PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(2): 1-7
https://doi.org/10.14719/pst.6038

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Influence of agronomic biofortification with Zn and Si on plant growth, yield and nutritional quality of rice (*Oryza sativa* L.) cultivars

Most. Morsada Khatun[1], Md. Kabir Uddin[1], Sadia Afroz Ritu[1], Md. Shihab Uddine Khan[2] & A K M Golam Sarwar[1*]

[1]Laboratory of Plant Systematics, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

[2]Agricultural Research Station, Bangladesh Agricultural Research Institute, Satkhira 9400, Bangladesh

*Email: drsarwar@bau.edu.bd

OPEN ACCESS

ARTICLE HISTORY
Received: 21 October 2024
Accepted: 11 January 2025
Available online
Version 1.0 : 29 April 2025
Version 2.0 : 19 June 2025

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Khatun MM, Md. Kabir U, Sadia AR, Md. Shihab UK, Sarwar AKMG. Influence of agronomic biofortification with Zn and Si on plant growth, yield and nutritional quality of rice (*Oryza sativa* L.) cultivars. Plant Science Today. 2025; 12(2): 1-7. https://doi.org/10.14719/pst.6038

Abstract

Around 165 million children under the age of five are at risk of impaired cognitive development and physical capability as a result of zinc deficiency. At the same time, over 1.6 billion individuals worldwide suffer from anaemia. Biofortification is envisioned as a sustainable, cost-effective and food-based means to deliver target micronutrients to populations through staple crops. To explore the effect of zinc (Zn) and silicon (Si) on the growth, yield and nutritional quality of rice, two factorial experiments with three rice cultivars and four fertilizer treatments were conducted following a split-plot design with 4 replications at the Field Laboratory of the Department of Crop Botany, Bangladesh Agricultural University in two consecutive Boro seasons of 2021-2022 and 2022-2023. Rice cultivars used were - Purple rice, Pahari rice and BRRI dhan28 and four fertilizer treatments, *viz.* T_0- Control (recommended dose of fertilizers; RDF), T_1- RDF + 6 kg ha^{-1} $ZnSO_4$, T_2- RDF + 60 kg $ha^{-1}$$CaSiO_3$ and T_3- RDF + 100 kg $ha^{-1}$$CaSiO_3$. Results revealed that the application of Zn and Si significantly improved the growth, yield and nutritional quality of rice. Except for ash and nitrogen-free extract (NFE) content, the application of Si greatly increased grain yield and all other nutritional indicators. The maximum ash and NFE levels were determined in grains with Zn application. The performance of Si fertilizer was significantly better than that of Zn fertilizer. Both the Purple and Pahari rice cultivars have comparable grain yields with the check BRRI dhan28. Further multi-location experiments may lead to the recommendation of these two traditional cultivars for production during the Boro season in Bangladesh.

Keywords

biofortification; cultivar; micronutrient; proximate composition, rice grain

Introduction

United Nations Sustainable Development Goals (SDGs #2, #3 & #12) emphasize the significance of food security directly or indirectly (1). Nowadays, food security includes regular access to healthy, inexpensive and safe food in addition to hunger. Rice provides the majority of the daily energy for more than half of the world's population, including many of those living in poverty. As they cannot afford or do not have access to nutrient-dense meals like fruits, vegetables, meat and dairy. Malnutrition, therefore, becomes a serious hazard, causing short- and long-term health issues for example stunting growth, heart disease, diabetes and obesity. The common types of mineral deficiencies are calcium (Ca), iron (Fe), magnesium (Mg), potassium (K) and zinc (Zn). Among these, Fe and Zn deficiencies are the most prevalent global nutrient deficiencies, affecting over 25 % of the population and causing 0.8 million deaths annually (2).

Therefore, enhancing the Fe and Zn content of food crop plants to enhance crop yield and promote human well-being is a significant endeavour worldwide (3). Ongoing initiatives include finding rice varieties with antioxidant qualities and reduced glycaemic index, as well as creating biofortified rice types with enhanced micronutrient content, such as provitamin A, Fe and Zn (4). The development of new (biofortified) varieties is a time-consuming process and these varieties might not fully express their genetic potential to take up enough Zn from the soil and store it in the grain (3). Hence, agronomic intervention through fertilizer management might be a short-term approach for the biofortification of existing rice cultivars (3, 5).

Silicon (Si), the eighth most abundant element in the universe and second most abundant in the Earth's crust, has numerous beneficial effects on plants, alleviating diverse forms of abiotic (e.g., salinity, drought, freezing, high temperature, nutrient imbalances, metal toxicities and UV radiation) and biotic stress (pests and diseases) (6, 7). Its deficiency in rice plants hinders the growth of strong leaves, stems and roots and increases susceptibility to diseases and pests. Si is not lacking in quantity, yet plant-available forms of Si can be limiting. Si-maintained increased availability of nutrients in the soil solution would probably compensate for the decrease in tissue concentration of those nutrient elements and influence nutrient uptake in non-stressed plants (8).

Zinc is the only element present in all six enzyme classes, the 23rd most prevalent element on Earth and usually the second most abundant transition metal in organisms after Fe (9). Thousands of proteins in plants require Zn, even though too much of it might be harmful. As one of the most prevalent micronutrient deficiencies, Zn deficiency is now acknowledged to be having a growing impact on agricultural output. Sublethal Zn deficiency results in mottled leaves, bronzing and a variety of auxin-deficiency-like symptoms, including goblet leaves, tiny leaves, rosetting and epinasty and severe deficiency typified by dieback. Agricultural practices and/or genetic advancements can help reduce the Zn deficit of crop production (9, 10).

Bangladesh is the storehouse of a large number of rice genetic resources. Names of more than 12000 traditional rice cultivars are documented from this area (11) and several high-yielding rice cultivars (HYVs) are released from different research institutions and universities. Traditional rice cultivars are generally low yielders, but superior in quality and micronutrient content. On the other hand, HYVs are high yielders, but inferior in quality and micronutrient content. The objective of the present study is to study the effects of supplemental application of Si and Zn on plant growth, yield and nutritional quality in rice cultivars.

Materials and Methods

During two consecutive Rabi seasons (December to May) in 2021-2022 and 2022-2023, the experiment was carried out at the Field Laboratory, Department of Crop Botany, Bangladesh Agricultural University (24^{0}75′N 90^{0}50′E; 18 m above sea level). The experimental site falls inside the Old Brahmaputra Floodplain Agro-ecological Zone (AEZ 9) and is composed of non-calcareous dark grey soil (12). The monthly average values of the agroclimatic conditions, *viz.* the maximum, minimum and average temperatures (°C), relative humidity (%), total rainfall (mm) and sunshine (hr) received at the experimental site throughout the study period are presented in Appendix 1.

A total of three rice cultivars - two traditional cultivars, Purple rice and Pahari rice and a mega cultivar BRRI dhan28 (as a check), were used as experimental materials. Seeds of Purple rice and Pahari rice were collected from the Laboratory of Plant Systematics, Department of Crop Botany, Bangladesh Agricultural University; and BRRI dhan28 from the Bangladesh Rice Research Institute (BRRI), Gazipur. Rice crops were cultivated following standard cultivation techniques with varying fertilizer management (13). The experiments were laid out following a split-plot design with 4 replications and the unit plot size was 2.5m X 2m. Four fertilizer doses were applied in the rice field. Treatment combinations were T_0- Recommended fertilizer dose (RDF; 13), T_1- RDF + 6 kg ha^{-1} $ZnSO_4$ (3g 5m^{-2}), T_2- RDF + 60 kg ha^{-1} $CaSiO_3$ (30g 5m^{-2}) and T_3- RDF + 100 kg ha^{-1} $CaSiO_3$ (50g 5m^{-2}). All fertilizers except Urea were applied as basal doses during final land preparation. Urea was applied in three instalments (13). Data related to growth and yield parameters were collected whenever necessary.

Appendix 1. Monthly average air pressure, temperature, relative humidity, rainfall, wind speed and sunshine during rice growing period. mbs Millibars.

Year/Month	Air pressure (mbs)	Air Temperature (°C)			Relative humidity (%)	Rainfall (cm)	Wind speed (km/h)	Sunshine (hr)
		Max.	Min.	Mean				
2021-2022								
December	1013.6	26.2	14.8	20.5	81.9	0.3	0.3	4.6
January	1012.3	24.2	13.6	18.9	81.0	0.9	0.5	5.0
February	1011.1	25.2	14.0	19.6	76.3	1.5	1.3	6.8
March	1003.1	32.0	20.5	26.3	72.9	0.0	2.0	7.1
April	1005.0	31.9	24.0	28.0	81.7	7.1	5.4	4.2
May	1001.5	31.9	24.3	28.1	82.8	30.7	3.7	4.5
2022-2023								
December	1066.7	26.4	14.7	20.6	84.8	0.0	0.0	6.1
January	1014.0	24.4	12.3	18.4	83.5	0.0	0.0	5.4
February	1011.7	27.9	16.3	22.1	78.6	11.0	0.1	6.1
March	1010.4	29.9	19.8	24.9	76.7	110.2	0.6	6.3
April	1006.4	34.1	22.6	28.4	74.2	15.5	0.7	8.7
May	1005.1	33.5	24.0	28.7	75.9	242.1	1.6	7.8

Source: Records of Climatological Observations, Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh.

The proximate composition, *viz.* dry mass (DM; AOAC Official Method 925.40), ash (AOAC Official Method 942.05), crude fibre (CF; AOAC Official Method 978.10), crude protein (CP; AOAC Official Method 984.13), fat (AOAC Official Method 920.39) and nitrogen free extract (NFE), of rice grains was analysed at the Department of Animal Nutrition Laboratory following standard procedure (14, 15).

Nitrogen-free Extract = 100 - (Moisture + Ash + Protein +Fiber + Fat)

Determination of Zn and Fe in aqueous extracts of rice grains was done using an atomic absorption spectrophotometer (AAS) (AA-7000, SHIMADZU, Japan) at the Laboratory of Department of Agricultural Chemistry, Bangladesh Agricultural University. Hollow cathode lamps of Zn and Fe were employed as light sources at wavelengths of 213.9 and 248.3 nm, respectively. All instrumental parameters were adjusted according to the manufacturer's instructions (14, 16).

Collected data were analyzed using Statistix 10 by analysis of variance (ANOVA) techniques and means were adjudged by DMRT.

Results

Effect on growth, yield attributing characters and grain yield

Plant height varied significantly among different rice cultivars (Table 1). Pahari rice produces taller (117.90 cm) plants than other varieties. Fertilizer application had little or no influence on plant height except in Pahari rice. The tallest plant (123.73 cm) was found in Pahari rice at treatment T_0 whereas the shortest plant (91.07 cm) was found in purple rice at treatment T_0. A similar trend in plant height was also found in the 2022-2023 season.

Different cultivars had a significant impact on the number of total tillers and effective tillers hill^{-1}. On the other hand, although a numerical increase/decrease was reported due to fertilizer treatment, it was not significant (Table 1). The maximum number of total and effective tillers hill^{-1} (14.27 and 13.53, respectively) was produced by BRRI dhan28 at treatment T_0 and the minimum number (9.87 and 8.60) by Pahari rice at treatment T_0. The size of rice flag leaf differed significantly with different fertilizer treatments and cultivars (Table 1). The largest flag leaf (39.34 cm x 1.00 cm) was observed in Pahari rice at treatment T_0 and the shortest length (22.83 cm) and width (0.67 cm) in purple rice and BRRI dhan28, respectively at treatment T_1.

Panicle length and number of primary and secondary branches of panicle^{-1} of rice differed significantly with different fertilizer treatments and cultivars (Table 2). Pahari rice produced the longest panicle (26.77 cm) at treatment T_2 on the other hand BRRI dhan28 produced the shortest (24.05 cm) at treatment T_3 in the 2021-2022 season. The maximum number of branches (10.60 and 33.53, respectively) was produced by purple rice at treatment T_3 whereas the minimum number (7.20 and 19.07) was produced by BRRI dhan28 at treatment T_3 and T_2, respectively.

Table 1. Vegetative growth features of rice cultivars. T_0- Recommended fertilizer dose (RDF); T_1- RDF + 6 kg ha^{-1} $ZnSO_4$; T_2- RDF + 60 kg ha^{-1} $CaSiO_3$; T_3- RDF + 100 kg ha^{-1} $CaSiO_3$

Cultivar/Treatment		Plant height (cm)		Total tiller (no.) hill^{-1}		Effective tiller (no.) hill^{-1}		Flag leaf length (cm)		Flag leaf width (cm)	
		2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023
Purple rice		92.63 b	93.70 b	11.52 b	12.25 a	10.92 b	10.98 a	25.62 c	24.29 b	0.91 a	0.96 a
Pahari rice		117.90 a	117.62 a	11.60 b	10.35 b	10.97 b	9.25 b	35.54 a	31.00 a	0.80 b	0.93 a
BRRI dhan28		92.87 b	87.13 c	12.80 a	12.20 a	12.32 a	11.33 a	27.84 b	24.97 b	0.77 b	0.72 b
LSD (at 5%)		3.02	2.38	1.15	0.88	0.98	0.86	1.64	1.96	0.06	0.05
CV (%)		3.45	2.82	11.05	8.99	9.97	9.69	6.39	8.65	9.03	6.74
Significance		***	***	NS	***	*	***	***	***	***	***
T0		102.93	97.98 b	12.56	11.40	11.73	10.18	30.48	29.55 a	0.82	0.90
T1		99.96	98.78 b	12.56	11.51	12.16	10.36	28.90	26.30 b	0.82	0.84
T2		100.31	99.11 b	11.58	11.67	11.24	10.82	29.21	26.08 b	0.83	0.85
T3		101.33	102.07 a	11.20	11.82	10.47	10.73	30.06	25.10 b	0.84	0.87
LSD (at 5%)		3.68	2.74	1.67	1.02	1.50	0.99	2.04	2.26	0.07	0.06
CV (%)		3.45	2.82	11.05	8.99	9.97	9.69	6.39	8.65	9.03	6.74
Significance		NS	*	NS	NS	NS	NS	NS	**	NS	NS
Purple rice	T0	91.07 c	89.47 d	11.53 bc	12.40 a	10.80 bc	10.67 a-d	23.82 g	26.89 b-e	0.87 a-d	0.94 ab
	T1	91.60 c	94.60 c	13.13 ab	12.00 a-c	12.53 ab	10.80 a-d	23.83 g	22.83 f	0.91 ab	0.95 ab
	T2	92.53 c	95.67 c	11.20 bc	12.27 a	10.87 bc	11.73 a	24.55 fg	24.37 d-f	0.89 a-c	0.99 a
	T3	95.33 c	95.07 c	10.20 c	12.33 a	9.47 c	10.73 a-d	30.26 cd	23.07 ef	0.96 a	0.93 ab
Pahari rice	T0	123.73 a	118.73 ab	11.87 bc	9.87 d	10.87 bc	8.60 e	39.34 a	35.25 a	0.85 a-d	1.00 a
	T1	115.00 b	114.20 b	11.47 bc	10.47 b-d	11.00 bc	9.27 de	35.29 b	30.42 b	0.78 cd	0.91 ab
	T2	116.80 b	115.73 b	11.13 bc	10.27 cd	10.87 bc	9.33 c-e	36.20 ab	30.15 bc	0.81 b-d	0.87 b
	T3	116.07 b	121.80 a	11.93 a-c	10.80 a-d	11.13 bc	9.80 b-e	31.31 c	28.19 b-d	0.75 d	0.92 ab
BRRI dhan28	T0	94.00 c	85.73 d	14.27 a	12.93 a-c	13.53 a	11.27 ab	28.27 c-e	26.50 c-f	0.76 d	0.77 c
	T1	93.27 c	87.53 d	13.07 ab	12.07 ab	12.93 ab	11.00 a-c	27.58 d-f	25.64 d-f	0.75 d	0.67 c
	T2	91.60 c	85.93 d	12.40 a-c	12.47 a	12.00 ab	11.40 ab	26.88 e-g	23.73 ef	0.78 cd	0.67 c
	T3	92.60 c	89.33 d	11.47 bc	12.33 a	10.80 bc	11.67 a	28.62 c-e	24.02 ef	0.79 b-d	0.75 c
LSD (at 5%)		6.14	4.75	2.50	1.76	2.19	1.73	3.36	3.92	0.13	0.77
CV (%)		3.45	2.82	11.05	8.99	9.97	9.69	6.39	8.65	9.03	6.74
Significance		NS	NS	NS	NS	NS	NS	***	NS	NS	NS

NS Not significant; * Significant at 5% level; ** Significant at 1% level; *** Significant at 0.1% level.

Table 2. Yield contributing features of rice cultivars. 1° branch Primary branch, 2° branch Secondary branch. T_0- Recommended fertilizer dose (RDF); T_1- RDF + 6 kg ha^{-1} $ZnSO_4$; T_2- RDF + 60 kg ha^{-1} $CaSiO_3$; T_3- RDF + 100 kg ha^{-1} $CaSiO_3$

Cultivar/Treatment		Panicle length (cm)		1° branch panicle^{-1} (no.)		2° branch panicle^{-1} (no.)		Filled grain (no.) panicle^{-1}		Unfilled grain (no.) panicle^{-1}	
		2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023	2021-2022	2022-2023
Purple rice		25.21 a	23.51 a	10.37 a	10.03 a	30.63 a	26.73 a	116.67 a	104.12	36.52 a	44.28 a
Pahari rice		25.29 a	23.65 a	7.92 b	9.05 b	25.40 b	25.88 a	116.02 a	110.25	16.25 b	31.58 b
BRRI dhan28		24.16 b	21.46 b	7.62 b	8.07 c	21.15 c	20.67 b	100.68 b	113.53	7.55 c	9.62 c
LSD (at 5%)		0.91	0.77	0.42	0.57	2.44	2.73	11.05	14.08	3.81	7.80
CV (%)		4.23	3.98	5.63	7.49	10.94	13.21	11.49	15.22	21.92	32.34
Significance		*	***	***	***	***	***	*	NS	***	***
T0		24.55 b	23.26	8.62	9.18	26.49 a	26.13	111.02	120.58	25.76 a	33.02
T1		24.59 b	22.59	8.58	9.31	25.76 a	23.69	114.24	106.29	17.80 b	27.09
T2		25.31 a	22.71	8.62	8.80	23.62 b	24.13	108.69	106.69	18.71 b	22.02
T3		25.09 a	22.92	8.71	8.91	27.18 a	23.75	110.53	103.64	18.16 b	31.84
LSD (at 5%)		0.45	0.89	0.42	0.66	1.96	3.15	13.59	16.26	3.98	9.01
CV (%)		4.23	3.98	5.63	7.49	10.94	13.21	11.49	15.22	21.92	32.34
Significance		*	NS	NS	NS	*	NS	NS	NS	**	NS
Purple rice	T0	24.83	24.66 a	10.27	10.53 a	29.53	29.93 a	112.73 a-c	126.27 ab	40.07 a	49.47 a
	T1	24.95	22.67 b-d	10.27	9.67 a-c	31.60	25.20 a-e	121.93 a	96.80 cd	41.27 a	42.93 a
	T2	25.01 b	23.29 a-c	10.33	9.73 a-c	27.87	25.93 a-d	115.07 ab	99.60 b-d	35.60 ab	35.93 a-c
	T3	26.04 ab	23.42 a-c	10.60	10.20 ab	33.53	25.87 a-d	116.93 ab	93.80 d	29.13 bc	48.80 a
Pahari rice	T0	24.74	23.63 a-c	7.73	9.67 a-c	27.47	28.40 ab	113.07 a-c	129.07 a	25.60 c	41.53 a
	T1	24.46	22.77 b-d	7.60	9.07 bc	23.80	23.53 b-f	116.60 ab	98.80 b-d	5.60 ef	24.47 b-d
	T2	26.77 a	24.31 a	8.00	8.80 cd	23.93	27.67 a-c	111.73 a-c	115.20 a-d	16.60 d	21.67 c-e
	T3	25.17 b	23.89 ab	8.33	8.67 cd	26.40	23.93 b-f	122.67 a	97.93 cd	17.20 d	38.67 ab
BRRI dhan28	T0	24.09	21.51 de	7.87	7.33 e	22.47	20.07 ef	107.27 a-c	106.40 a-d	11.60 de	8.07 e
	T1	24.37	22.32 cd	7.87	9.20 bc	21.87	22.33 c-f	104.20 a-c	123.27 a-c	6.53 ef	13.87 de
	T2	24.14	20.53 e	7.53	7.87 de	19.07	18.80 f	99.27 bc	105.27 a-d	3.93 f	8.47 e
	T3	24.05	21.46 de	7.20	7.87 de	21.60	21.47 d-f	92.00 c	119.20 a-d	8.13 ef	8.07 e
LSD (at 5%)		1.55	1.54	0.81	1.15	4.43	5.46	22.53	28.16	7.38	0.21
CV (%)		4.23	3.98	5.63	7.49	10.94	13.21	11.49	15.22	21.92	32.34
Significance		NS	NS	NS	*	NS	NS	NS	NS	**	NS

NS Not significant; * Significant at 5% level; ** Significant at 1% level; *** Significant at 0.1% level.

The Si treatment (T_3) produced the highest grain yield in different cultivars and seasons (Table 3). The highest grain yield (5.22 and 4.94 t ha^{-1}) was recorded in 2021-2022 and 2022-2023, respectively and the lowest was 3.87 and 4.06 t ha^{-1}.

Effect on proximate composition, Fe and Zn content of rice grain

Proximate analysis is recognized as a method for measuring a compound's chemical qualities based on four specific ingredients: moisture content, fixed carbon, volatile matter and ash content. A wide variation was observed in the proximate composition, Fe and Zn content of rice grains due to different cultivars and treatments. The dry matter (%) varied from 88.01-88.38, Ash (1.50-2.25 %), crude fibre (1.83-3.41 %), crude protein (8.21-11.76 %), Fat (1.78-2.86 %), nitrogen-free extract (68.71-73.01 %), Fe (107.75-200.50 ppm) and Zn (14.86-34.05 ppm) (Table 4).

Discussion

Almost all studied features varied significantly with different cultivars, fertilizers and/or both. Generally, the genetic makeup of a cultivar controls the morphological features and yield of the respective cultivar (5, 13). Both Zn and Si have little effect on the morphological and growth descriptors of rice; however, the cumulative effects of Si increase the grain yield significantly. Although Zn-supplementation techniques were equally successful in boosting yield, fertilizers containing blended Zn were more successful in raising plant Zn concentration. This is most likely because the blended Zn had fewer interactions with the NPK fertilizer and/or soil components (3). An adequate amount of Zn helps accelerate the metabolism of auxin in plants and the activity of its enzymes. The significant genetic variation for grain Zn content has been demonstrated in several rice and maize germplasms and this diversity is being utilised in breeding efforts (17). Typically, proteins and other macromolecules contain zinc. The stability of DNA and RNA structure, the activity of enzymes that synthesise DNA, aldolases, isomerases, transphosphorylases, dehydrogenases and the regulation of enzymes that break down RNA are also significantly influenced (18). Zn may, therefore, have an impact on grain quality and yield by controlling the expression of certain genes (8). Si is mostly found in the glumes, stems and leaves of rice, with the glumes containing the greatest quantity (19). The rise in glume silicon accumulation may be the reason for the increase in

Table 3. 1000-grain weight and grain yield of rice cultivars. T_0- Recommended fertilizer dose (RDF); T_1- RDF + 6 kg ha^{-1} $ZnSO_4$; T_2- RDF + 60 kg ha^{-1} $CaSiO_3$; T_3- RDF + 100 kg ha^{-1} $CaSiO_3$

Cultivar/Treatment		1000-seed weight (g)		Grain yield (t ha^{-1})	
		2021-2022	2022-2023	2021-2022	2022-2023
Purple rice		22.41 b	23.16 b	4.56 ab	4.73 a
Pahari rice		21.85 c	23.11 b	4.38 b	4.53 b
BRRI dhan28		25.58 a	24.02 a	4.82 a	4.58 b
LSD (at 5%)		0.15	0.21	0.40	0.13
CV (%)		0.74	1.06	10.02	3.43
Significance		***	***	NS	*
T0		24.22 a	23.50 b	4.60	4.87 a
T1		23.14 c	23.15 c	4.84	4.49 b
T2		23.30 b	22.71 d	4.30	4.36 b
T3		22.46 d	24.36 a	4.60	4.72 a
LSD (at 5%)		0.05	0.24	0.48	0.15
CV (%)		0.74	1.06	10.02	3.43
Significance		***	***	NS	***
Purple rice	T0	22.51 ef	21.78 h	4.88 ab	4.76 ab
	T1	22.20 g	22.84 fg	4.80 ab	4.50 b-d
	T2	22.27 fg	21.16 i	4.66 a-c	4.76 ab
	T3	22.68 e	26.84 a	3.88 c	4.88 a
Pahari rice	T0	21.33 h	23.48 de	4.26 bc	4.98 a
	T1	23.17 d	22.60 g	4.50 a-c	4.54 bc
	T2	23.03 d	23.24 ef	3.87 c	4.26 de
	T3	19.87 I	23.12 ef	4.88 ab	4.32 c-e
BRRI dhan28	T0	28.83 a	25.24 b	4.65 a-c	4.86 a
	T1	24.05 c	24.00 c	5.22 a	4.44 cd
	T2	24.61 b	23.72 cd	4.38 bc	4.06 e
	T3	24.82 b	23.12 ef	5.03 ab	4.94 a
LSD (at 5%)		0.25	0.42	0.80	0.27
CV (%)		0.74	1.06	10.02	3.43
Significance		***	***	*	***

NS Not significant; * Significant at 5% level; ** Significant at 1% level; *** Significant at 0.1% level.

Table 4. Proximate analysis, Fe and Zn content of rice grains. DM Dry mass; CF Crude fibre; CP Crude protein; NFE Nitrogen free extract. T_0- Recommended fertilizer dose (RDF); T_1- RDF + 6 kg ha^{-1} $ZnSO_4$; T_2- RDF + 60 kg ha^{-1} $CaSiO_3$; T_3- RDF + 100 kg ha^{-1} $CaSiO_3$

Cultivar	Treatment	DM (%)	Ash (%)	CF (%)	CP (%)	Fat (%)	NFE (%)	Fe (ppm)	Zn (ppm)
Purple rice	T0	88.38	2.14	3.42	9.31 e	2.22	71.36	166.43 d	20.41 g
	T1	88.07	1.83	2.07	9.37 e	2.73	72.07	131.43 g	15.87 i
	T2	88.19	1.85	1.83	10.10 d	1.78	72.36	123.49 h	16.80 h
	T3	88.29	2.00	2.70	9.42 e	2.54	71.63	150.04 f	14.86 j
Pahari rice	T0	88.33	2.12	2.60	11.05 b	2.32	70.24	178.57 c	22.66 e
	T1	88.17	2.15	2.57	11.53 a	2.29	69.63	167.03 d	21.05 f
	T2	88.32	1.99	1.87	10.41 c	2.55	71.50	158.30 e	34.05 a
	T3	88.20	1.55	3.41	11.76 a	2.86	68.71	183.19 b	27.53 b
BRRI dhan28	T0	88.02	1.50	3.23	8.21 g	2.21	72.87	150.59 f	23.19 d
	T1	88.45	2.25	2.34	8.78 f	2.07	73.01	110.05 i	23.51 d
	T2	88.16	1.84	2.55	8.77 f	2.17	72.83	107.75 i	16.59 h
	T3	88.01	1.75	2.73	8.88 f	2.02	72.63	200.50 a	26.84 c
LSD (at 5%)		-	-	-	0.37	-	-	4.26	0.54
CV (%)		-	-	-	1.79	-	-	0.80	1.26
Significance	Cultivar (A)	-	-	-	***	-	-	***	***
	Treatment (B)	-	-	-	NS	-	-	***	***
	A × B	-	-	-	***	-	-	***	***

NS Not significant; *** Significant at 0.1% level.

1000-grain weight. Zn fertilizer, on the other hand, raises the nitrogen content, which raises the amount of RNA, ribosomes and RNA in cells and encourages protein synthesis, giving grains a fuller, harder texture and increasing the rate at which whole milled rice is produced (19). The bigger flag leaf size (length & width) might affect the number the filled grain panicles^{-1} ultimately grain yield in the 2022-2023 season. Different environmental aspects for example, temperature, relative humidity, sunshine hour, etc. across the growing seasons may be the causes of the differences in growth and yield attributing characteristics of rice cultivars between 2021-2022 and 2022-2023 (20). Variations between the growth seasons, transplant Aman *vs*. Boro, in the same year were also noted for comparable causes (21). The impact of Si and Zn on rice growth and grain yield could also be significantly influenced by the soil fertility status, application techniques and application timing (3, 19).

Both rice cultivars and production technology, flooded *vs*. unflooded, profoundly affect the mineral concentration of rice grains (17). Plants with prolonged vegetative phases possess an extended period for extracting minerals from the soil, which may enable them to accumulate reserves in their leaf tissues for subsequent grain production. In contrast, Fe and Cu are negatively associated with days from planting to heading, which would be consistent with these elements being poorly remobilized within plants, making the Fe and Cu stored in vegetative tissues unavailable to the developing grain. Additionally, the mineral concentrations of different rice types depend on their genetic or geographic origins, indicating that a heritable mechanism underlies their shared increased ionomers (elemental compositions). For instance, there were more *indica* accessions than *japonica* subgroups with high Ca, Mg, or K; temperate *japonica* accessions had low As most of the time; and numerous lines high in Mo originated in neighbouring Brunei or Malaysia (17). Some interrelationships among the different minerals in rice grains were described by Pathak et al. (22). They have reported a significant positive correlation between Zn and Fe contents of rice cultivars, however, our findings do not confirm their findings. This discrepancy might be due to differences in the genetic makeup of rice cultivars, soil physical and chemical properties, soil microorganisms, environmental conditions, etc.

Silicon has a profound effect on Fe and Zn concentration of rice grains, even on Zn concentration, compared to Zn application. Si improves nutrient absorption and translocation in rice, remobilizing iron and increasing protein and mineral concentrations, improving rice's nutritional value. Silicon-induced Fe-deficiency stress amelioration involves silicon-driven Fe chelators and gene activation. The phloem pathway in Gramineae is crucial for Fe remobilization, promoting protein and mineral concentrations in rice (23). It also mitigates stress through changes in transpiration rates, phytolith deposition, defence enzyme production, antioxidant enzyme activity and CO_2 absorption. Si absorption influences plant metabolism and the optimal delivery modes of silicon, such as calcium silicate and sodium silicate, are crucial for optimal translocation and accumulation (6). Si contributes to plant homeostasis by creating Fe-Si complexes and preserving redox potential in root apoplast and xylem sap solutions, promoting Fe transport and accumulation in shoot tissues.

In Fe-deficient environments, Si's antioxidant benefit preserves photosynthetic pigments like carotenoids and chlorophyll, promoting chlorophyll synthesis (7). The enhanced uptake of Si promotes the accumulation of Fe throughout the plant's entire body. Si also promotes the flow of Fe in the phloem by reducing the formation of calluses in the conducting channels. Furthermore, it's possible that the manufacture of chemicals that mobilise iron, including citrate in leaves and roots and catechins in roots, has increased. These compounds appear to be crucial for enhancing the redistribution and utilisation of iron. The higher Fe flow in the phloem might enable an increased accumulation of this micronutrient in grains (7). Ash fraction in the proximate analysis includes all the mineral components mixed. The application of Si improved the Fe and Zn content of rice grains in this research; however, the ash contents did not increase proportionally, even sometimes decreasing. This might indicate that the mineral composition of rice grains modifies with the increase of Fe and Zn content. The varying levels of ash content in rice grains would be attributed mainly to variations in cultivars, climate and soil nutrient status (22). They also reported a positive correlation between grain Fe and Zn content in Assamese rice genotypes, although such a relationship was not observed in this study (22). Si fertilizer application increased grain protein levels and significantly affected rice's amylose content (19). Fertilizers containing Zn may also raise the number of aromatic compounds in fragrant rice.

Conclusion

The application of both Si and Zn fertilizers could boost rice grain growth, yield and nutritional quality. In comparison to Zn fertilizer, Si fertilizer performed noticeably better. Both the traditional rice cultivars, purple rice and Pahari rice, produced comparable yields with the check BRRI dhan28. Multi-locations trial would be effective in recommending these two cultivars for the Boro season in Bangladesh.

Acknowledgements

This research was supported by the Bangladesh Agricultural University Research System project grant #2021/58/BAU (July/2021-June/2023).

Authors' contributions

AKMGS was responsible for the conception and design of the study. MMK, MKU, SAR and MSUK contributed to experimentation and data acquisition. MMK and AKMGS played a key role in formal analysis. MMK, SAR and MSUK assisted with writing the original draft preparation. AKMGS and MMK took part in the review writing and editing process. AKMGS handled the supervision, project administration and funding acquisition. All authors have read and agreed to the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. United Nations. The 17 goals sustainable development [Internet]. 2015. [cited 2023 September 08]. Available from: https://sdgs.un.org/goals
2. World Health Organization. Micronutrient deficiencies Iron deficiency anaemia [Internet]. 2009. [cited 2023 September 08]. Available from: http://www.who int/nutrition/topics/ida/en/.
3. Cakmak I. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil. 2008;302:1–17. https://doi.org/10.1007/s11104-007-9466-3
4. IRRI (International Rice Research Institute). Nutrition and food security [Internet]. 2023. [cited 2023 September 08]. Available from: https://www.irri.org/our-work/impact-challenges/nutrition-food-security
5. Sarwar AKMG, Mridul A-M, Chanda SC, Shelly IJ. Effect of potassium on panicle structure and spikelet morphology of a double grained rice cultivar. Bangladesh J Bot. 2020;49:663–70. https://doi.org/10.3329/bjb.v49i3.50007
6. Frew A, Weston LA, Reynolds OL, Gurr GM. The role of silicon in plant biology: a paradigm shift in research approach. Ann Bot. 2018;121:1265–73. https://doi.org/10.1093/aob/mcy009
7. Teixeira GCM, Prado RdM, Rocha AMS, Princi MB, de Andrade CS. Silicon mitigates iron deficiency in two energy cane cultivars by modulating physiological and nutritional mechanisms. Front Plant Sci. 2023;14:1204836. https://doi.org/10.3389/fpls.2023.1204836
8. Greger M, Landberg T, Vaculík M. Silicon influences soil availability and accumulation of mineral nutrients in various plant species. Plants. 2018;7(2):41. https://doi.org/10.3390/plants7020041
9. Broadley MR, White PJ, Hammond JP, Zelko I, Lux A. Zinc in plants. New Phytol. 2007;173:677–702. https://doi.org/10.1111/j.1469-8137.2007.01996.x
10. Brown PH, Cakmak I, Zhang Q. Form and function of zinc plants. In: Zinc in soils and plants: Proceedings of the International Symposium on 'Zinc in Soils and Plants' held at The University of Western Australia; 27-28 September 1993. pp. 93-106. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-011-0878-2_7
11. Hamid A, Uddin MN, Hoque M, Hoque AKGE. Deshi Dhaner Jat. Bangladesh Rice Research Institute, Gazipur, Bangladesh. 1982 (rev & enlarg ver 2003). (in Bangla)
12. UNDP (United Nations Development Programme)/FAO (Food and Agricultural Organization). Land Resources Appraisal of Bangladesh for Agricultural Development. Report No. 2. Agro-ecological Regions of Bangladesh. UNDP and FAO, Rome, Italy. 1988.
13. BRRI (Bangladesh Rice Research Institute). Adhunik Dhaner Chash. 22nd sp. ed., Bangladesh Rice Research Institute, Gazipur, Bangladesh. 2019. (in Bangla)
14. AOAC (Association of Official Analytical Chemists). Official Method of Analysis. 21st ed., Association of Official Analytical Chemists. Washington, D.C., USA. 2019.
15. Kabir AKMA, Moniruzzaman M, Gulshan Z, Rahman ABMM, Sarwar AKMG. Biomass yield, chemical content and *in vitro* gas production of different *dhaincha* (*Sesbania* spp.) accessions from Bangladesh. Indian J Anim Nutr. 2018;35:397–402. https://doi.org/10.5958/2231-6744.2018.00060.9
16. Sarwar AKMG, Haque MS, Hossen MZ, Kabir AKMA. Supplementary potassium application enriched micronutrient status of purple rice. Res Crops. 2022;23:719–28. https://doi.org/10.31830/2348-7542.2022.ROC-871
17. Pinson SRM, Tarpley L, Yan W, Yeater K, Lahner B, Yakubova E, et al. Worldwide genetic diversity for mineral element concentrations in rice grain. Crop Sci. 2015;55:294–311. https://doi.org/10.2135/cropsci2013.10.0656
18. Tsonev T, Lidon FJC. Zinc in plants - An overview. Emir J Food Agric. 2012;24(4):322–33.
19. Wei X, Zhang Y, Song X, Zhao L, Zhao Q, Chen T, et al. Silicon and zinc fertilizer application improves grain quality and aroma in the japonica rice variety Nanjing 46. Foods. 2024;13:152. https://doi.org/10.3390/foods13010152
20. Yoshida, S. Fundamentals of rice crop science. International Rice Research Institute, Loa Bãnos, Philippines; 1981
21. Sarwar AKMG, Khatun MM, Konok MKU, Ritu SA. Application of zinc and silicon fertilizer: influences on yield and nutritional quality of purple rice in rice (T Aman) - rice (Boro) cropping pattern. BAU Research Progress. 2024;34:115.
22. Pathak K, Rathi S, Baishya S, Verma H, Rahman SW, Sarma RN. Variability in mineral content of *indica* rice genotypes of Assam, India. Indian J Plant Genet Resour. 2017;30(2):136–42. https://doi.org/10.5958/0976-1926.2017.00020.1
23. Nikolic´ D, Bosnic´ D, Samardzˇic´ J. Silicon in action: between iron scarcity and excess copper. Front Plant Sci. 2023;14:1039053. https://doi.org/10.3389/fpls.2023.1039053