547.32	9.30	6.41	0.24	3.94	2.16
Elemental component						
Mn (mg•g⁻¹)	Ni (mg•g⁻¹)	Cu (mg•g⁻¹)	Zn (mg•g⁻¹)	B (mg•g⁻¹)	Fe (mg•g⁻¹)	Be (mg•g⁻¹)
0.07	0.00	0.11	1.00	0.10	0.69	5.42

The rice quality was significantly improved after rice husk biochar and aluminum sulfate application in saline-sodic of paddy soil. In general, the influences of B+A+F on rice quality were significantly higher than that of other treatments (Table 2).

Table 2. Rough rice and milled grain quality characteristics.

Treatment	Rough Rice Rate	Brown Rice Rate	White Rice Rate	Brown Rice Ratio	White Rice Ratio	Rice Length-Width Ratio	Milled Rice Rate
Ck + F	223.7b	188.7b	163.00b	0.843a	0.729a	1.533a	49.800b
	± 22.7	± 19.1	± 14.18	± 0.001	± 0.011	± 0.057	± 1.375
A + F	250.7b	208.0b	186.3b	0.558a	0.485a	1.533a	50.80ab
	± 7.22	± 32.4	± 32.1	± 0.483	± 0.420	± 0.057	± 3.47
B + F	279.0ab	235.00 ab	208.00ab	0.832a	0.750a	1.566a	56.23a
	± 19.7	± 17.06	± 16.09	± 0.0357	± 0.0388	± 0.057	± 2.25
B + A + F	338.0a	285.3a	254.3a	0.561a	0.497a	1.533a	56.90a
	± 40.1	± 35.2	± 30.4	± 0.486	± 0.431	± 0.057	± 1.91
Source of variation							
Biochar (B)	ns	ns	ns	ns	ns	ns	*
Aluminum Sulfate (A)	ns	ns	ns	***	ns	ns	ns
B X A	**	**	**	*	ns	ns	*

Means were followed by different lowercase letters into a column in each treatment and parameter, as are significantly different $p < 0.05$ according to the Tukey test. ± , indicates standard division, *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns, Non-significant.

The rough rate, brown rice rate, white rice rate, milled rice ratio, brown rice ratio (Table 2) of biochar with aluminum sulfate (B+A+F) and biochar (B+F) applied treatments were significantly higher than aluminum sulfate (A+F) and control (CK+F) treatments. Among them, rough rice rate, brown rice rate, and white rice rate had highly significant (P<0.01) differences in B+A+F treatment. And, brown rice ratio showed the highest significant (P<0.001) difference in B+F treatment (Table 2). However, no significant differences were found about the above-mentioned parameters including the rice grain length-width ratio in A+F treatment (Table 2). For illustration, B+A+F, B+F, A+F, CK+F performed for milled rice rate, 56.90, 56.23, 50.80, 29.80 respectively (Table 2). In summary, B+A+F treatment was found to be the most effective treatment among all treatments for rice grain quality parameters.

Treatments A+F and B+A showed weak to non-significant effect for most of the different traits evaluated in this study.

Table 3. Correlations for rice grain quality include rough rice rate, brown rice rate, white rice rate, brown rice ratio, white rice ratio, rice length-width rate and milled rice rate under the effect of biochar and aluminum sulfate addition in saline-sodic soil.

	Rough Rice Rate	Brown Rice Rate	White Rice Rate	Brown Rice Ratio	White Rice Ratio	Rice Length-Width Ratio	Milled Rice Rate
Rough Rice Rate	1	.995**	.992**	0.197	0.001	0.019	.498*
Brown Rice Rate		1	.997**	0.154	-0.034	-0.015	.512*
White Rice Rate			1	0.144	-0.081	-0.06	.505*
Brown Rice Ratio				1	0.391	0.402	-0.217
White Rice Ratio					1	.999**	-0.049
Rice Length-Width Ratio						1	-0.023
Milled Rice Rate							1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 4. Physical and chemical characteristics of rice grain quality.

Treatment	Chalkiness Ratio%	Chalky Grain Rate%	Whiteness Rate%	Transmission Rate%	Amylose Content%	Protein Content%	Taste Value%
Ck + F	1.533ab	6.067a	76.333b	1.9600c	19.0767c	6.780a	72.570c
	± 0.351	± 1.007	± 1.155	± 0.036	± 0.0902	± 0.0265	± 0.062
A + F	1.233b	5.700a	79.333ab	2.0200bc	19.0533c	6.576b	72.983b
	± 0.057	± 0.600	± 0.577	± 0.108	± 0.0950	± 0.047	± 0.075
B + F	1.833a	7.667a	80.00ab	2.1667ab	20.6033b	6.403c	73.210a
	± 0.208	± 1.290	± 2.65	± 0.037	± 0.1102	± 0.0057	± 0.010
B + A + F	1.933a	7.57a	83.00a	2.206a	21.3533a	6.393c	73.346a
	± 0.115	± 1.88	± 2.00	± 0.040	± 0.1365	± 0.065	± 0.064
Source of variation							
Biochar (B)	ns	ns	ns	*	***	***	***
Aluminum Sulfate (A)	**	ns	ns	ns	***	ns	ns
B X A	*	ns	**	**	***	***	***

Means were followed by different lowercase letters into a column in each treatment and parameter, as are significantly different $p < 0.05$ according to the Tukey test. ±, indicates standard division, *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns, Non-significant.

Our findings are similar to those reported by numerous researchers who found the use of the different types of biochars could improve rice grain quality including Liu *et al.* (2016) using bamboo and rice straw biochars in a cold waterlogged paddy field, Feng *et al.* (2018) by applying biochar of peanut-shell in saline-sodic soil, and also our previous study Ran *et al.* (2019) with wheat-straw biochar application in the saline-sodic soil of paddy field, and found that biochars beside its positive influences in the soil quality and rice production, could improve physical characteristics of rice grain quality. So, we same to other researchers (Rani *et al.*, 2006) and (Fofana *et al.*, 2011) strongly have been emphasized that the physical characteristics of milled rice are very important to the consumer, which in turn marks it more significant to the dealer and the miller. Thus, to promote rice grain quality, several methods and practices are required for a better biochar and aluminum amendment.

Table 5. Correlations for physiochemical characteristics of rice grain quality involve amylose content, protein content, taste value, chalkiness ratio, transmission percentage, chalky grain rate and whiteness rate under the effect of biochar and aluminum sulfate addition in saline-sodic soil.

	Amylose Content %	Protein Content %	Taste Value %	Chalkiness Ratio %	Transmission Rate %	Chalky Grain Rate %	Whiteness Rate %
Amylose Content %	1	-.968**	.970**	-.962**	-0.108	-.930**	-0.129
Protein Content		1	-1.000**	1.000**	0.319*	.987**	0.309
Taste Value%			1	-.999**	-0.314	-.987**	-0.304*
Chalkiness Ratio %				1	0.338*	.991**	0.326
Transmittance Rate %					1	0.378	.720**
Chalky Grain Rate %						1	0.358
Whiteness Rate %							1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Rice husk biochar and aluminum sulfate addition effects on the physicochemical characteristics of rice grain quality

The presence of chalkiness in rice grain has been known as a downgrading factor of grain quality that affects the storage, milling, and marketing activities (Adu-Kwarteng *et al.*, 2003). The analysis of variance results about the effect of biochar and aluminum treatments related to chalkiness has shown that aluminum sulfate treatment had a highly significant effect in reducing the chalkiness ratio among treatments (Table 4).

In contrast, no significant differences were observed with biochar treatment (Table 4). Statistically, all treatments did not show any effect in the chalky grain rate, but there was an increasing tendency B+F > B+A+F > Ck+F > A+F, (Table 4).

Whiteness as a combination of different physical specifications and the grade of milling, which are milling, whitening, and polishing greatly influences rice grain quality (Ahmad *et al.*, 2009). Based on the results, a highly significant increase in whiteness was found by B+A+F treatment whereas the effects of A+F and B+A were not statistically significant (Tabe 4). As a result, B+A+F> B+F> A+F> Ck+F, about the whiteness ratio.

Transmission as a method that uses for determining amylose content in whole grain rice which is the percentage of light that goes through the sample (near-infrared transmission) (Zhang *et al.*, 2011). Our study indicated that biochar combined with aluminum sulfate (B+A+F) increased transmission percentage with a highly significant difference among the treatments, while biochar (B+F) had a significant effect, and aluminum sulfate (A+F) was having no significant effect (Tabel). Amylose content was highly affected by all treatments (Table 4). It has been observed that amylose content increased significantly high with all treatments compared to the control to an extent of 21.3533, 20.6033, 19.0767, 19.0533, in B+A+F, B+ F, CK+F, and A+F, respectively. The protein content and taste value were improved after biochar and aluminum sulfate application significantly except for A+F treatment which did not display any significant difference in protein content and taste value (Table 4). Interestingly, these results are very close to those obtained by Feng *et al.* (2018).

Conclusion

The result of this study demonstrated that the quality characteristics of milled grain rice and physiochemical rice grain properties are improved with the application of rice husk biochar and aluminum sulfate in the saline-sodic soil of paddy field. There were observed highly significant differences in rice grain quality parameters by treatment, as which the combined effect of rice husk biochar with aluminum sulfate, and the individual effect of biochar treatment had better influenced the rice grain quality than aluminum sulfate alone compared to the control. Independently, rice husk biochar (B+F) in this study showed that the amylose content, taste value, and protein content improved significantly most of the measured qualitative parameters. Aluminum sulfate treatment (A+F) has shown only a statistical difference effect in chalkiness and brown rice ratio. The combination of biochar and aluminum sulfate(B+A+F) revealed highly significant effects in amylose content, protein content, and taste value, as well as in rough rice grain, brown rice rate, white rice rate, whiteness, and transmission percentage.

Taken together, it can be concluded that biochar and aluminum sulfate treatment exhibited the highest effect on rice grain quality characteristics and soil physiological properties. Thus, our findings express to suggest the using of rice husk biochar combined with aluminum sulfate might strongly improve rice grain quality and production under saline-sodic soil conditions.

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Conflicts of Interest

The authors declare that no conflict of interest exists in the publication of this work.

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