Environment and Ecology 44 (4) : 1042—1050, October—December 2026
Article DOI: https://doi.org/10.60151/envec/APDO6326
ISSN: 0970-0420 (Print), ISSN: 3049-3625 (Online)

Nutraceutical Profiling of Some Underutilized Folk Rice Cultivars from 'Rarh West Bengal' for Nutritional Security and Malnutrition Alleviation

Deblina Auddya, Priyabrata Roy, Anjan Kumar Sinha

Received 8 June 2026, Accepted 14 October 2026, Published on 9 November 2026

ABSTRACT

Nutraceutical profiling of underutilized traditional rice genotypes are very much essential for identification of promising lines for future food security and mitigating malnutrition. These underutilized rice line could be utilized in future rice breeding program either through molecular breeding or through genetic engineering. Considering this significance, nutraceutical profiling of a group of folk rice germplasm maintained by Community seed bank of ARSW society of South Bengal was studied in detail. Nine agronomic and seven important nutraceutical treats like- starch, amylose, protein, oil content, and three metal micronutrients (Fe, Zn and Mn) were evaluated for their ready identification and introgression in higher yield background to developed high yielding improved value-added rice genotypes. Majority of the rice lines shown long bold grain having long bold karnel which is one of the preferable grain characters of the rural people. Total protein, oil, starch and amylose content of the studied landraces was varied from 9.21g% to 11.2g%, 2.32 mg/g–2.88 mg/g, 73.8 g% – 75.6 g% and 6.5 g% to 30.5 g% respectively. Considerable variations in Fe, Zn and Mn were found in the grains of rice landraces varied in the range of 8.43 ppm to 60.05 ppm, 7.50 ppm to 43.19 ppm and 8.40 ppm to 52.63 ppm, respectively. Farm soil and irrigation water also played a vital role in the accumulation of metal micronutrients. Fe and Zn present in the soil showed a positive correlation with grain Fe and Zn content. It was also found that Fe and Mn content were significantly higher ($P < 0.01$) in some pigmented rice landraces. Greater content of mineral micronutrients in several rice landraces suggesting their genetic potentiality to increase the nutrient concentrations in rice grains and could probably use in breeding programs for ensuring future food security.

Keywords Micronutrients, Food security, Biofortification, Traditional rice landraces, Nutrition.

Deblina Auddya[1]

[1]PhD Research Scholar
Department of Botany, Sidho-Kanho-Birsha University, Purulia, India

Priyabrata Roy[2]

Researcher
Department of Molecular Biology and Biotechnology, University of Kalyani, India & Center of Excellence in Rice Value Addition (CERVA), International Rice Research Institute (IRRI), South Asia Regional Center, Varanasi, India

Anjan Kumar Sinha[3]*

Assistant Professor
Department of Botany, Raghunathpur College, Purulia, West Bengal 723133, India

Email: anjansinha06@gmail.com
*Corresponding author

INTRODUCTION

Rice (*Oryza sativa*) is a staple food for more than half of the population worldwide (Khush 1997). India is one of the centers of origin of Asian rice and thousands of ecotypes of rice genetic resource have been evolved and flourished in the agricultural land of India. Characterizations of different rice landraces are very important in terms of agronomical, morphological, physical and chemical attributes. Although, amazing genetic diversity for the phenotypic characters of the various rice landraces have been observed (Kovach *et al.* 2009). Micronutrient contents of rice may vary with the characteristics of the farm soil (Baxter *et al.* 2012), and also with the water used for irrigation (Fendorf *et al.* 2010). Geographical conditions, environmental and genetic factors are known to influence the vitamin and metal accumulation in rice landraces (Miller and Engel 2006). Traditional rice landraces have been used for their therapeutic and nutritional properties since ancient times (Roy 2019). *Pichhavari* and *Karthigai samba* of Tamil Nadu and *Dudhsar* of West Bengal are indigenously believed to enhance milk production in lactating mothers. Several folk rice landraces, like *Kelas* and *Bhutmoori* of West Bengal, are believed to cure anemia in women during and after childbirth (Deb 2005). Popularly consumed as polished white rice contains very low levels of essential micronutrients (Deepa *et al.* 2008) in comparison with the some traditional black rice varieties (Roy *et al.* 2021), leading to the development of micronutrient deficiency upon continuous consumption, which warrants the situation of developing micro-nutrient and vitamin rich rice through genetic engineering (Ye *et al.* 2000). Micronutrient deficiencies leads to weak the immune system and physical growth and even sometimes death. Vitamin B complex, Fe, Mn and Zn deficiencies are common in micronutrient deficiencies and have serious consequences. Biofortification is believed to be an important way to boost the micronutrient content of food crops like rice. It's also a viable and long-term strategy for addressing micronutrient deficiencies in people who eat mostly rice and have limited access to a variety of healthy diet. A detail investigation on the micronutrient contents of folk rice germplasms are essential for understanding their role in human health and nutrition. Meenakshi *et al.* (2010) found that though, some governing bodies took up micronutrient supplementation program but their affordability remains doubtful. Mayer *et al.* (2008) have expressed their concern that a majority of world population with ≤ $2/day wages, how far can access the industrially processed foods under post-harvest micronutrient fortification programs. Authors like Hurrell (2002); Abbaspour *et al*. (2014) further added that food fortification can alter quality attributes like color and flavor which may influence consumer acceptance behavior. Beside these, agro-environmental components were also known to reduce micronutrient content in rice (Moulick *et al*. 2020; White and Broadley (2009); Bouis *et al.* (2011) were of the opinion that, enrichment of micronutrient in the edible parts of field crops as the most maintainable way to get rid of micronutrient deficiencies. Among the field crops, in terms of area of cultivation, popularity among world population as preferred dietary item has made rice as most sort after target crop for biofortification (Wessells and Brown 2012, WHO 2015; FAO 2016).

In this study, we evaluate the morphological characters, presence of some micronutrients in the grains of selected indigenous rice landrace. The actual goal of the investigation is to promote these landraces and to explore their potential to ensure the nutritional security with greater micronutrient content under biofortification program.

MATERIALS AND METHODS

Forty-one (41) rice landraces were selected on the basis of agronomic and morphological attributes. Samples were collected from the Community Seed bank of Amarkanan Rural Socio Environmental Welfare Society (ARSWS-CSB), located in Bankura district of West Bengal (23° 22' 32.394'' N, 87° 5' 53.9592'' E) (Fig. 1). These landraces are being cultivated and conserved *in situ* in the farmland of ARSW Society (Fig. 2). The cultivation of local landraces is part of an *in situ* rice genetic diversity conservation effort of these endangered landraces, and to highlight the nutritional significance of these neglected germplasms. We cultivated these landraces in the four consecutive Monsoon / *Kharif* season (June to December 2022-2025 session) (Fig. 3). Rice landraces were grown in separate plots at a density of 16 hills/m^2 in the tropical

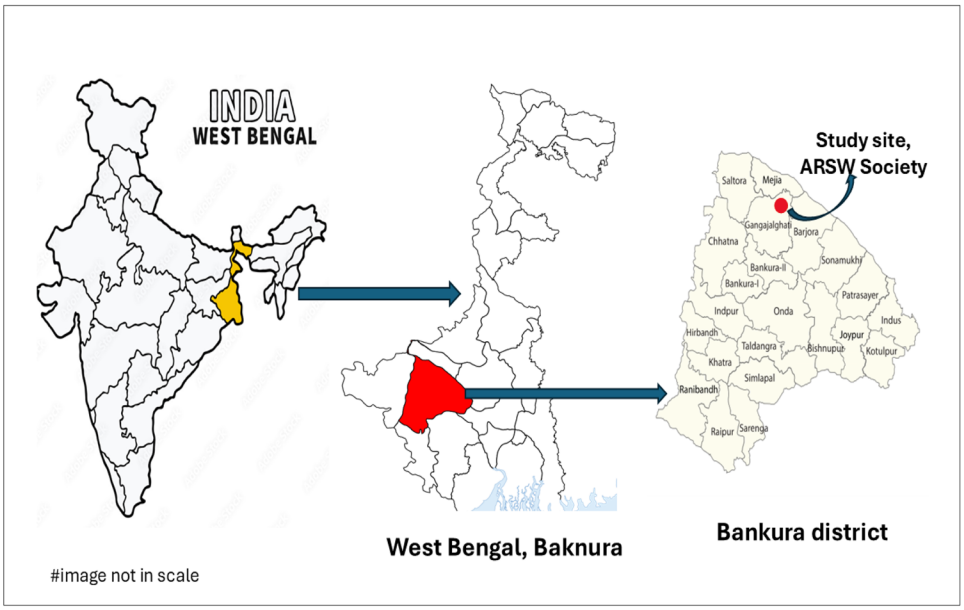


Fig. 1. Location of study site.

climate by regular irrigation but without the application of any type of chemical fertilizers, pesticides and herbicides. At maturation, rice plants were harvested and threshed manually. Rice grains were decorticated in the lab using a mechanical huller and were ground to find powder using mortar & pestle and stored in -20°C before analysis.

Chemicals

All the chemicals used in this study were of analytical grade (AR Grade). Analytical standards were purchased from Sigma-Aldrich (India). Methanol and Chromatographic grade water were purchased from Merck (India).



Fig. 2. A glimpse of traditional rice landraces used in this study.
First Row Left to Right- Kalobhat, Kashiphool, Lalpatni, Patnai-23, Bachi, Nikunja, Sundari, Dudhkalam, Valki, Daharlagra, Nonabogra, Ashinlaya, Arka, Jhumur, Letasole, Birahi, Gokulsal, Kelesh, Bombaimugi, Bhurisal.
Second Row Left to Right- Gangajali, Kaksal, Bhadoi, Ayan, Bhramarmali, Sindurmukhi, Dadkhani, Khandagiri, Kheuch, Moti, Dharansal, Boishali, Fulkhar, Jhilik, Badamsaru, Chandrakanta, Chotodidi, Kalobyar, Binnidhan, Jamainadu.



Fig. 3. Seed bed of studied traditional rice lines in on-farm condition.

Morphological properties

We reported here some important agronomic and morphological characteristics of forty rice landraces. Measurements of different morphological characteristics of the landraces were recorded, following Biodiversity International guidelines (2007). Details of the features are provided in Table 1.

Analyses of micronutrients

Analysis of micronutrient like Protein content, Oil content, starch and amylose content were performed by using standard methods. Total soluble starch and amylose content were analyzed following the method describe by Chow and Landhäusser (2004). Total protein contents were analyzed by following Bradford method (Bradford 1976) and oil content of the studied rice landraces were analyzed following method described by Bligh and Dyer (1959).

Analyses of metal micronutrients

Metal detection (Mn, Fe and Ze) and analysis were performed by using Inductively Coupled Plasma Mass Spectrometer (Agilent Technologies 7800 ICPMS, USA) as described by Sen Gupta *et al.* (2017). The results were repeated three times in all cases.

Statistical analysis

Values were expressed as mean value (n= 3). Further, the obtained data were subjected to Pearson's correlation analysis. The resolution of confidence limit was narrowed to $p<0.01$, at which the strongest correlations between the pairs of biochemical properties were identified.

RESULTS AND DISCUSSION

Morphological characterization

The morphological characters of the rice landraces are presented in Table 1. Grain color, weight, size, shape, aroma, etc. are considered as the main criteria for understanding the quality of rice and its various physical characteristics (Deb 2005; Moulick *et al.* 2020). Accessions of rice can be differentiated by morphological features such as crop height, basal leaf sheath color, leaf shape and size, flag leaf angle, grain size, presence/absence of awn, grain color, seed coat color, awn color, seed weight, panicle size, structure and density, threshability and aroma, among others. Farmers are still growing a wide range of rice varieties with a variety of characteristics such as aroma, drought, flood, or salinity tolerance, and pest and disease resistance after centuries of selective breeding. This study looked at and documented some of these important agronomic and morphological characteristics. Rice floral biology is also critical for preserving genetic purity. Hopefully, this register of folk rice genetic diversity will spur the creation of other community-owned biodiversity documents, affirming indigenous farmers' sovereign right to freely use their heirloom crop genetic diversity (Table 1 & Fig. 2).

Table 1. Morphological properties of the seeds of 34 traditional rice landraces.

Serial No.	Landrace Name	Lemma palea color	Grain color	Grain length (mm)	Grain width (mm)	Decorticated GL (mm)	Decorticated GW (mm)	Awn length (cm)	1000 grain weight (gm)	Aroma
1	Arka	Red	White	8	2.5	6.16	2.08	absent	18.9	absent
2	Ashinlaya	Straw	Light red	8.66	2.75	5.83	2.33	absent	24	absent
3	Bachi	Brown furrow on straw	White	7.26	3.27	4.87	2.66	absent	23.3	absent
4	Badam Soru	Straw	White	9.1	2.3	6.3	2	absent	19.2	absent
5	Bhadoi	Brown furrow on straw	Varigated brown	8.38	2.81	6	2.39	absent	24.1	absent
6	Bhramarmali	Straw	White	7.5	2.4	6.3	2	absent	22.3	absent
7	Bhurisal	Straw	White	7.91	2.5	6.16	2.16	absent	20.1	absent
8	Binni Dhan	Straw	Red	8.91	2.58	6.5	2.16	absent	21.4	absent
9	Birahi	Brown furrow on straw	Light red	7.76	2.41	6.08	2.25	absent	18.6	absent
10	Boishali	Straw	Light red	8.3	4	6.3	3	absent	24.3	absent
11	Chandrakanta	Gold furrow on straw	Light red	8.6	2.6	4.8	2.1	absent	23	absent
12	Choto Didi	Straw	Varigated brown	8.52	3.31	5.97	2.99	absent	31.9	absent
13	Dadhkani	Reddish to ligt purple	White	8.3	2.3	5.8	1.8	absent	15.8	absent
14	Dahar Lagra	Straw	White	8.9	2	7	1.7	absent	19.1	absent
15	Dharan Sal	Straw	White	8.82	2.61	6.28	2.26	absent	22.4	absent
16	Dudh Kalma	Straw	White	8.75	2.75	6.42	2.33	absent	24.5	absent
17	Fulkhar	Straw	White	9.24	2.46	6.54	2.21	absent	22.1	absent
18	Gokul Sal	Straw	White	7.84	2.17	5.84	1.75	absent	18.2	absent
19	Jamainadu	Purple	White	8.6	3	6.6	2.3	absent	23.5	absent
20	Jhilik	Straw	White	8.66	2.25	6.16	1.91	absent	17.5	absent
21	Jhumur	Straw	White	8.25	2.75	6.41	2.25	absent	22.1	absent
22	Kaksal	Purple spot on straw	Light red	8.97	3.08	6.58	2.7	absent	30.3	absent
23	Kalobhat	Purple furrow on straw	Black purple	9.98	3.19	6.68	2.57	absent	27	Present
24	Kalobyar	Black	Light brown	7.84	3.26	5.63	2.86	absent	20.5	absent
25	Kasiphul	Straw	White	7.75	2.92	5.83	2.58	absent	25	absent
26	Kelesh	Black	Light brown	7.82	2.79	5.42	2.46	absent	19.7	absent
27	Khandagiri	Straw	White	9.6	2.8	7.3	2.2	absent	25.1	absent
28	Kheuch	Red furrow on straw	White	8.11	3.23	5.71	2.84	absent	27.1	absent
29	Lal Patni	Red furrow on straw	White	8.6	2.9	6.4	2.5	absent	24.3	absent
30	Nayanmani	Straw	White	8.65	2.21	6.34	1.99	absent	22.5	absent
31	Patnai-23	Straw	White	11.2	2.8	8.3	2.2	absent	27.6	absent
32	Sindurmukhi	Red furrow on straw	White	9.15	2.67	6.67	2.35	absent	26.2	absent
33	Sundari	Gold furrow on straw	White	7.62	2.95	5.85	2.4	absent	19.1	absent
34	Valki	Purple furrow on straw	Varigated brown	7.94	3.19	5.64	2.74	absent	27.1	absent

Table 2. Concentrations of mineral micronutrients in the grains of traditional rice landraces.

Sl. No.	Landrace Name	Mn (ppm)	Fe (ppm)	Zn (ppm)	Protein (mg/100 gm)	Oil (mg/100 gm)	Starch (gm/100 gm)	Amylose (gm/100 gm)
1	Arka	13.46	8.96	9.99	9.80	2.75	75.6	24.3
2	Ashinlaya	18.56	8.10	8.43	10.1	2.55	74.0	20.5
3	Bachi	34.84	12.32	19.71	9.71	2.53	74.4	16.3
4	Badam Soru	15.86	11.78	13.93	9.81	2.65	75.0	28.1
5	Bhadoi	16.54	14.93	21.40	10.5	2.78	74.5	19.7
6	Bhramarmali	31.40	21.60	29.10	9.08	2.53	74.5	24.5
7	Bhuri Sal	18.70	7.50	11.55	9.76	2.59	74.1	27.1
8	Binni Dhan	15.37	22.53	24.40	10.2	2.67	74.5	28.4
9	Birahi	21.06	14.66	23.39	10.5	2.87	74.4	23.5
10	Boishali	24.46	10.98	20.62	8.92	2.70	75.1	26.2
11	Chandrakanta	11.85	23.90	28.20	9.68	2.58	74.4	29.4
12	Choto Didi	8.40	20.63	21.80	10.1	2.56	74.1	19.2
13	Dadhkani	15.89	9.33	11.21	10.4	2.78	75.3	24.3
14	Dahar Lagra	44.84	13.46	24.44	10.9	2.32	73.2	30.5
15	Dharan Sal	21.69	12.16	18.94	9.52	2.64	74.7	30.4
16	Dudh Kalma	11.69	11.07	17.94	9.8	2.61	74.9	27.2
17	Fulkhar	18.41	43.19	60.05	9.21	2.59	74.5	25.2
18	Gokul Sal	33.05	8.93	24.12	10.3	2.58	73.8	19.5
19	Jamainadu	13.28	12.61	20.60	10.2	2.46	74.7	22.1
20	Jhilik	27.38	11.55	14.80	10.2	2.62	74.2	27.6
21	Jhumur	13.58	8.11	13.52	10.2	2.77	75.1	21.6
22	Kaksal	16.36	10.96	15.94	10.0	2.72	74.2	19.8
23	Kalobhat	15.50	8.70	11.35	11.1	2.75	73.9	15.7
24	Kalobyar	18.40	11.90	12.28	10.5	2.81	74.9	17.5
25	Kashi Phul	41.50	25.57	44.60	10.7	2.73	74.1	17.8
26	Kelesh	29.86	12.82	18.80	11.2	2.88	74.1	6.5
27	Khandagiri	25.02	12.87	24.49	10.2	2.65	73.9	24.9
28	Kheuch	21.76	34.72	41.40	10.4	2.71	74.3	14.6
29	Lal Patni	14.90	7.95	9.28	9.28	2.81	74.5	17.6
30	Nayanmani	0.00	22.80	32.60	9.64	2.78	74.1	23.6
31	Patnai-23	20.62	12.58	16.36	9.91	2.62	74.9	26.8
32	Sindoor Mukhi	16.41	13.69	16.90	9.94	2.57	74.4	22.0
33	Sundari	52.63	23.22	34.97	10.4	2.58	73.9	24.2
34	Valki	19.90	12.90	19.55	9.83	2.42	75.1	23.6

* Values are the mean of three determinations in all the cases.

Micronutrients contents in rice landraces

Micronutrients are essential for normal metabolic functions, production of essential hormones and enzymes and are required components for a balanced diet. As shown in the Table 2, rice landraces studied here were an excellent source of micronutrients, which could be helpful to prevent various health related problems in the human body. The presence of essential and nutritionally important nutrient like Protein, starch content, amylose content and oil content was analyzed in all rice landraces and are given in Table 2. Among the studied rice landraces highest total protein content (11.2 g %), and highest oil content (2.88 mg/g) was observed on Kelesh variety. Highest amount of total starch content was observed on Arka variety (75.6 g %) and highest amount of amylose content was observed on Daharlagra variety (30.5 g %).

Metal micronutrients in rice landraces

The presence of essential and nutritionally important metal ions was analyzed in all rice landraces and are given in Table 2. In the present study, we found most of the rice landraces contained a higher amount

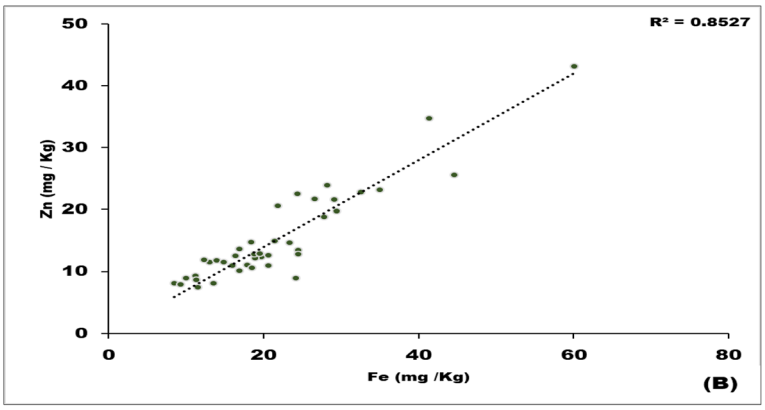


Fig. 4. Correlation of Fe against Zn (B) in the traditional rice landraces.

of metal micronutrients. Among the rice landraces, Fulkhar content highest amount of Fe (43.19 mg Kg^{-1}) and Zn (60.05 mg Kg^{-1}) in its grains and another landrace, Sundari content highest amount of Mn (52.63 mg Kg^{-1}). Micronutrients must be present in the soil solution for plants to absorb them. There's a lot of evidence that the chemical makeup of micronutrients in solution influences their availability to plants (Parker *et al.* 1995). When plants uptake metals, Cabrera *et al.* (1988) found a high level of correlation with the activity of free metals ions in soil solution rather than total element concentrations in soils. The total concentrations of micronutrients in soils are likely to influence soluble heavy metal concentrations in soils to some extent.

Also, we found a strong positive correlation between Fe and Zn content in the grains of studies rice landraces (Fig. 4). The slope of the regression ($R^2 = 0.97$, $P < 0.01$) indicates a common metabolic pathway likely involved in the accumulation of Fe and Zn in rice rhizosphere. It is known that phytosiderophores (PSs) can attach to Fe^{3+} to produce the soluble complex Fe (III)-PS, and these compounds can be absorbed into root cells by Yellow Stripe-Like Proteins (YSLs) in the rhizosphere (Santos *et al.* 2017). Also, the phytic acid pathway could play a role for Fe and Zn accumulation in grains (Majumder *et al.* 2019).

Rice is the staple food for more than half of the world's population, particularly in developing countries, so efforts are being made to improve its nutritional status in order to prevent malnutrition. Many researchers have looked into the possibility of increasing the concentrations of metal-binding proteins in grains to improve bioavailability of micronutrients. Micronutrient uptake and translocation efficiency from root to grain are also factors in grain micronutrient content. In different rice and maize germplasm, there was a lot of genetic variation for grain iron and zinc, which was exploited in breeding programmes (Graham *et al.* 1999). Rice lines in IRRI germplasm were screened for high Fe and Zn content by Gregorio *et al*. (2000). Fe concentrations ranged from 6.3 to 24.4 mg Kg^{-1} in a subset of 1,138 samples analyzed, while Zn concentrations ranged from 15.3 to 58.4 mg Kg^{-1}. Anandan *et al*. (2011) have shown that traditional rice cultivars have high Fe and Zn content than improved cultivars. Roy and Sharma (2014) have screened 84 landraces for iron and zinc content. Fe content varied between 0.25 to 34.8 mg $Kg^{-1}$and Zn content from 0.85 to 195.3 mg Kg^{-1}. Deb *et al.*, (2015) studied 130 rice landraces and variation in Fe (0.2 to 130 mg Kg^{-1}), Zn (2.4 to 155.31 mg Kg^{-1}), and Mn (14.9 to 138.0 mg Kg^{-1}) content. Recently, Sen Gupta *et al.* (2017) screened 505 traditional rice landraces from India. The Fe content varied between 0.20 to 150.85 mg Kg^{-1}, the Zn content varied between 0.89 to 282.80 mg Kg^{-1}, and the Mn content varied between 1.87 to 503.51 mg Kg^{-1} (Table 2). There is no consistent value of Fe, Mn and Zn for a genotype, according to previous studies and the current study. Micronutrient homeostasis, sampling method, grain nature, soil properties, analytical methods, environment, genotypes, and several interactions between the factors all influence variation (Zwolak *et al.* 2019).

Rice landraces with the higher concentration of Fe, Zn and Mn, could be provided to the patients suffering from anaemia. Indigenous people of West Bengal used Fe and Zn rich rice landraces for lactating mothers (Deb 2005). Metal micronutrient rich rice landraces have a long history for treating various diseases and malnutrition as they have shown selective therapeutic properties (Deb 2017, Roy 2019). Though micronutrient content varies due to a variety of factors, the rice germplasm stock has enough variation to exploit for developing stable lines (White and Broadley 2005, Singh *et al.* 2016). Because micronutrient malnutrition is a major global problem, the development of micronutrient-rich genotypes is urgently needed. The rice landraces discovered with high metal micronutrients in this study, will be useful in selecting and breeding micronutrient-rich lines.

CONCLUSION

This research demonstrates the properties of the rice landraces could be clarified by high levels metal micronutrients. Micronutrient deficiency is recognised as one of the most pressing threats to food and nutrition security, especially in the developing countries, and a food-based approach is increasingly being recognised as a viable solution. The diversity of plant genetic resources makes it possible to find micronutrient-rich genotypes for direct use or to use breeding strategies to improve the genetics of staple crops. Hopefully, our findings may encourage a more comprehensive exploration of the nutritional potential of indigenous landraces, which in mainstream rice research have remained largely neglected. In order to provide community health and nutritional security, particularly in the global South, our results here could further etch out the imperative to preserve these rare and evanescent landraces.

ACKNOWLEDGMENT

Authors are grateful to the Community seed bank of ARSW society, Amarkanan, Bankura, India for providing indigenous rice germplasms for the work.

REFERENCES

Abbaspour, N., Hurrell, R., & Kelishadi, R. (2014). Review on iron and its importance for human health. *Journal of Research in Medical Sciences*, 19 (2), 164—174.

Anandan, A., Rajiv, G., Eswaran, R., & Prakash, M. (2011). Genotypic variation and relationships between quality traits and trace elements in traditional and improved rice (*Oryza sativa* L.) genotypes. *Journal of Food Science*, 76 (4), H122—H130.

Baxter, I., Hermans, C., Lahner, B., Yakubova, E., Tikhonova, M., Verbruggen, N., Chao, D.Y., & Salt, D. E. (2012). Biodiversity of mineral nutrient and trace element accumulation in Arabidopsis thaliana. *PLoS One*, 7 (4).

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37 (8), 911—917.

Bouis, H. E., Hotz, C., McClafferty, B., Meenakshi, J. V., & Pfeiffer, W. H. (2011). Biofortification: A new tool to reduce micronutrient malnutrition. *Food and Nutrition Bulletin*, 32, S31—S40.

Bradford, M. M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Annals Biochem*, 72, 248—254.

Cabrera, D., Young, S. D., & Rowell, D. L. (1988). The toxicity of cadmium to barley plants as affected by complex formation with humic acid. *Plant and Soil*, 105 (2), 195—204.

Chow, P. S., & Landhäusser, S. M. (2004). A method for routine measurements of total sugar and starch content in woody plant tissues. *Tree Physiol*, 24 (10), 1129—1136.

Deb, D. (2005). Seeds of Tradition, Seeds of Future: Folk Rice Landraces from East India. *Research Foundation for Science Technology & Ecology*. New Delhi.

Deb, D., Sen Gupta, S., & Pradeep, T. (2015). A profile of heavy metals in rice (*Oryza sativa* ssp. indica) landraces. *Current Science*, 109 (3), 407.

Deb, D. (2017). Folk rice varieties, traditional knowledge and nutritional security in South Asia. Agroecology, Ecosystems and Sustainability in the Tropics, 117—134.

Deepa, G., Singh, V., & Naidu, K. A. (2008). Nutrient composition and physico-chemical properties of Indian medicinal rice–Njavara. *Food Chemistry*, 106 (1), 165—171.

FAO. (2016). Save and grow in practice: Maize, rice and wheat. A guide to sustainable cereal production. Food and Agriculture Organization of the United Nations, Rome.

Fendorf, S., Michael, H. A., & Van Geen, A. (2010). Spatial and temporal variations of groundwater arsenic in South and Southeast Asia. *Science*, 328, 1123—1127.

Graham, R., Senadhira, D., Beebe, S., Iglesias, C., & Monasterio, I. (1999). Breeding for micronutrient density in edible portions of staple food crops: Conventional approaches. *Field Crops Research*, 60 (1-2), 57—80.

Gregorio, G. B., Senadhira, D., Htut, H., & Graham, R. D. (2000). Breeding for trace mineral density in rice. *Food and Nutrition Bulletin*, 21 (4), 382—386.

Hurrell, R. (2002). How to ensure adequate iron absorption from iron-fortified food. *Nutrition Review*, 60, S7—S15.

International Plant Genetic Resources Institute and West Africa Rice Development Association. (2007). Descriptors for Wild and Cultivated Rice (*Oryza* Spp.). *Biodiversity International.*

Khush, G. S. (1997). Origin, dispersal, cultivation and variation of rice. *Plant Molecular Biology*, 35 (1-2), 25—34.

Kovach, M. J., Calingacion, M. N., Fitzgerald, M. A., & McCouch, S. R. (2009). The origin and evolution of fragrance in rice (*Oryza sativa* L.). *Proceedings of National Academy of Science*, 106 (34), 14444—14449.

Majumder, S., Datta, K., & Datta, S. K. (2019). Rice biofortification: High Iron, Zinc and vitamin-A to fight against "hidden hunger". *Agronomy*, 9 (12), 803.

Mayer, J. E., Pfeiffer, W. H., & Beyer, P. (2008). Biofortified crops to alleviate micronutrient malnutrition. *Current Opinion in Plant Biology*, 11, 166—170.

Meenakshi, J. V., Johnson, N. L., Manyong, V. M., De Groote, H., Javelosa, J., Yanggen, D. R., Naher, F., Gonzalez, C., Garcıa, J., & Meng, E. (2010). How cost-effective is biofortification in combating micronutrient malnutrition ? Anex ante assessment. World Dev 38, 64—75.

Miller, A., & Engel, K. H. (2006). Content of γ-oryzanol and composition of steryl ferulates in brown rice (*Oryza sativa* L.) of European origin. *Journal of Agricultural and Food Chemistry*, 54 (21), 8127—8133.

Moulick, D., Sarkar, S., Awasthi, J. P., Ghosh, D., Choudhury, S., Tata, S. K., Bramhachari, K., & Santra, S. C., Rice Grain Quality Traits: Neglected or Less Addressed ? In Rice Research for Quality Improvement: Genomics and Genetic Engineering 2020 (pp, 729—745). Springer, Singapore.

Parker, D. R., Chaney, R. L., & Norvell, W. A. (1995). Chemical equilibrium models: Applications to plant nutrition research. *Chemical Equilibrium and Reaction Models*, 42, 163—200.

Roy, P., Deb, D., Pradeep, T., Talai-Mukhopadhyay, S., Sinha, A. K., & Saha, T. (2021). Comparative analyses of the nutraceutical potentialities of selected Indian traditional black rice (*Oryza sativa* L.) landraces. *ORYZA- An International Journal on Rice*, 58 (2), 295—309.

Roy, S. C., & Sharma, B. D. (2014). Assessment of genetic diversity in rice [*Oryza sativa* L.] germplasm based on agromorphology traits and zinc-iron content for crop improvement. *Physiology and Molecular Biology of Plants*, 20 (2), 209—224.

Roy, P. (2019). Importance of Traditional Rice Landraces as Nutraceutical Foods. In: *Folk Rice Diversity of Eastern India*: *Hope for The Future Food Security*. (Eds. Sinha, A.K *et al*.) pp, 123—136.(IP Innovative Publication Pvt. Ltd. Delhi).

Santos, R. S. D., Araujo, A. T. D., Pegoraro, C., & Oliveira, A. C. D. (2017). Dealing with iron metabolism in rice: From breeding for stress tolerance to biofortification. *Genetics and Molecular Biology*, 40, 312—325.

Sen Gupta, S., Baksi, A., Roy, P., Deb, D., & Pradeep, T. (2017). Unusual accumulation of silver in the Aleurone layer of an Indian rice (*Oryza sativa*) landrace and sustainable extraction of the metal. *ACS Sustainable Chemistry & Engineering*, 5 (9), 8310—8315.

Singh, U., Praharaj, C. S., Chaturvedi, S. K., & Bohra, A. (2016). Biofortification: Introduction, approaches, limitations and challenges. In *Biofortification of Food Crops* (pp, 3—18). Springer, New Delhi.

Wessells, K. R., & Brown, K. H. (2012). Estimating the global preva-lence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS ONE7*, e50568.

White, P. J., & Broadley, M. R. (2005). Biofortifying crops with essential mineral elements. *Trends in Plant Science*, 10 (12), 586—593.

White, P. J., & Broadley, M. R. (2009). Biofortification of crops with seven mineral elements often lacking in human diets - iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist*, 182, 49—84.

WHO. (2015). The global prevalence of anaemia in 2011. World Health Organization, Geneva.

Ye, X., Al-Babili, S., Kloti, A., & Zhang, J. (2000). Engineering the provitamin A (beta-carotene) biosynthetic path way into (carotenoid-free) rice endosperm. *Science*, 287 (5451), 303—305.
https://doi.org/10.1126/science.287.5451.303

Zwolak, A., Sarzyńska, M., Szpyrka, E., & Stawarczyk, K. (2019). Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. *Water, Air & Soil Pollution*, 230 (7), 1—9.