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Taste Evaluation of Rice Grown in Soil Treated with Commercial Silica and Recycled Rice Husk Silica

Ryoko Sekifuji[1] and Masafumi Tateda[1*]

[1]School of Environmental Engineering, Toyama Prefectural University, 5180 Kurokawa, Imizu, 939-0398, Toyama, Japan.

Authors' contributions

The present study was carried out in collaboration between both the authors. Author RS designed, performed, analyzed, interpreted and drafted manuscript. Author MT provided technical support, revised the manuscript and also supervised the research. Both the authors read and approved the final manuscript.

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ABSTRACT

Aim: To evaluate the taste of rice grown in soil treated with rice husk silica in order to elucidate the potential use of rice husk silica as a fertilizer in terms of taste of rice.
Study Design: Rice plants were grown in soil treated with rice husk silica and officially approved, commercial silica fertilizer. The taste of the rice plants was compared based on their quality evaluation value (QEV).
Location and Duration of Study: The study was conducted in the city of Imizu where the Toyama Prefectural University is located. The period of study was from March 2015 to April 2016.
Methodology: Paddy fields were divided based on the type and amount of silica applied. The rice plants were grown under different conditions. The growth of rice plants and silica sorption by rice plants were analyzed to obtain data on the physical state of the rice plants. Taste of rice was evaluated by the QEV based on four parameters, contents of protein, water, amylose, and fatty acid.

**Corresponding author: E-mail: tateda@pu-toyama.ac.jp;*

Results: It was observed that the taste of rice grown in soil treated with rice husk silica was not different from that of the rice grown in soil treated with commercial silica fertilizer.
Conclusions: Rice husk silica can be used as a silica fertilizer in terms of taste of rice.

Keywords: Rice husk; silica; taste of rice; quality evaluation value; ideal agriculture.

1. INTRODUCTION

Rice plants require silicon for their growth. They endure severe damages under silicon deficient conditions, such as insect attack and fungal infection [1]. It has been observed, especially in Japan that the development of rice blast is closely related to low level of silica [2]. At the start of the 20th century, the level of silica in the environment was low. The effect of silica on rice plants was studied extensively in the mid-1900s [3], because rice is the most important crop in Japan. In Japan, rice is cultivated by a special method known as repeated cultivation in paddy field. This leads to a gradual decrease in the available silica in paddy fields, therefore extrinsic addition of silica to the soil is important for the healthy growth of rice plants [2]. In Japan, silica (excluding rice husk silica) is officially designated as a fertilizer. Slag from iron industry was formally designated as one of the silica fertilizers. Currently, in Japan, rice is cultivated using the silica in slag. The objective of the present study was to use indigenous silica for cultivating rice, because the silica in the slag is of extrinsic nature to the rice plants. Furthermore, the rice husk silica might be more suitable for the rice plants than the slag, which comes from a completely different sector. Studies on the effect of silica on the growth in rice plant are scarce. To the best of our knowledge, the present study and study conducted by Abdel-Haliem et al. [4] are the only studies on the role of silicon extracted from rice straw in rice plants.

Tateda [5] has proposed an ideal agriculture system, where the silica in rice husk is returned to the paddy field via recycling (Fig. 1).

Rice husk is generated while harvesting paddy annually. The husk generated is mostly used as a fuel in boilers. In the boiler, the rice husk is burned to produce heat, which is used to generate either hot water or electricity. The ash, residue of combustion, produced during the process is returned to paddy fields. The subsequent year, the rice plants cultivated use the silica in the ash for their growth. This cycle is repeated every year. Therefore, the rice husk generated is used to produce heat and silica fertilizer, which is a recycled source of silica to produce rice sustainably— an ideal agriculture system. However, there is a concern related to the taste of rice. The recycling process is good in terms of resource recycling, however if the taste of rice decreases because of this, it would negatively affect the economy.

In the present study, the evaluation and comparison of taste of rice grown in soil treated with officially approved, commercial, best-quality silica fertilizer and rice husk silica were conducted. In this well-fed era of Japan, obtaining food is not difficult, however obtaining tasty food is of concern. The key aspect here is not about achieving better taste, but it is about not altering the taste of rice by following the usual production process.

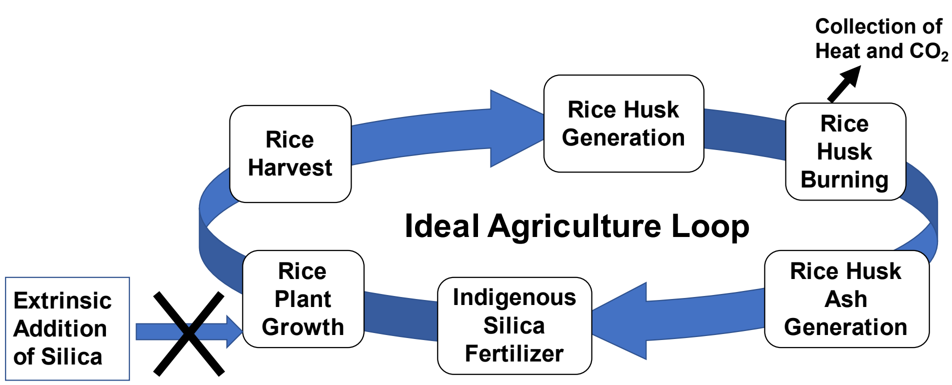

Fig. 1. Ideal agriculture loop

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Rice plants and husks used

The rice variety Koshihikari (*Oryza sativa L.*) was used in the present study. The rice husk was burned in a boiler system (capacity: 100 kg/h) as described by Tateda et al. [6]. Tateda [5], based on the sodium hydroxide method, reported that silica content in rice husk ash is 90% and the solubility of the silica in the ash is 50%.

2.1.2 Chemical fertilizer

The rice plants grown on soil treated with silica-gel fertilizer (Super Energy, Fuji Silysia, Japan) were used for a comparative study. The silica-gel fertilizer used is the best silica fertilizer available, however it is very expensive (> 100 USD/10 kg, silica content: 90%). This fertilizer was used to observe the effects of silica on rice plants. Further, slag silica fertilizer was not used in the present study. According to Japan Standard Methods for measuring the solubility of silica in fertilizer (4.4.1. a–c), the solubility of silica-gel fertilizer is 90% [7].

2.2 Methods

2.2.1 Analysis of growth and production of rice plant

The following were measured to evaluate the growth of rice plant: fine brown rice weight, number of ears, number of grains per ear, percent of ripened grains, and percent of cracked rice. To evaluate silica sorption, amount of silica in leaf blades, leaf sheath, and ear during sprouting and maturity seasons were measured.

2.2.2 Analysis of rice husk ash

Rice husk ash was analyzed for its chemical and physical properties. To evaluate the chemical property, the following were measured and presented as percent: alkali content (Standard Method 4.5.4), total potassium, citric acid soluble potassium, water soluble potassium (Standard Method 4.3), total phosphoric acid, citric acid soluble phosphoric acid, water soluble phosphoric acid (Standard Method 4.2), and sodium hydroxide soluble silica (Standard Method 4.4) according to Japan Standard Testing Method for fertilizer [8]. To evaluate the physical property, contents of fixed carbon, volatiles, water, and ash were measured according to Japan Industrial Standard [9].

2.2.3 Analysis of rice taste

Although the taste of rice is an important parameter, it is difficult to evaluate [10]. There are several ways to evaluate the taste of rice. In the present study, quality of brown rice was evaluated by quality evaluation value (QEV), which is a self-evaluation indicator employed by rice producers. The evaluation is based on the contents of protein (%), water (%), amylase (%), and fatty acid (mg KOH) in rice determined using an automatic analyzer (VPA-5500X-ES-TM, Shizuoka Seiki, Japan). The QEV is automatically obtained from the analyzer. The relevant equation for obtaining QEV has not opened to the public. Each analyzer machine has its own calculation mothed. The weak point of QEV is that QEV values are different among analyzers although it is the commonly used value to evaluate the taste of rice in Japan. Because of the weal point, Tanaka et al. [11] proposed that the taste of rice should be evaluated by protein content. The full score is 100 points and it can be said that rice with more than 85 points is excellent, 80–85: very good, 75–80: good, 70–75: fair, 65–70: poor, and less than 60: no good.

2.2.4 Cultivation of rice plants

Two paddy fields —A and B—were selected in Imizu city where Toyama Prefectural University is located. The types of soil were alluvial sandy soil and alluvial clay in paddy fields A and B, respectively. Water from river and spring was used for irrigating paddy field A, and only river water was used for irrigating paddy field B. Each paddy field was divided into three large areas (test, comparison, and control) by constructing ridges between areas, each area was subdivided into four smaller areas. The test areas 1 and 2 were treated with 10 and 30 kg/100 m^2 rice husk ash, respectively. The comparison areas 1 and 2 were treated with 5.5 and 16.6 kg/100 m^2 silica-gel fertilizer, respectively. The control area was not treated with silica. The amount of rice husk ash and silica-gel was deduced from silica content and solubility. The divisions of paddy fields have been represented in Figs. 2 and 3. The divisions with similar soil conditions have been shown as one division.

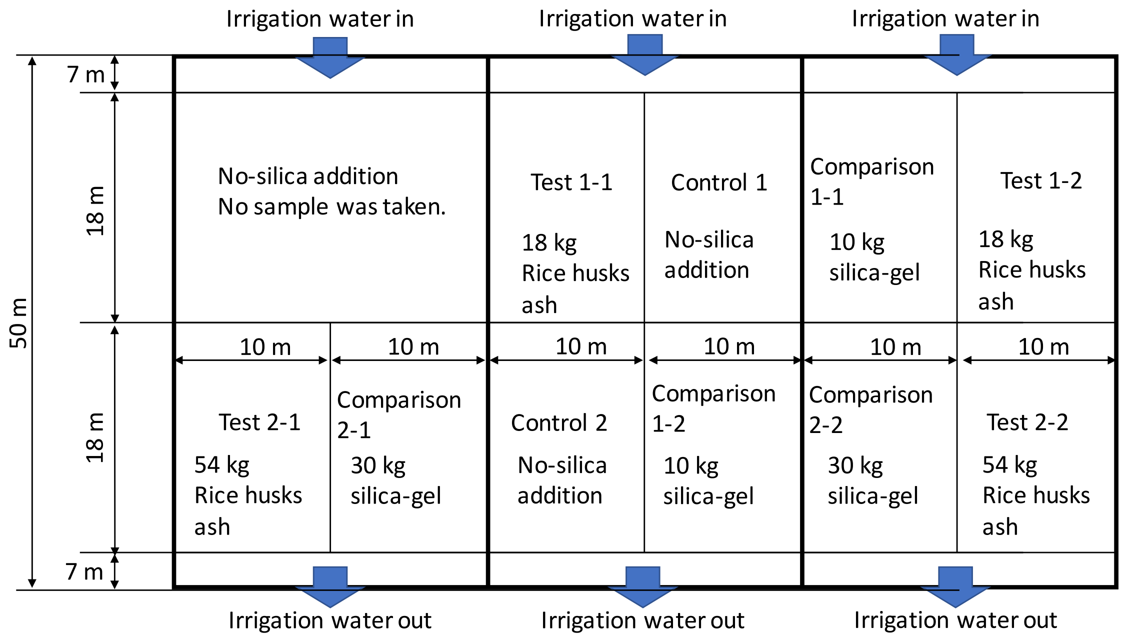

Fig. 2. Divisions of paddy field A

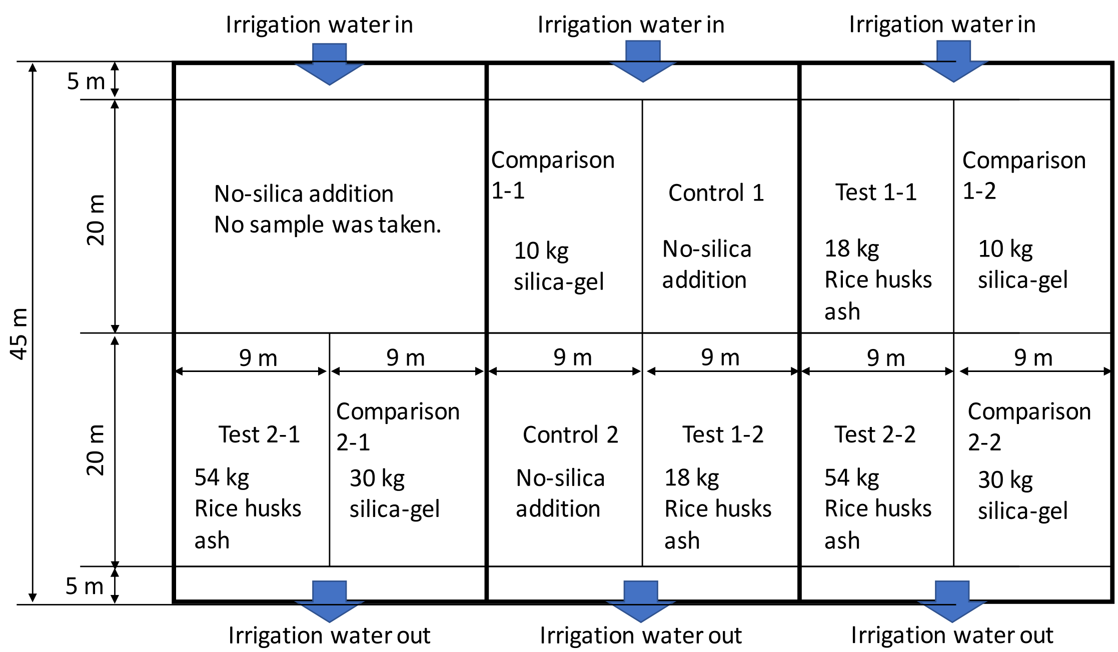

Fig. 3. Divisions of paddy field B

3. RESULTS

Experimental data obtained were of multiple trials; means of the data were used for analysis.

3.1 Chemical and Physical Properties of Rice Husk Ash

The chemical and physical properties of rice husk ash have been presented in Table 1. Rice husk mainly consists of carbohydrates, silica, and elements, such as phosphorus, calcium, ferrous, and potassium [12]. Potassium is usually present in rice husk, and its level depends on the fertilizer used. Because of the potassium, the pH of rice husk ash is high (about 11). In the present study, when the rice husk was burned without pre-washing treatment, fixed carbon or unburned carbon remained on the surface of the rice husk ash. The fixed carbon content was found to be 6.5%, therefore the color of the ash was black (Table 1).

3.2 Growth of Rice Plant

The growth analysis results have been shown in Tables 2 and 3. The growth of rice plants did not differ significantly among the divisions of paddy field. However, silica sorption by plants exhibited differences among the divisions. In paddy field A, silica sorption by rice plants was relatively high in the silica-treated divisions. A relatively low silica sorption by the plants was observed in test 1, which was lower than that of control.

Table 1. Chemical and physical properties of rice husk ash

	Variables	Percent (%)
Chemical property	Alkali content	0.4 ± 0.1
	Total potassium	2.0 ± 0.14
	Citric acid soluble potassium	1.9 ± 0.21
	Water soluble potassium	0.5 ± 0.1
	Total phosphoric acid	0.3 ± 0.1
	Citric acid soluble phosphoric acid	0.1 ± 0.0
	Water soluble phosphoric acid	0.1 ± 0.0
	Sodium hydroxide soluble silica	57 ± 2.9
Physical property	Fixed carbon	6.5 ± 5.2
	Volatiles	4.9 ± 1.2
	Water	1.0 ± 0.21
	Ash	87.8 ± 6.51

Table 2. Growth of rice plant and silica sorption by rice plant in paddy field A

		Divisions	Test 1	Test 2	Comparison 1	Comparison 2	Control
Growth of rice plant		Fine brown rice weight (kg/100 m^2)	63	68	70	63	65
		Number of ears (ear/m^2)	343	387	367	334	358
		Number of grains per ear	80	90	84	96	89
		Percent of ripened grains (%)	89.2	87.9	89.2	88.9	87.2
		Percent of cracked rice (%)	9.8	7.7	9.5	4.2	10.8
Silica sorption (g/m^2)	Sprouting season	Leaf blades	7.9	17.9	14.6	18.9	12.0
		Leaf sheath	15.0	42.5	24.9	45.1	25.1
		Ear	4.2	9.1	5.8	8.0	5.5
		Total	27.1	69.5	45.4	72.0	42.6
	Maturity season	Leaf blades	10.8	19.2	17.3	20.1	13.1
		Leaf sheath	20.2	37.0	30.7	39.5	22.1
		Ear	18.8	27.8	21.2	27.8	16.4
		Total	49.8	83.9	69.2	87.3	51.6

Table 3. Growth of rice plant and silica sorption by rice plant in paddy field B

		Divisions	Test 1	Test 2	Comparison 1	Comparison 2	Control
Growth of rice plant		Fine brown rice weight (kg/100 m^2)	59	59	61	63	60
		Number of ears (ear/m^2)	434	414	434	410	383
		Number of grains per ear	70	76	71	71	75
		Percent of ripened grains (%)	86.8	88.6	81.0	87.8	88.5
		Percent of cracked rice (%)	3.9	2.6	2.8	2.8	2.8
Silica sorption (g/m^2)	Sprouting season	Leaf blade	21.2	23.5	25.9	31.0	18.5
		Leaf sheath	41.9	46.1	45.3	58.7	37.1
		Ear	8.7	10.5	9.8	9.5	9.0
		Total	71.8	80.2	81.0	99.2	64.6
	Maturity season	Leaf blade	26.3	32.6	26.9	35.7	23.1
		Leaf sheath	47.3	60.2	58.3	73.1	45.8
		Ear	22.8	30.6	29.1	30.3	24.7
		Total	96.5	123.5	114.4	139.1	93.6

The highest silica sorption was recorded in comparison 2. In paddy field B, a similar trend was observed. That is higher the silica application, higher the silica sorption by plants. In paddy field B, a relatively low silica sorption by plants was observed in control, while the highest silica sorption by plants was recorded in comparison 2. In both the fields, the plants of comparison 2 exhibited relatively high silica sorption.

3.3 Taste of Rice

The taste analysis results have been shown in Figs. 4 and 5. There was no significant difference in the taste of rice among the plants from different divisions of the paddy field. In paddy field A, the ranges of protein, water, amylose, fatty acid, and QEV were 6.3%–6.5%, 13.8%–13.9%, 18.9%–19.0%, 16.8–17.2 mg KOH, and 72–73, respectively. In paddy field B, the ranges of protein, water, amylose, fatty acid, and QEV were 6.1%–6.2%, 13.9%–14.0%, 18.9%–19.0%, 17.1–17.7 mg KOH, and 73–74, respectively.

4. DISCUSSION

The two paddy fields used for the study had divisions of similar size (Figs. 2 and 3). The divisions were designed such that the silica applied to one division does not affect the silica concentration of other divisions—minimal influence.

In both the fields, there was no difference in the growth of rice plant between divisions. However, there was significant difference in silica sorption by plants between divisions. The plants of comparison 2 and test 1 exhibited relatively high and low silica sorption, respectively, in paddy field A. In paddy field B, the plants of comparison 2 and control showed relatively high and low silica sorption, respectively. The difference between the two paddy fields might be attributed to the difference in the soil type. The soil of paddy field A was alluvial sandy soil and that of B was alluvial clay. To assess the growth of rice plants, graphs were obtained for each factor to identify trends.

The results revealed that the weight of rice in paddy field A was higher than that of paddy field B (Fig. 6). The number of ears was higher in paddy field B when compared with that of paddy field A (Fig. 7). Further, the number grains per ear was higher in paddy field A than that of paddy field B (Fig. 8). Further, the percent of ripened grains observed in Comparison 1B was relatively low (Fig. 9). It was also observed that the number of cracked rice in paddy field A was higher than that in paddy field B (Fig. 10). The results indicated that the rice produced in paddy field B was better than that of paddy field A.

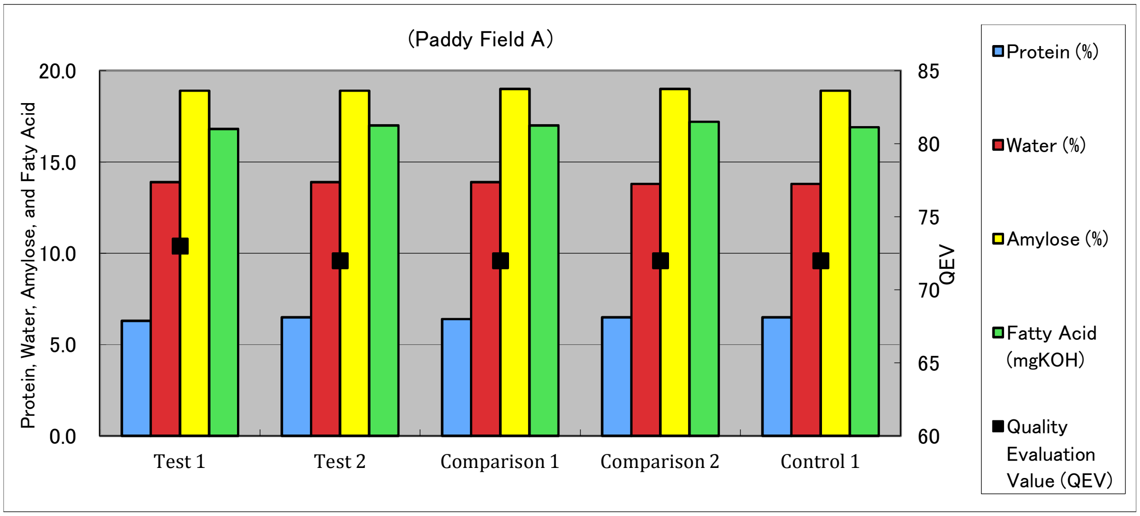

Fig. 4. Taste of rice in paddy field A

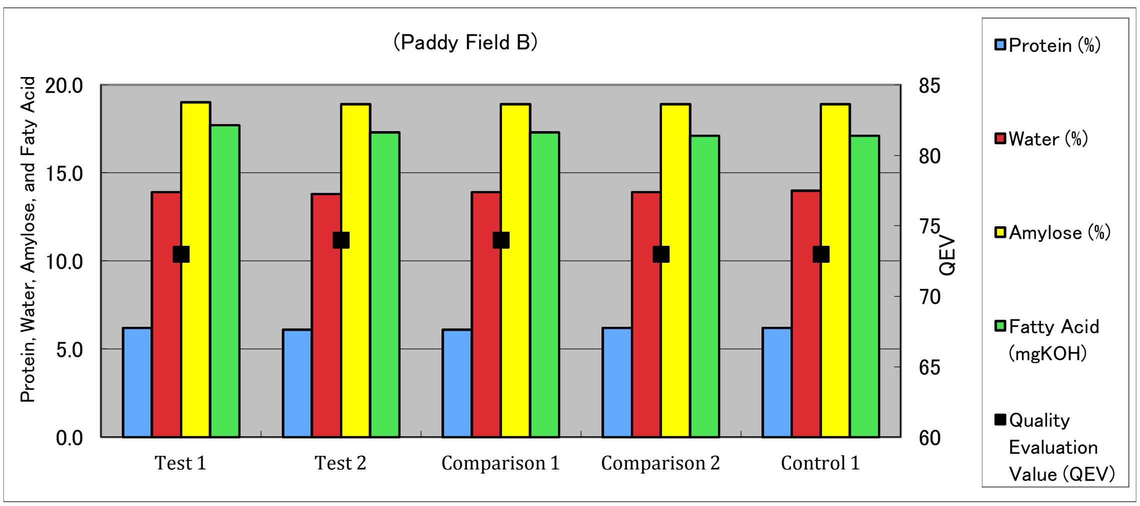

Fig. 5. Taste of Rice in paddy field B

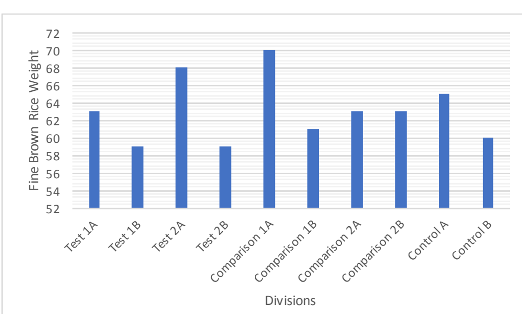

Fig. 6. Fine brown rice weight

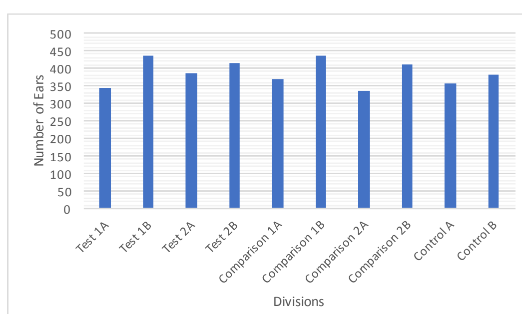

Fig. 7. Number of ears

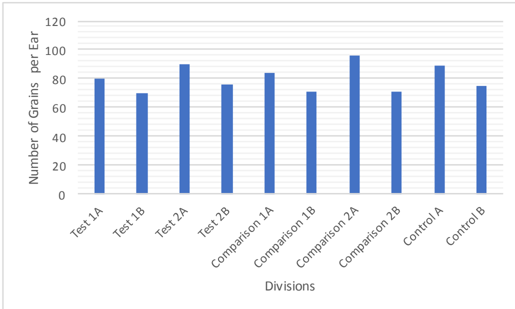

Fig. 8. Number of grains per ear

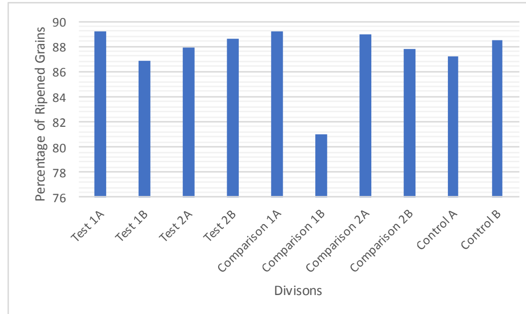

Fig. 9. Percent of ripened grains

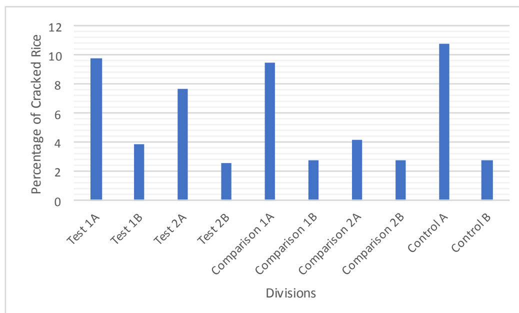

Fig. 10. Percent of cracked rice

The taste of rice was evaluated based on four parameters: protein, water, amylose, and fatty acid contents, which were used to obtain the QEV. Analysis of the four factors indicated the following [13]. Since proteins block water, it interferes with the absorption of water by rice. Rice loses its stickiness if the content of protein is high. However, in Japan, rice with low protein content is preferred, because it increases the stickiness of rice. In general, the average protein content of rice is 6.8% in Japan. According to the official standard, the water content of brown rice can be up to 16%. Furthermore, high water content is not desirable while storing rice, because it favors the growth of molds on the rice. However, if the water content is less than 14%, it results in poor taste of the rice. Therefore, the optimal water content of rice might be around 15%. Low amylose content results in sticky rice, which is preferred in Japan. The amylose content of sticky rice is generally 16%–18 %, while that of dry rice is 22%–24 %. The fatty acid content in rice increases with time; less the fatty acid content, fresher the rice. The fatty acid content of fresh rice is generally 10–20 mg KOH. The Figs. 4 and 5 indicate that the four parameters—protein, water, amylose, and fatty acid contents— of the plants from both the paddy fields were almost similar to the standard values. Furthermore, there was no significant difference in relation to the four parameters among the divisions and also between the paddy fields. This suggested that the application of rice husk silica did not affect the taste of rice when compared with that of the rice grown in soil treated with commercial silica fertilizer.

5. CONCLUSIONS

Rice husk ash contains silica, which can be recycled as a silica fertilizer. Silica fertilizer is an inevitable part of rice production, because it is essential for the healthy growth of plants. Currently, an extrinsic silica material—slag from iron production processes—is being used in rice cultivation. To pursue the ideal sustainable agriculture, recycling rice husk ash after burning the rice husk to obtain heat is essential. However, the application of rice husk silica for plant growth should not affect the taste of the rice. In this milieu, the present study was conducted, where the rice plants were grown in soil treated with rice husk silica, obtained as a part of resource recovery, for sustainable agriculture. The taste of rice was evaluated using four parameters. The results revealed that the taste of rice grown in soil treated with rice husk silica was not significantly different from that of the rice grown in soil treated with commercial silica fertilizer. Therefore, rice husk silica can be used as a silica fertilizer. Further, this would reduce the problem associated with the disposal of rice husk, as it used to obtain heat, and also used as a silica fertilizer simultaneously. Thus, the rice growing countries can benefit from it.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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