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An economic analysis of biofortified rice varieties

Nirmala Bandumula*, CN Neeraja, Amtul Waris, D Sanjeeva Rao and P Muthuraman

ICAR-Indian Institute of Rice Research, Hyderabad, Telangana State, India

***Corresponding author e-mail: bnirmaladrr@gmail.com, Nirmala.B@icar.gov.in**

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ABSTRACT

Rice provides up to 60 per cent of the daily energy requirement. The current popular rice varieties grown in India have an incomplete amino acid profile and limited zinc. The development of high zinc rice varieties by ICAR-Indian Institute of Rice Research and high protein variety by ICAR-National Rice Research Institute is an effort to address malnutrition through biofortification in rice. This study was undertaken to assess the economic performance of zinc biofortified rice varieties and to analyse the technology efficacy of protein biofortification in rice. Information on input-output details, cost of production, yields and output prices and other variables pertaining to DRR Dhan 45 for the kharif season of 2017 were collected through a survey from 150 farmers of Telangana. The results revealed that the economic performance of the zinc biofortifed rice varieties was at par with Samba Mahsuri, a popular variety of the study area. The study also revealed that the technology efficacy of the protein biofortification of rice was in the range of 31 to 39 per cent and 62 to 74 per cent under pessimistic and optimistic scenarios, respectively. Large scale adoption of biofortified rice varieties depend on the availability of seed, certification and premium market price for the biofortified products.

Key words: *Rice, zinc biofortification, DRR Dhan 45, protein biofortification, CR Dhan 310*
Jel codes: I15,I18, Q1

INTRODUCTION

Rice, the staple food crop of India, contributes to 'No Poverty' and 'Zero Hunger' Sustainable Development Goals. It provides up to 60 per cent of the daily energy requirement and therefore is crucial for food and nutritional security. Rice is consumed in polished form (white rice) and starch constitutes the chief component of rice, followed by proteins, lipids, minerals and negligible levels of vitamins. Thus, rice provides more energy than the essential nutrients leading to micronutrient deficiency which is also known as "hidden hunger" (Rao et al., 2014). Zinc and protein deficiencies are the most important challenges of nutritional security of India. Though rice is the major food crop of India, the daily zinc and protein requirement cannot be achieved through typical rice-based vegetarian diet. The popular rice varieties grown in India have an incomplete amino acid profile and limited zinc (Sautter et al., 2006).

The zinc deficiency in human beings may induce a number of critical functional abnormalities, including impaired reproductive performance, depressed immune function and secondary increases in the incidence and severity of infections, growth failure and secondary nutritional stunting, and abnormalities of neuro-behavioural development. In India, about 42 per cent of the children are stunted (Herforth, 2009). Because of the likely high global prevalence of zinc deficiency and the serious range of complications that can be induced by this condition, public health programs were advocated to prevent low zinc-intake and poor absorption of zinc (Brown et al., 2001). Protein is essential for growth and maintenance of muscle mass. Deficiency of protein causes 'kwashiorkor' characterised by swollen and puffy skin, loss of muscle mass, increased risk of fractures, constant appetite and fatty liver.

The research efforts in agriculture initially aimed at achieving self-sufficiency of foodgrains. Presently, biofortification of major food crops is considered as a viable strategy to address malnutrition and to ensure nutritional security. The long-term solution to alleviate malnutrition lies in increasing the essential nutrient contents of the staple food crops, *viz*., cereals through crop biofortification strategy (Neeraja et al., 2017). Biofortification is the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology (Nestel et al., 2006). Biofortification refers to the enhancement of the nutrient levels of the crops through plant breeding and genetic engineering and is a cost effective strategy to combat the ill effects of the micronutrient and protein malnutrition (Bouis, 2002). Investment into biofortification related research has enormous potential to combat the adverse health effects of micronutrient deficiencies (Nirmala et al., 2016).

Rice biofortification program aims at biological and genetic enrichment of food products with vital nutrients, vitamins and proteins. Ideally, once rice is biofortified with vital nutrients, the farmer can grow the variety indefinitely without any additional input to produce nutrient packed rice grains in a sustainable way, so that the produce reaches the malnourished population in rural India (Ravindra Babu, 2013). The development of high zinc rice varieties, DRR Dhan 45, 48 and 49 by ICAR-Indian Institute of Rice Research (ICAR-IIRR) and high protein rice variety CR Dhan 310 by ICAR-National Rice Research Institute (ICAR-NRRI) is an effort to address malnutrition, through biofortification in rice.

The estimation of the economic benefits generated by the adoption of technological innovations is usually done based on the productivity effects in agricultural production. The aggregate benefits could be estimated by calculating a shift in the supply curve of the product. This approach is suitable for technologies with improved agronomic traits. Technologies that enhance the quality of commodities are rather associated with benefits at the level of consumption (Zimmermann and Qaim, 2004). Capturing the benefits of biofortified rice varieties in a market model is therefore not appropriate. Instead, the technology's positive health effects have to be identified and measured. The impact of biofortification of rice varieties mainly depends on the technology's efficacy which is defined as the capacity to improve the health status of a nutrient deficient individual. Hence, the present study was conducted to assess the economic performance of zinc biofortified rice varieties and to analyse the technology efficacy of protein biofortification in rice.

MATERIALS AND METHODS

DRR Dhan 45, a zinc biofortified rice variety was released in 2016. The agronomic and economic performance of DRR Dhan 45 was assessed through surveysand focus group discussions with the selected farmers in Telangana state of India.DRR Dhan 45 was demonstrated on selected farmers' fields by ICAR-IIRR in Telanagana state. 'Purposive sampling' method was adopted for the study because DRR Dhan 45 was a newly released variety and the seed was available only with ICAR-IIRR in a very small quantity. Hence, limited number of demonstrations of DRR Dhan 45 were conducted on farmer fields in Telangana.To assess the changes in the agronomic and economic performance that can be attributed to the adoption of DRR Dhan 45, an ex-post impact analysis was applied. Seventy farmers who have cultivated DRR Dhan 45 and eighty farmers who have cultivated Samba Mahsuri, a popular variety of the study area were selected. DRR Dhan 45 seed was distributed to eighty farmers initially, however, data from ten farmers was not collected as they could not transplant seedlings to main field due to drying up

Table 1. Characteristics of selected biofortified rice varieties.

Variety	States	Year of release	Duration (days)	Grain quality	Nutri-ent	Yield (t/ha)
DRR Dhan 45	Tamil Nadu, Andhra Pradesh, Karnataka	2016	130	Medium slender	Zinc	5-6
DRR Dhan 48	Andhra Pradesh, Telangana, Karnataka, Tamil Nadu and Kerala	2018	135-140	Medium slender	Zinc	5-5.5
DRR Dhan 49	Gujarat, Maharashtra and Kerala	2018	130-135	Medium slender	Zinc	5-5.5
CRR Dhan 310	Odisha, Madhya Pradesh and Uttar Pradesh	2016	123	Medium slender	Protein	4.5

of bore-wells on their fields, even though nursery was sown. Information on input-output details, cost of production, yields and output prices and other variables pertaining to the kharif season of 2017 were collected through primary survey from the selected farmers. DRR Dhan 45 was demonstrated on farmer fields and hence the survey data pertaining to costs and returns in cultivation of DRR Dhan 45 were used for the study.The other zinc biofortified rice varieties, DRR Dhan 48 and DRR Dhan 49 were recently released in 2018 and have not yet been adopted by the farmers. Hence, the yield performance of these two varieties in All India Coordinated Rice Improvement Project (AICRIP) trials in three years (2014-16) are presented in results section.

The technology efficacy was estimated for the protein biofortified rice variety CR Dhan 310. Based on the current protein-intake levels from rice in India and assuming that the current rice consumption patterns are maintained, protein intake after biofortification was calculated. The technology efficacy (E) is calculated as:

$$\text{Technology Efficacy } (E) = \frac{\ln\left[\frac{IP}{CP}\right] - \left[\frac{IP - CP}{RDA}\right]}{\ln\left[\frac{RDA}{CP}\right] - \left[\frac{RDA - CP}{RDA}\right]} \times 100$$

(Zimmermann and Qaim, 2004;Hans et al., 2012;Nirmala et al., 2016)

where, IP is the improved protein intake, CP is the current protein intake (7 per cent), and RDA is the recommended dietary allowance of protein. The effect of higher protein intake through biofortification under optimistic (16 percent) and pessimistic scenario (10.3 per cent) was analyzed by evaluating the degree to which improved intakes reach the recommended dietary allowance of protein.

The protein-content of the existing varieties of rice is 7 per cent. The consumption of protein biofortified rice in future will lead to higher protein intakes, 10.3per cent under pessimistic and 16 per cent under optimistic scenarios. This increased intake of protein will avert the incidence of protein deficiency - related health outcomes. As the biofortified rice variety has been recently released and many more such varieties with higher protein-content are expected to be developed in future, pessimistic (with protein contentof 10.3 per cent) and optimistic (with protein content of 16 per cent) scenarios were assumed to calculate the impact of protein biofortification on health outcomes.

RESULTS AND DISCUSSION

i) Profile of the selected biofortified rice varieties

æ CR Dhan 310

The ICAR-National Rice Research Institute (NRRI), Cuttack has developed a high protein rice variety CR Dhan 310 with an average 10.3 per cent protein in milled rice, by improving the popular high yielding variety Naveen. Rice is generally low in grain protein content (6-8 per cent). The average grain yield of this variety at national level in the multi-locational testing was 4483 kg/ha, wherein it outperformed the yield-check, Samba Mahsuri by registering yield superiority of 6.81%. This high protein rice variety has been identified for release for Odisha, Uttar Pradesh and Madhya Pradesh. It has long panicle with medium slender grains. It is medium early (123 days) with semi-dwarf (110 cm), compact plant type and has good initial growth and tillering ability. This variety is higher in glutelin fraction and essential amino acids such as lysine and threonine compared to its parent, Naveen (http://icar-nrri.in/icar-nrri-cuttack-releases-high-protein-rice-variety-cr-dhan-310/).

æ DRR Dhan 45

DRR Dhan 45 is a biofortified semi-dwarf, medium duration (125 days) variety with non-lodging plant type and long slender grains for irrigated conditions. It is the first high zinc rice variety notified at national level with overall mean zinc content of 22.6 ppm (24.0 ppm in Andhra Pradesh, Karnataka and Tamil Nadu) in polished rice, developed through conventional breeding without compromising yield using the material from HarvestPlus. Based on high zinc content and yield performance over 5 t/ha, it is released for the states of Tamil Nadu, Andhra Pradesh and Karnataka. It has good cooking quality with desirable amylose content (20.7 per cent). It is moderately resistant to blast, sheath rot and rice tungro virus. The variety is a proof of concept for biofortfication and can address the hidden hunger or mineral malnutrition, thus targeting nutritional security of the nation.

æ DRR Dhan 48

Table 2. Comparison of yields of DRR Dhan 45 with Samba Mahsuri(t/ha).

	Mean	Std. dev.	t stat.	Prob
Samba Mahsuri	5.09	1.038	-1.54	0.06
DRR Dhan 45	5.33	0.755		

DRR Dhan 48 is a high zinc variety (20.91 ppm) suitable to irrigated ecology. It is semi-dwarf, medium slender variety with duration of 135-140 days. It is a variety resistant to BLB having genes of *xa21+xa13+xa5*. It has a yield potential of 5-5.5 t/ha and is released for the states of Telangana, Karnataka, Tamil Nadu and Kerala.

æ DRR Dhan 49

DRR Dhan 49 is semi-dwarf variety with duration of 130-135 days and has medium slender grain type. It is suitable for the irrigated ecologies. It is a high zinc variety (25.2 ppm) with BLB resistance having genes of *xa21+xa13* and moderately tolerant to Blast. It is released in 2018 for the states of Gujarat, Maharashtra and Kerala.

ii) Farm level performance of DRR Dhan 45

A comparison of the yields of Samba Mahsuri and zinc biofortified rice variety, DRR Dhan 45 grown on sample farmers during rainy season of 2017 are presented in Table 2.

The variety DRR Dhan 45 had a yield advantage of 5 per cent over Samba Mahsuri. Based on the results obtained (P=0.06), we can infer that yield of both the varieties are significantly different with 94% of confidence.

The cost of cultivation of Samba Mahsuri and zinc biofortified rice variety, DRR Dhan 45 grown on the sample farms in the rainy season of 2017 are compared in Table 3. The cost of production per ton of paddy grain was almost same for the two varieties. The total cost of cultivation of Samba Mahsuri was around one per cent higher than the DRR Dhan 45. The cost on seed accounted for 5-6 per cent,human labour accounted for 36-42 per cent and manure and fertilisers accounted for 13 per cent of the total variable costs. These shares were similar and did not vary much for the two varieties. However, the cost incurred on pesticide was less in DRR Dhan 45 in comparison to

Table 3. Cost of cultivation and returns from Samba Mahsuri and DRR Dhan 45.

Particulars	Samba Mahsuri	DRR Dhan45
Seed (Rs./ha)	2581 (6)	2325 (5)
Manures and Fertilisers (Rs./ha)	5843 (13)	5590 (13)
Pesticides (Rs./ha)	4016 (9)	3422 (8)
Machine operations (Rs./ha)	13341 (30)	11762 (27)
Animal labour (Rs./ha)	2187 (5)	2375 (5)
Human labour (Rs./ha)	16055 (36)	18192 (42)
Total cost (Rs./ha)	44023	43666
Grain yield (t/ha)	5.09	5.33
Price of grain(Rs./t)	15450	14480
Grain value (Rs./ha)	78641	77178
Straw value(Rs./ha)	7049	7856
Gross revenue (Rs./ha)	85689	85034
Net revenue (Rs./ha)	41666	41368
Cost of production (Rs./qtl)	865	819

*Figures in parentheses indicate percentage to the total cost.

Samba Mahsuri, which is due to comparatively less pest incidence in DRR Dhan 45. The gross and net revenue were slightly higher for Samba Mahsuri over DRR Dhan 45 variety, owing to slightly higher price received for Samba Mahsuri.

These results indicate that the yield and profits were nearly equal and not compromised with the adoption of biofortified rice variety. Hence, switching over to the biofortified rice variety would result in harnessing the benefits of biofortification and will avert the ill effects of zinc deficiency related outcomes. The farmers during the focus group discussion opined that the availability of seed of biofortified variety and premium market price for the grain would motivate them to cultivate biofortified rice varieties in future. Hence, to encourage and for sustaining the interest of farmers to grow biofortified rice varieties, seed availability and certification of biofortified product(s) and premium market price could be considered as the major drivers of adoption.

The yield performance of DRR Dhan 48 and DRR Dhan 49 are presented in Table 4. DRR Dhan 48 yielded more than the best check variety, Samba Mahsuri with 6.0 per cent to 22.4 per cent yield superiority in All India Coordinated Rice Improvement Project (AICRIP) trials. DRR Dhan 49 yielded more than the best check variety,Samba Mahsuri to the extent of 8 to 22.3 per cent. The cooking quality, amylose content and hard gel consistency of both these varieties

Table 4. Yield performance of DRR Dhan 48 and DRR Dhan 49.

Variety	Year	Overall mean Yield (Kg/ha)	% Yield advantage over Samba Mahsuri
DRR Dhan 48	2016	5008	6
	2015	4989	12.5
	2014	6202	22.4
DRR Dhan 49	2016	4562	8
	2015	5079	22.3
	2014	6373	12.1

Source: Progress report (AICRIP) - Crop Improvement 2016, ICAR-IIRR, Hyderabad.

appears to be similar to Samba Mahsuri. If the ascribed cooking quality of thesebiofortified varieties is realised at consumer level, the yield advantage will certainly help in increasing the farmers' income.

iii) Technology efficacy of protein biofortification

Rice protein contents range from 4.5 to 15.9 percent for *Oryza sativa* varieties and from 10.3 per cent to 15.9 per cent for *Oryza glaberrima* varieties (Kennedy and Burlingame, 2003). The ICAR-National Rice Research Institute (NRRI) has developed a high protein rice variety CR Dhan 310 with an average 10.3 per cent protein in milled rice.

The per capita consumption of rice was 175 gms (NSSO, 2012). The protein content of the existing varieties of rice is 7 per cent. It is assumed that the consumption of protein biofortified rice in future will lead to higher protein intake of 10.3 per cent under pessimistic and 16 per cent under optimistic scenario. This increased intake of protein averts the incidence of protein deficiency related health outcomes. As the protein biofortified rice varieties with high protein are expected to be developed in future, optimistic and pessimistic scenarios were assumed to calculate the impact of protein biofortification on health outcomes (Table 5).

Table 5. Characteristics of protein-biofortified rice.

Technology characteristics	Pessimistic scenario	Optimistic scenario
Initial protein content (%)	7	7
Improved protein content (%)	10.3	16
Added protein content (%)	3.3	9

The recommended dietary allowance (RDA) for protein for men is 60 gms and 55 gms for women as per the report of the National Institute of Nutrition (NIN, 2011). With the existing rice varieties, the protein intake through rice consumption is 12.25 gms/day/ person (Table 6). The effect of higher protein intake through biofortification was analyzed by evaluating the degree to which improved intakes reach the recommended dietary allowance of protein. Under pessimistic scenario, the protein intake accounted for 30 per cent of the RDA with 36 per cent efficacy of protein biofortification of rice for male and 33 per cent of the RDA with 39 per cent efficacy for female. In case of pregnant and lactating mothers, the technology-efficacy of protein biofortification of rice was in the range of 31 to 34 per cent. Under optimistic scenario, the protein intake accounted for 47 and 51 per cent of the RDA with 71 per cent and 74 per cent efficacy of protein biofortification for male and female respectively. In case of pregnant and lactating mothers, the technology efficacy of protein biofortification of rice

Table 6. Rice consumption and protein intake with and without protein biofortification.

Particulars	Daily protein intake (per person)								
	RDA (g)	Status-Quoamount (g)	RDA (%)	With protein biofortification					
				Pessimistic scenario			Optimistic scenario		
				Amount (gms)	RDA (%)	Efficacy (%)	Amount (gms)	RDA (%)	Efficacy (%)
Male	60	12.25	20.4	18.02	30.03	36.54	28	46.67	71.15
Female	55	12.25	22.27	18.02	32.76	38.79	28	50.91	74.57
Pregnant	78	12.25	15.7	18.02	23.1	30.94	28	35.9	61.96
Lactation (0-6months)	74	12.25	16.55	18.02	24.35	31.94	28	37.84	63.67
Lactation (6-12 months)	68	12.25	18.01	18.02	26.5	33.67	28	41.18	66.55

was in the range of 62 to 66 per cent.

CONCLUSION

It can be concluded from the results that the agronomic and economic performance of biofortifed varieties was at par with the Samba Mahsuri a popular variety of the study area. The study also revealed that the technology efficacy of the protein biofortification of rice was in the range of 31 to 39 per cent and 62 to 74 per cent under pessimistic and optimistic scenarios, respectively. Thus, it can be inferred that the biofortication of rice with zinc and protein will contribute to combat zinc and protein deficiencies in the country. Large scale adoption of biofortified rice varieties depends on the availability of seed,certification and premium market price for the biofortified products. Therefore, efforts are needed to make the seeds of these varieties available in the rice market and ensuring premium price to the biofortified rice for wide dissemination of biofortified rice varieties.

REFERENCES

Bouis H (2002). Plant breeding: A new tool for fighting micronutrient malnutrition. J. Nutr. 132(3): 491S-494S

Brown KH, Wuehler SE and Peerson JM (2001). The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency.Food and Nutr. Bulletin 22(2): 113-125

Dietary guidelines for Indians: A manual (2011). Published by National Institute of Nutrition. pp. 127

Hans DS, Xavier G, Dieter B, Willy L, Dominique VD and Matin Q (2012). Potential impact and cost-effectiveness of multi-biofortified rice in China. New Biotech. 29 (3): 432-442

Herforth A (2009). The Policy process of increasing micronutrient programming in India, In: Case Studies in Food Policy for Developing Countries: Policies for Health, Nutrition, Food Consumption, and Poverty. Ed: Andersona,P.P and Fuhi Cheng. Cornell University Press pp. 47-56

http://icar-nrri.in/icar-nrri-cuttack-releases-high-protein-rice-variety-cr-dhan-310

Kennedy G and Burlingame B (2003). Analysis of food composition data on rice from a plant genetic resources perspective. Food Chem. 80: 589-596

Neeraja CN, Ravindra BabuV, Sewa Ram, Firoz Hossain, K. Hariprasanna, BS Rajpurohit, Prabhakar T, Longvah, KS Prasad, JS Sandhu and Swapan K Datta (2017). Biofortification in cereals: progress and prospects.Current Science 113(6): 1050-1057 doi: 10.18520/cs/v113/i06/1050-1057

Nestel P, Bouis HE, Meenakshi JV and Pfeiffer P (2006). Biofortification of staple food crops. The J. Nutr. 136 (4): 1064-1067

Nirmala B, Ravindra Babu V, Neeraja CN, Waris A, Muthuraman P and Sanjeeva Rao D (2016). Linking agriculture and nutrition: an ex-ante analysis of zinc biofortification of rice in India. Agric. Econ. Res. Rev. 29(Conf.): 171-177

NSSO (2011-12). Government of India

Progress Report (AICRIP)-Crop Improvement (2016). ICAR-Indian Institute of Rice Research, Hyderabad

Rao DS, Madhu B, Swarnalatha P, Suneetha K, Bhadana VP, Varaprasad GS, Surekha K, Neeraja CN and Ravindra Babu V (2014). Assessment of grain zinc and iron variability in rice germplasm using energy dispersive X-Ray fluorescence spectrophotometer (ED-XRF). J. Rice Res.7(1 &2): 45-52

Ravindra Babu V (2013). Importance and advantages of rice biofortification with iron and zinc. J. SAT Agric. Res.11: 1-6

Sautter C, Poletti S, Zhang P and Gruissem W (2006). Biofortification of essential nutritional compounds and trace elements in rice and cassava.Proc. Nutr. Soc. 65: 153-159 doi: 10.1079/PNS2006488

Zimmermann R and Qaim M (2004). Potential health benefits of golden rice: A Philippine case study. Food Policy 29: 147-168