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Linking Agriculture and Nutrition: An *Ex-ante* Analysis of Zinc Biofortification of Rice in India

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Abstract

Biofortification has been recognized as a promising option to combat the micronutrient deficiencies, including zinc deficiency. Rice is the staple food crop in India, but, the daily zinc requirement cannot be achieved through typical rice-based vegetarian diet. ICAR- IIRR has developed the high zinc-content rice variety, 'DRR Dhan 45', with overall mean zinc content of 23.66 ppm in polished rice. This study has measured the potential impact of zinc-biofortified rice using disability-adjusted life years (DALYs) saved based on the counterfactual approach, estimating the impact as the difference in the number of DALYs attributable to zinc deficiency before and after the introduction of the zinc-biofortified rice. The current zinc-content of the popular rice varieties is about 13 ppm and the potential zinc content of the biofortified rice is 23-24 ppm with a potential increase of 80 per cent. The calculated annual burden of zinc deficiency in India in 2011 is 1.3 million DALYs lost and with biofortified rice this burden could be lowered up to 35 per cent. The study has revealed that the cost of saving one healthy life year through zinc biofortification of rice costs US$ 20 under pessimistic scenario and US$ 3 under optimistic scenario, proving the cost-effectiveness of the intervention.

Key words: Rice, zinc biofortification, DRR Dhan 45, DALYs, ex-ante analysis, efficacy

JEL Classification: I10, I12, Q16

Introduction

Biofortification is the enhancement of micronutrient levels of staple crops through biological processes, such as plant breeding and genetic engineering (Bouis, 2002). It could be effective in reducing the problem of malnutrition as part of a strategy that includes dietary diversification, supplementation, chemical fortification and such other measures. This approach will lower not only the number of severely malnourished people who require treatment by complementary interventions, but will also help them maintain improved nutritional status (Bouis *et al.,* 2013). Biofortification has several advantages, including the capitalization on the regular daily intake of a consistent amount of staple food by all the family members. Biofortification provides a feasible means of reaching the undernourished population in the remote rural areas, delivering naturally fortified foods to people with limited access to commercially marketed fortified foods that are more readily available in the urban areas (Nestel *et al*., 2006).

Rice provides up to 60 per cent of the daily energy requirement and a substantial part of the protein intake, and therefore is crucial for nutritional security. The Indian Institute of Rice Research (ICAR-IIRR), formerly Directorate of Rice Research (DRR), Hyderabad, collected various landraces, basmati, non-basmati and high-yielding rice cultivars from different parts of the country and the material identified by

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HarvestPlus. The rice varieties with relatively high iron and zinc contents in grains were identified and introduced in the breeding programs as donors and some fixed rice lines with high iron (>10 ppm) and zinc (>20 ppm) contents after 10 per cent polishing were tested under All India Coordinated Rice Improvement Programme (AICRIP) (Ravindra Babu, 2013). The efforts have translated into a high zinc rice variety, 'DRR Dhan 45', notified at the national level with overall mean zinc content of 23.66 ppm in polished rice.

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 neurobehavioural development. 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 are urgently needed to prevent low zinc-intake and poor absorption of zinc (Brown *et al*., 2001). Development and release of high zinc rice variety, DRR Dhan 45, developed by ICAR-IIRR is one such effort to address zinc deficiency. This study was therefore undertaken to measure the potential impact and cost effectiveness of zinc biofortification of rice in India.

Methodology

The zinc biofortification of rice aims at improving the human health and well-being by reducing the burden of diseases in terms of functional outcomes and mortality, caused by zinc deficiency. When it comes to analyzing the impact of biofortification, it is necessary to quantify and value 'health'. Once this is done, it becomes possible, for instance, to compare the public health improvement that can be achieved through other interventions such as food fortification or pharmaceutical supplementation. In recent years, it has become increasingly popular to measure health or rather its inverse, the burden of disease using 'disability-adjusted life years' (DALYs) (Stein *et al.*, 2005). In particular, this article attempts to quantify the extent to which the biofortification strategy can help ameliorate zinc deficiency. Since zinc-rich rice varieties have not yet been disseminated, the quantification necessarily is *ex-ante* in nature.

The DALY Framework

The DALY method provides a single index to measure the morbidity and mortality related to a particular disease, and thus the burden of the disease. To assess the burden of disease, the 1990 Global Burden of Disease (GBD) study used a time-based metric that measures both premature mortality (years of life lost because of premature mortality or YLL) and disability (years of healthy life lost as a result of disability or YLD, weighted by the severity of the disability). The sum of the two components, namely, DALYs, provides a measure of the future stream of healthy life (years expected to be lived in full health) lost as a result of the incidence of specific diseases and injuries. This method became the standard evaluation tool to estimate the burden of the micronutrient malnutrition and the cost-effectiveness of the related interventions (Qaim *et al.,* 2007). The DALYs lost are related to the sum of the 'years of life lost' (YLL) due to cause-specific mortality and the sum of 'years lived with disability' (YLD), i.e.

DALYs lost = YLL + YLD

where, the sum of the DALYs lost for each disability and due to mortality, gives the total burden of disease. It can be mathematically expressed as:

$$\text{DALYs lost} = \sum_j T_j M_j \left[\frac{1-e^{-rLj}}{r}\right] + \sum_i \sum_j T_j I_{ij} D_{ij} \left[\frac{1-e^{-rdij}}{r}\right]$$

where,

T_j = Total number of people in the target group j

M_j = Mortality rate associated with the deficiency in target group j

L_j = Average remaining life expectancy of the target group j

I_{ij} = Incidence rate of disease i in target group j

D_{ij} = Disability weight for disease I in target group j

d_{ij} = Duration of disease I in target group j, and

R = Discount rate for future life years.

Based on the current zinc-intake levels from rice in India and assuming that the current rice consumption patterns are maintained, zinc intake after biofortification was calculated.

The technology efficacy (E) is calculated as:

$$\text{Technology efficacy}(E) = \frac{\ln\left[\frac{IZ}{CZ}\right] - \left[\frac{IZ - CZ}{RDA}\right]}{\ln\left[\frac{RDA}{CZ}\right] - \left[\frac{RDA - CZ}{RDA}\right]}$$

where, IZ is the improved zinc intake, CZ is the current zinc intake, and RDA is the Recommended Dietary Allowance of zinc.

Results and Discussion

The deficiency of micro nutrients such as zinc, wreak havoc on survival, health and productivity. The micronutrient deficiencies, including zinc deficiency, are called 'hidden hunger', because they do not manifest themselves in immediate physical signs, but are insidious in causing diseases. About 42 per cent of the children in India are stunted (Herforth, 2009).

The known adverse health outcomes from zinc deficiency that do not necessarily result in death are diarrhoea, pneumonia and stunting. Zinc deficiency is responsible for 4.4 per cent of the childhood deaths. (Fischer Walker *et al*., 2009). Zinc is known to inhibit growth, and stunting is widely considered the best anthropometric indicator of risk of zinc deficiency (Brown, 2004). The parameters used for calculation of DALYs lost due to zinc deficiency in India are summarized in Table 1. The target groups for the adverse health outcomes due to zinc deficiency included infants (below one year of age) and children (1-5 years of age). Incidence rates of diarrhoea and pneumonia among children were split up into infants and children below five years of age. The size of target

Table 1. Parameters for calculation of DALYs lost due to zinc deficiency in India

Functional outcomes related to zinc deficiency	Target groups (Tj)	AL ZD (%)*	Incidence rate (Iij)@	TjIij§	Disability weight (Dij)$	Discount rate	Average age of death	Average age of onset	Duration of disease (dij)
Non-fatal outcomes									
Diarrhoea	Infants	18	0.468	9505658	0.2	3	NA	NA	3/365
	Children (1-5 years)	18	0.234	27740647	0.15	3	NA	NA	4/365
Pneumonia	Infants	41	0.1189	2415006	0.3	3	NA	NA	4/365
	Children (1-5 years)	41	0.1189	14095568	0.2	3	NA	NA	4/365
Stunting	Infants	100	0.455	9241611	0.0001	3	NA	6 months	Rest of life
Fatal outcomes			Mortality rate (Mj)	TjMj					Average remaining life expectancy (Lj)
Increased mortality	Infants	4	0.176	4645808	NA	3	8 months	NA	66.29
Increased mortality	Children (1-4 years)	4	0.044	1161452	NA	3	2years	NA	64.96

* Attribution level zinc deficiency
@ Fraction of target group that experienced health outcome
§ Affected child population (number)
$Extent of disability caused by the health outcome
Diarrhoea and pneumonia are considered to have a certain risk of lethal outcome. Because mortality rates are usually given for children under 5 years old, in this case the target group is defined as "children under 5 years''. For stunting, the target group is infants only.

Table 2. Characteristics of zinc-biofortified rice and expected coverage by impact scenario

Technology characteristics	Pessimistic scenario	Optimistic scenario
Initial zinc content (ppm)	13	13
Improved zinc content (ppm)	23	23
Post-harvest losses, including cooking (%)	0	0
Added zinc content (ppm)	10	10
Coverage rate (%)	20	40

groups were taken from the Census of India data. The mortality rates for infants and children below the age of five years were also obtained from Census of India data (Census of India, 2011). The standard life tables for India were used to derive the remaining life expectancy in the case of child mortality and for duration of stunting (WHO, 2001).

The zinc-content of the existing varieties of rice is 13 ppm. The consumption of zinc biofortified rice in future will lead to higher zinc intakes, 23 ppm under pessimistic and 40 ppm under optimistic scenarios. This increased intake of zinc will avert the incidence of zinc-deficiency- related health outcomes. As the biofortified rice variety has been recently released and many more such varieties with higher zinc-content are expected to be developed in future, optimistic and pessimistic scenarios were assumed to calculate the impact of zinc biofortification on health outcomes. It was assumed that in the next 30 years the 20 per cent and 40 per cent of the Indian consumers may switch to zinc-biofortified rice in the pessimistic and optimistic scenarios, respectively (Table 2).

The rice variety, 'DRR Dhan 45' is a zinc-biofortified variety released by ICAR-IIRR at the national level. Zinc levels are enhanced through conventional breeding. The assumptions on the improved zinc-contents after biofortification, as well as on post-harvest losses and bioavailablity are based on the previous literature for optimistic scenario and also on the actual zinc content in the DRR Dhan 45 (Pessimistic scenario). Table 3 summarizes the current rice consumption and zinc intake with and without zinc biofortification by impact scenario.

Rice is the staple food in India and most of the people depend solely on rice and they are rarely accessible to nutrient-rich food sources to supplement rice. In fact, rice is consumed in polished form (white rice) and it constitutes starch as the chief component followed by proteins, lipids, minerals and negligible levels of vitamins and thus, rice supplies more energy than essential nutrients leading to micronutrient deficiency which is known as 'hidden hunger'(Rao *et al.*, 2014). The per capita consumption of rice was 182 grams in 2011 (*Agricultural Statistics at a Glance*, 2014). It is based on the fact that if maternal zinc status can be improved through (long-term) consumption of zinc-biofortified rice, it is plausible that the status of her new born infant will be better than it otherwise would be; consequently, infants may be less at risk of succumbing to morbidity due to infectious diseases (Stein *et al.,* 2007). The recommended dietary allowance for zinc is 12 ppm. With the existing rice varieties, the zinc intake through rice consumption is 2.37 mg/day/person. The effect of higher zinc intake through biofortification under optimistic (40 ppm) and pessimistic scenario (23 ppm) was analyzed by evaluating the degree to which improved intakes reach the recommended dietary allowance of zinc. Under pessimistic scenario, the zinc intake accounted for 40 per cent of the RDA and for optimistic scenario, it accounted for 58 per cent with 54 per cent and 87 per cent efficacy of zinc biofortification.

Table 3. Rice consumption and zinc intake with and without zinc biofortification by impact scenario

Daily rice consumption (per person)	Daily zinc intake (per person)								RDA (mg)
	Status quo amount (mg)	RDA (%)	With Zn-biofortification						
			Pessimistic scenario			Optimistic scenario			
			Amount (mg)	RDA (%)	Efficacy (%)	Amount (mg)	RDA (%)	Efficacy (%)	
182	2.37	19.75	4.37	40	54.32	7.28	58	87.01	12

Table 4. Current health burden of zinc deficiency in India and potential impacts of zinc biofortification

Current burden (DALYs lost)		
	YLD	1,21,374
	YLL	1,189,269
	Total	1,310, 643
Health impact (DALYS saved)		
Pessimistic scenario	YLD	13,186
	YLL	1,29,202
	Total	1,42,388
Optimistic scenario	YLD	42,243
	YLL	4,13,913
	Total	4,56,156
Reduction of zinc deficiency burden (%)		
	Pessimistic scenario	10.86
	Optimistic scenario	34.8

Table 4 summarizes the current health burden of zinc deficiency in India and potential impacts of zinc biofortification. As per the Census 2011 data of India, zinc malnutrition is responsible for 1.31 million DALYs lost per year. Stein (2007) has reported that the annual burden of zinc deficiency in India was 2.8 million DALYs lost as per the analysis of 2001 data from Census of India. As per the present analysis of the 2011 Census data, this burden of zinc deficiency in India corresponds to 1.31 million DALYs lost. This difference is mainly because of two reasons, one, due to increase in the average life expectancy in India from 62.5 years in 2001 to 66.96 years in 2011 and two, due to reduction in infant and child mortality rates in the previous decade.

The infant mortality rate in 2001 was 66 per 1000 live births, whereas it was 44 per 1000 live births in 2011. Between 2001 and 2011, the infant mortality rate has decreased by 33.3 per cent. Also, for the under-five children mortality rate was 96 in 2001 and it declined to 55 in 2011, a reduction of 42.7 per cent. The mortality rate pertaining to the children of 1 to 4 years age group was 30 per 1000 live births in 2001 and 11 per 1000 live births in 2011. The mortality rate of the children in 1-4 years age group has decreased by 63.3 per cent. The reduction in infant and child mortality rates may be due to the improvement in literacy and health care facilities and also due to increase in institutional deliveries in India.

The expected health impacts of zinc biofortification in rice are also shown in Table 4. The increased intakes of micronutrients through biofortified crops are expected to improve the health status of deficient individuals (Haas *et al.,* 2005). Depending on the assumptions made, the introduction of zinc-biofortified rice in India could save 0.142 million DALYs each year in the pessimistic scenario, while 0.456 million DALYs can be gained annually under the optimistic scenario. This corresponds to a reduction of the burden of zinc deficiency of 11 per cent and 35 per cent, respectively.

The cost effectiveness of zinc-biofortified rice in India was assessed and is presented in Table 5. A 30-year time horizon was chosen, as due to the discounting procedure-costs and benefits accruing beyond that horizon would hardly change the results anyway (Hans *et al*., 2012). The cost per DALY saved was worked out for both optimistic and pessimistic scenarios. Juxtaposing the net present cost and the (undiscounted) number of infant and child deaths and DALYs that can be averted yielded a cost of US$ 20.37 and US$ 3 under pessimistic and optimistic scenarios for each DALY saved respectively, proving the cost-effectiveness of the intervention.

The DALY approach was first used by the World Bank in its World Development Report 1993 to classify

Table 5. Cost and cost-effectiveness of zinc biofortification of rice in India

Average annual costs (million US$)*	Basic R&D costs (8 years)	Country-specific costs (6 years)	Social marketing costs (until end)	Maintenance breeding costs (until end)	Cost-effectiveness (US $ per DALY saved)#
Pessimistic scenario	1.6	0.8	-	0.2	20.37
Optimistic scenario	0.8	0.5	-	0.1	3.42

**Source*: Stein *et al*. (2007), # Authors' calculations the cost-effectiveness of public health interventions and it was suggested by the World Bank that all interventions that cost less than US$ 150 per DALY saved can be categorized as highly cost-effective; in real terms this translates into approximately US$ 233.5 in 2011 [To convert the nominal US Dollar values into real terms, the inflation calculator of the US Bureau of Labor Statistics was used, which is based on the average consumer price index (CPI)].

Conclusions

Combating zinc malnutrition through crop breeding is a relatively new approach. This study has analysed the economic implications and cost-effectiveness of zinc biofortification in rice. ICAR-IIRR has developed and released a zinc-biofortified rice variety, 'DRR Dhan 45'. This article has made an *ex-ante* impact assessment of the biofortified rice varieties such as recently released DRR Dhan 45 and similar such zinc-biofortified rice varieties with improved zinc contents, that are expected to be developed and released in future. The wider economic implications, including the potential health benefits and cost-effectiveness of the zinc bioforotifcation in rice have been analysed.

Every year 1.31 million DALYs are lost in India due to zinc malnutrition. The study has revealed that out the 1.31 million DALYs lost, 0.142 million and 0.456 million DALYs could be saved in pessimistic and optimistic assumptions, if zinc-biofortified rice is introduced. Investment into biofortification and related research has enormous potential to combat the adverse health effects of zinc deficiency.

The success of the biofortification program, however, depends especially on two important stakeholders, the farmers for the cultivation of biofortified varieties and consumers or target population for including it in their daily diet. Therefore, concentrated efforts are needed to make available these varieties in the rice market chain and dissemination of its benefits to the vulnerable population. Thus, it can be concluded that the biofortication of rice with zinc, will contribute to combating zinc deficiency in the country.

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