



Optimization of Zinc Fortification Parameters in Paddy using Response Surface Methodology

RINA SABALPARA^{1*}, SHADANAN PATEL² and DHARMENDRA KHOKHAR²

¹Department of Process and Food Engineering, Junagadh Agricultural University, Junagadh, India.

²Department of Agricultural Processing and Food Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, India.

Abstract

This study investigates the fortification of IGKV-R1 paddy with zinc to enhance its nutritional value. Raw paddy samples were sourced from Indira Gandhi Krishi Vishwavidyalaya, Raipur, and fortified using zinc oxide (ZnO) at concentrations of 0.1, 0.2, and 0.3 g/100 g of paddy. The fortification process involved soaking the paddy at temperatures of 50, 60, and 70 °C for 1, 2, and 3 hours, followed by steaming and drying. The fortified paddy was then dehusked and polished, and various physico-chemical properties were analyzed. Zinc retention in polished rice ranged from 10.05 to 13.89 mg/100 g, with the optimal condition being 70 °C, 3 hours, and 300 mg/100 g of paddy. The milling quality of fortified rice showed improved head rice yield and reduced broken yield compared to raw rice. The study also observed changes in biochemical properties post-fortification, with increases in ash and fiber content and decreases in protein, carbohydrate, and energy values. Statistical analysis using Response Surface Methodology (RSM) confirmed the significant impact of soaking time, temperature, and fortificant concentration on zinc retention. The findings suggest that zinc fortification is an effective method to enhance the nutritional quality of rice, providing a viable approach to addressing micronutrient deficiencies.



Article History

Received: 19 November 2024

2024

Accepted: 10 April 2025

Keywords

Deficiency;
Fortification;
Fortified Rice;
Micronutrients;
Zinc.

Introduction

Micronutrient Deficiencies (MNDs) are becoming a major global public health issue that cut across all socioeconomic divides. These inadequacies disproportionately affect women, children, middle-aged adults, and the elderly, among other vulnerable

groups. Their widespread impact on health issues suggests that immediate intervention is required, regardless of the level of wealth.¹

India's population has been impacted by Hidden Hunger,^{2,3} a serious public health issue that primarily

CONTACT Rina Sabalpara ✉ sabalpararina1707@gmail.com 📍 Department of Process and Food Engineering, Junagadh Agricultural University, Junagadh, India.



© 2025 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: <https://dx.doi.org/10.12944/CRNFSJ.13.2.32>

affects women and children. Its effects reverberate across the country, making prompt action to solve this nutritional crisis imperative.⁴ It is impossible to overestimate the serious consequences of micronutrient deficiency for public health. It is extremely important to consider when developing strategies to fight diseases including HIV/AIDS, malaria, TB, and chronic illnesses linked to food.³

Food fortification is a critical and economical strategy intended to improve the nutritional value of staple foods and serve large populations. When executed appropriately, fortification is a simple and effective way to add important vitamins and minerals to diets.³ This approach is crucial for both developed and developing countries since it guarantees that processed meals include the necessary nutrients that humans need to survive.¹

In international agriculture, rice is a key crop, especially in Asia, where 90% of the world's rice production is grown and consumed. This cereal grain is very important to diet because it accounts for 30% of total calories consumed by most cultures on average. Notably, this number can rise to almost 70% in low-income nations, emphasizing the critical role that rice plays in these diets. The names for "food" and "rice" are frequently interchangeable among the many languages spoken in these regions.⁵ Important micronutrients like iron, folic acid, B-complex vitamins, vitamin A, and zinc can be added to its kernels for enrichment. Some of these additions are meant to restore the kernels' intrinsic nutritional content before milling, while others are made expressly for fortification.⁶ The widespread myths and misconceptions around FRK (Fortified Rice Kernels) were what hindered its widespread application.⁷

Long-standing public health issues persist in India, such as the high incidence of iron deficiency anaemia, which affects more than 50% of women between the ages of 15 and 45 and children under the age of five.⁸ Moreover, 62% of Indians have serum blood levels of essential vitamins A and D that are insufficient, ranging from 50% to 94%.⁹ Stunting, increased vulnerability to infectious diseases, physical disability, cognitive deficiencies, visual impairment, and premature mortality are all consequences of this micronutrient shortage.

Recent studies have outlined a crucial window of time for the prevention of chronic malnutrition. Insufficient food intake, frequently combined with recurrent infections and subpar care methods, causes stunting (short length of growth) and deficits in critical micronutrients throughout the course of 1,000 days, from conception to the age of two. The child that is stunted has not had enough nutrients to eat during this critical developmental stage, which can lead to micronutrient shortages. It can also be used as a tool to determine the population-wide risk of insufficient consumption of certain micronutrients.¹⁰

Micronutrient deficiency, which includes vitamins and vital trace elements, is regarded as a silent epidemic and a major global health concern.¹¹ It is the reason behind the demise of a large number of poor children, especially in emerging nations.¹² In terms of the micronutrients required by humans, zinc (Zn) is ranked second only to iron,¹³ and a zinc deficiency is considered important.¹⁰ Lack of zinc suppresses the immune system, making a person more prone to infections, limits growth in babies, limits a number of other outcomes in adults, and affects women after giving birth.¹⁴ Foods derived from animals are regarded as foods high in zinc when it comes to human nutrition. It is stated that omnivores consume more zinc on average than vegetarians do. Zinc is mostly obtained in developing nations from dietary grains like cereals and legumes.¹⁵ However, consumption of zinc is inadequate, and zinc insufficiency is common in developing nations.¹⁶ About 0.4 million people die each year in South Asia alone due to zinc deficiency, which affects about 95% of the population.¹⁷ Various approaches are implemented to mitigate zinc deficiency in low-income communities. These consist of bio-fortification of basic food crops, supplementation, fortification of staple foods and beverages,^{18,19,20} and dietary plan modifications. Nevertheless, the processes of supplementing, dietary modification, and bio-fortification are expensive and time-consuming.²¹

In order to address the pervasive deficiency of micronutrients in the general population, fortifying rice presents a promising approach to increase the consumption of vital vitamins and minerals.²² Choosing the right food vehicle—one that is routinely consumed, reasonably priced, aesthetically pleasing, and culturally acceptable—is critical to the success

of fortification programs. Additionally, under local storage and usage conditions, fortified foods must retain their natural qualities and appearance while guaranteeing the stability of added nutrients.²³ Since rice is widely consumed, reasonably priced, and readily available, it is an excellent choice for fortification. Technological developments in recent times have made it possible to produce fortified rice that is nearly identical to its unfortified cousin, which could increase the rice's acceptability.

Fortification has been incorporated as a complementary strategy within the policy framework of the Government of India (GoI) and various key healthcare programs and policies, such as Anaemia Mukh Bharat and POSHAN Abhiyaan 2.0, as evidenced by the National Nutrition Strategy of 2017. Among staple food fortification initiatives, rice fortification has the most potential because it is consumed by 70% of the population and plays a significant part in government safety net programmes like PM POSHAN, AWS, and PDS. The standard dosage for fortifying rice and other food items is outlined in the "Food Safety and Standards (Fortification of Foods) Regulation, 2018". Despite the existence of these standards, India's rice fortification programme is still not at its best. A major stride forward was taken by the Indian government with the approval of the Centrally Sponsored Pilot Scheme on "Fortification of Rice & its Distribution under Public Distribution System." This programme is a proactive step in treating nutritional inadequacies in the nation, with a significant financial allocation of Rs 174.64 Cr (USD \$21,248,780.49).²⁴

In conclusion, rice fortification represents a glimmer of hope in the fight against micronutrient deficit. It is a proactive step towards improving the nutritional value of basic foods, which could have an effect on millions of people's health and wellbeing in India. With further impetus behind this program, the future seems bright, with fortified rice playing a critical role in improving public health and reducing the subtle but widespread effects of Hidden Hunger. There are various methods for fortification of micronutrients in paddy. But in this study the soaking method was used as it is cheap and liable. The research addresses this gap by exploring an innovative method for zinc fortification of rice through soaking, which could offer a cost-effective and scalable solution without compromising the quality of rice. The main aim of this

study was to fortify IGKV-R1 paddy with zinc using a soaking method that avoids starch gelatinization, and to evaluate its impact on zinc uptake, milling quality, and physico-chemical properties of the fortified rice. The paper demonstrates a clear understanding of existing gaps in the current knowledge. It acknowledges that despite efforts like bio fortification and supplementation, zinc deficiency remains widespread, especially in low-income countries. The research addresses this gap by exploring an innovative method for zinc fortification of rice through soaking, which could offer a cost-effective and scalable solution without compromising the quality of rice.

Materials and Methods

Procurement of Raw Material

A raw paddy sample of the IGKV-R1 variety was chosen and obtained from the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), University Research Cum Instructional Farm. Due to its widespread consumption among Chhattisgarh residents, this cultivar is appropriate for fortification. Chemicals of analytical grade were employed in the analysis. To store the fortified rice, polypropylene (PP) packing material was purchased from the Raipur local market.

Experimental Procedure for Fortification in Paddy with Zinc

Higher soaking temperatures and longer soaking times cause the rice grain to cook or the starch to gelatinize. According to preliminary experiments, soaking grains for longer than three hours (above 70°C) causes them to cook or gelatinize. Therefore, to prevent the starch from gelatinizing, the maximum soaking temperature and duration were set at 70°C and 3 hours, respectively. In order to prevent zinc toxicity and achieve the daily requirement for zinc fortification as per the RDA suggested by ICMR-NIN 2021, the concentration of fortificants was also restricted to 300 mg/100 g of paddy. As a result, three soaking temperatures—50, 60, and 70°C—and three soaking durations—1, 2, and 3 hours—were used in the trials. To fortify raw paddy, soaking water containing three different concentration levels of zinc oxide (ZnO) (100, 200, and 300 mg/100 g) was employed; the ratio of paddy to water was 1:2. For 10 minutes, every sample was subjected to a constant temperature of 120°C during steaming. Fig. 1 illustrates the experimental process utilized to fortify

zinc in paddy. Fortification of zinc in paddy was done by soaking method. On fortified rice, the effects of various soaking temperatures, times, and chemical concentrations of zinc were investigated. Following cleaning, two to three tap water washes, and a rinse with distilled deionized water were performed on IGKV-R1 raw paddy samples. Following washing, the rice grains were soaked for 1, 2, and 3 hours, respectively, at three different soaking temperatures of 50, 60, and 70 °C, in distilled water containing ZnO at concentrations of 0.1, 0.2, and 0.3 g/100 g of paddy. Based on filler trails, study found that above mentioned three independent has significant effect on the fortification and quality of fortified rice. So,

above three independent parameters was finalized. The ratio of paddy to water at the time of soaking was 1:2. Soaking was done in the lab using a water bath. Following soaking, the products were dried off and placed in a tabletop autoclave to steam for 10 minutes at 120 °C. After being soaked and steamed to a moisture content of around 12 % (db), the paddy was dried in a hot air oven at 40 °C for 12 to 14 hours before being used for a further processing. optimization was done based on only one dependent parameter i.e., Zinc uptake as given in Table 1. After that validation of the model, milling efficiency and other quality parameters for validated condition was done.

Table 1: Independent parameters and their coded and actual values and dependent variable employed for zinc fortification

Parameters		Coded variables			Dependent variable
		-1	0	+1	Zinc uptake
Soaking time (h)	A	1	2	3	
Soaking temperature (°C)	B	50	60	70	
Concentration of fortificant, mg/100 g of paddy	C	100	200	300	

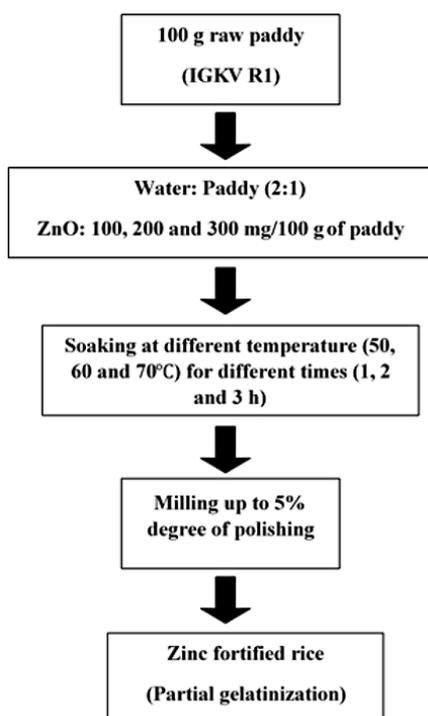


Fig. 1: Overview of experimental design

Dehusking and Polishing

After being weighed on a digital balance, 100 g of treated paddy was shelled using the rice testing mill (Lab model – PZA-1/DTA). After physically removing the residual paddy, the brown rice was reshelled. Using the same rice testing mill, the brown rice that had been dehusked was weighed and polished to a 5% degree. When polishing, the bran was automatically separated using the same rice testing mill. After the cleaned polished rice was obtained from the rice testing mill, it was graded and separated into fractions of head rice (which included whole grains and brokens larger than or equal to 3/4 length of the whole kernel) and brokens (which included less than 3/4 length of the whole kernel) by using a laboratory rice grader. The following formulas were used to calculate the total yield, head rice yield percentage, and percent of brokens.²⁵

$$\text{Total yield, \%} = \frac{\text{Weight of total polished rice}}{\text{Weight of paddy}} \times 100 \quad \dots(1)$$

$$\text{Degree of polishing, \%} = \frac{\text{Wt. of brown rice} - \text{Wt. of milled rice}}{\text{Weight of paddy}} \times 100 \quad \dots(2)$$

$$\text{Head yield, \%} = \frac{\text{Weight of head rice}}{\text{Weight of paddy}} \times 100 \quad \dots(3)$$

$$\text{Broken yield, \%} = \frac{\text{Weight of broken}}{\text{Weight of total polished rice}} \times 100 \quad \dots(4)$$

Biochemical Analysis of Raw and Processed Samples

Determination of Physico-Chemical Properties

To determine various properties of rice, different methods were employed. Axial dimensions (length, width, and thickness) were measured using digital vernier calipers with 0.01 mm sensitivity. Moisture content was assessed by drying a 5 g sample in a hot air oven at 105±2°C for 24 hours and weighing before and after.²⁶ Ash content was determined by burning a 2 g sample in a muffle furnace at 550°C for 6 hours.²⁷ Protein content was measured using the Micro Kjeldahl method,²⁶ converting nitrogen content to protein by multiplying by 5.95.²⁸ Carbohydrate content was determined via acid hydrolysis followed by spectrophotometric analysis at 630 nm.²⁶ Fat content was assessed using Soxhlet extraction with petroleum ether.²⁶ Fiber content was estimated by sequential acid and alkali washes, followed by drying and ashing.²⁶ The total energy value was calculated using the formula:²⁹

$$\text{Energy (kcal/100g)} = 4 \times (\text{protein, g} + \text{carbohydrate, g}) + 9 \times (\text{fat, g}).$$

Determination of Zinc Content

For Zn analysis of rice, the wet digestion method was used, involving a 9:4 mixture of HNO₃ and HClO₄. A 1 g rice sample was placed in digestion tubes with 10 mL of the acid mixture and left overnight for pre-digestion. The next day, the tubes were heated to 100°C on a hot plate and then to 260°C until the red NO₂ fumes ceased and the volume reduced to 3-5 mL. Once the liquid became colorless, indicating complete digestion, it was cooled, and 20 mL of deionized water was added. The solution was filtered into a 100 mL volumetric flask and diluted to volume. Aliquots of this solution were used to determine Zn using atomic absorption spectroscopy (AAS). Standard concentrations were prepared to calibrate the AAS for zinc content.

$$\text{Zinc (mg/100 g)} = \text{AAS reading (ppm)} \times \text{dilution factor} \times 1/10 \quad \dots(5)$$

Statistical Analysis

Statistical analysis of all the experimental data was carried out by following standard procedures. Box-Behnken design (BBD) was used and the effect of different independent variables on the dependent variables was analyzed. Graphical analysis was done by using Microsoft Excel. Optimization of process parameters has been analyzed with the Design Expert software (10.0.5 version). Design Expert numerical optimization will maximize, minimize or target a single response or combination of two or more responses.

Results

Optimization of Process Parameters

Zinc uptake in polished rice ranged from 10.05 to 13.89 mg/100 g of paddy, according to the data shown in Table 1. The condition at 60°C - 3 h - 300 mg/100 g of paddy showed the higher uptake of zinc in polished rice (13.89 mg/100 g of rice). The condition at 60°C - 1 h - 100 mg/100 g of paddy yielded the lowest zinc uptake in polished rice (10.05 mg/100 g of rice). The ideal conditions for zinc-fortified rice were 300 mg/100 g of rice, 3 hours, and 70°C. Table 3. displayed the response and desire levels for the optimum condition.

Based on the response of 17 treatments as shown in Table 1, one optimized condition was selected based on the uptake of zinc in polished grain recommended dietary allowances (RDA) value of zinc by Design Expert software as shown in Table 2. There was a significant variation of zinc uptake among the 17 treatments. At optimized condition it was found that, there was small changes in physico-chemical properties like viz., Ash, protein, carbohydrates and fiber of zinc fortified rice as compared to raw rice. The results revealed that there was increase in ash content and fiber content and decrease in protein and carbohydrate content of rice after fortification.

Analysis of variance (ANOVA) was used to assess the effect of dependent process parameters on the response variable. Analysis of variance showing the effect of soaking time, soaking temperature and concentration of fortificants on zinc uptake through polished rice were presented in Table 4. The significant F-value (40.45) at p<0.0001 and significant lack of fit indicated that the model for zinc uptake in polished rice was fitted and reliable. The value of coefficient of determination of model

and Adj-R² value for the zinc uptake were 0.9604 and 0.9367, respectively, indicating the adequacy, good fit and high significance of the model. The Pred.-R² (0.8428) was in reasonable agreement with the Adj-R². The high Adeq. Precision value (>4) again supported the significance of the model for zinc uptake. The small value of coefficient of variation (2.70%) for zinc uptake explained that the experimental results were precise and reliable.

Milling Quality of Fortified Rice

For both raw and zinc-fortified paddy samples, milling was done, and repeated observations were recorded and averaged. For the IGKV-R1 variety, milling parameters such as milling yield, degree of polishing, head rice yield, and broken rice yield of raw and zinc-fortified rice were noted. For both raw and fortified samples, the reported head rice yield ranged from 59.41 to 71.29%, the percentage of broken from 6.93 to 19.22%, and the milling yield from 73.54 to 77.00%. At optimum conditions (70°C - 3

h - 300 mg/100 g of paddy), the zinc uptake in rice bran and husk was 21.99 mg/100 g of rice bran and 28.15 mg/100 g of husk, respectively.

Discussion

Zinc penetration increased with increases in soaking time, soaking temperature, and fortificant content, as shown in Table 2. The effects of fortificant concentration were found to be more important in terms of zinc uptake than those of soaking temperature and duration. When paddy was fortified with ZnO during soaking process, zinc efficiently absorbed by the husk layers of the paddy and its penetration into the rice grain increased when fortificant concentrations were raised. During the initial phase of soaking, the additional iron fortificants quickly absorbed, but after that, the rate of absorption reduced. Soaking temperature and soaking durations not effectively affect the uptake of zinc as compared to concentration of fortificants.

Table 2: Zinc fortification in paddy at different soaking time, soaking temperature and concentration of zinc

Std	Run	Soaking time, h	Soaking temperature, °C	Concentration of fortificant, mg/100 g of paddy	Zinc uptake, mg/100 g
4	1	3	70	200	12.41
14	2	2	60	200	10.44
12	3	2	70	300	13.46
9	4	2	50	100	10.39
17	5	2	60	200	10.33
2	6	3	50	200	11.8
15	7	2	60	200	10.43
8	8	3	60	300	13.89
3	9	1	70	200	11.47
13	10	2	60	200	10.46
5	11	1	60	100	10.05
7	12	1	60	300	12.52
1	13	1	50	200	10.15
10	14	2	70	100	12.41
11	15	2	50	300	12.38
6	16	3	60	100	11.5
16	17	2	60	200	10.45

The linear effects of soaking time, temperature and concentration of fortificant were found positively significant at $p < 0.001$, on zinc uptake in polished

rice. Similarly, the quadratic effects of soaking time, temperature and concentration of fortificant were also found positively significant at $p < 0.001$, on zinc

uptake in polished rice. The derived model giving the empirical relationship between the zinc uptake and the test variables in coded units was obtained as under given in equation 6.

$$\text{Zinc uptake (mg/100g of polished rice)} = 10.42 + 0.6763A + 0.6288B + 0.9875C + 0.4328A^2 + 0.6028B^2 + 1.14C^2 \quad \dots(6)$$

Table 3: Optimized condition for zinc fortified rice

Treatment	Optimum condition	Desirability	Response values
IGKV – R1	Soaking time : 3 h Soaking temperature : 70 °C Concentration of fortificants : 300 mg/100 g of paddy	0.928	15.18 mg/100 g of rice

Table 4: Analysis of variance (ANOVA) showing the effect of soaking time, soaking temperature and concentration of fortificants on zinc fortified rice.

Source Squares	Sum of square	df	Mean	F-value	p-value	
Model	23.09	6	3.85	40.45	< 0.0001	significant
A-Soaking time	3.66	1	3.66	38.45	0.0001	
B-Soaking temperature	3.16	1	3.16	33.24	0.0002	
C-Concentration of fortificant	7.80	1	7.80	82.00	< 0.0001	
A2	0.7885	1	0.7885	8.29	0.0164	
B2	1.53	1	1.53	16.08	0.0025	
C2	5.43	1	5.43	57.04	< 0.0001	
Residual	0.9514	10	0.0951			
Lack of fit	0.9403	6	0.1567	56.58	0.0008	significant
Pure Error	0.0111	4	0.0028			
Cor total	24.04	16				

Fit Statistics

Sr.no.	Particulars	Values	Sr. no.	Particulars	Values
1	Standard Deviation	0.3084	5	R ²	0.9604
2	Mean	11.44	6	Adjusted R ²	0.9367
3	C.V. %	2.70	7	Predicated R ²	0.8428
4	PRESS	3.78	8	Adeq Precision	18.3087

Milling Quality of Fortified Rice

The amount of polishing that was done on both raw and fortified paddy was increased after 60 seconds, which decreased the amount of zinc retained in the fortified rice kernels. When comparing head rice recovery values for raw rice and zinc-fortified rice, the former showed higher results. The findings

showed that following fortification, rice milling quality increased. Because the soaking process led to the loosening of the paddy husk that was adhered to the rice, soaking and steaming therefore boosted the head rice production for fortified rice.³² The amounts of zinc in raw paddy were considerably raised via fortification. It was established how much zinc was

present in bran from fortified polished rice and in both raw and zinc fortified paddy husk. Paddy husk that had been fortified showed higher levels of zinc absorption. Paddy husk comprises 9–20 % lignin, which, when soaked in fortificants, has the ability to both absorb and attract zinc.³³ Zinc content is higher in fortified rice bran than in fortified rice kernels. The zinc level dropped as the degree of polishing increased, possibly as a result of the zinc being lost from the rice kernel's bran layers.

Effect of Fortification on Physico-Chemical Properties

For this variety of paddy, fortification resulted in slight modifications to grain dimensions. The fortified paddy showed a little increase in both width and length when compared to the raw paddy. However, the thickness of the raw and fortified paddy did not significantly alter, suggesting that the starch granules do not swell throughout the soaking process. The length to breadth ratio of the raw and zinc-fortified paddy did not significantly change, indicating that starch does not gelatinize throughout the soaking and steaming procedure.³⁴ According to,³⁵ there was no discernible change between the physical characteristics of the fortified and unfortified paddy.

The moisture content of IGKV–R1 paddy rice was found to be 12.17% (db) for raw rice and 12.35% (db) for zinc-fortified rice. Raw rice had an average ash concentration of 0.80 and zinc-fortified rice had an average ash content of 1.38%. The findings demonstrated that the ash level increased following fortification, indicating an increase in the mineral content of the fortified samples. Vani (2021)³⁶ have also noted an increase in the ash content of fortified rice.

The results of this study are consistent with those of,^{37,38} who reported that nutrients loss may be attributed to the leaching of soluble nitrogen, mineral, and other nutrients into fortification solution during soaking process. The protein content of IGKV–R1 decreased from raw to zinc fortified rice and values were 8.29 to 6.89%, respectively. Additionally, Ebuehi and Oyewole (2007)³⁹ demonstrated that because of some soluble protein, there was a modest decrease in the amount of protein during the soaking procedure. As per the findings of Scherz *et al.* (2000) and Juliano *et al.* (1985)^{40,41} the milled rice's

protein level in commercial rice varied between 6.3% and 7.3%.

It has been demonstrated that rice, whether raw or zinc-fortified, has a significant carbohydrate content. The percentage of carbohydrates in raw rice and rice fortified with zinc was 84.15 and 76.94%, respectively. The findings show how the carbohydrate contents of raw and fortified rice differed. When compared to raw rice, samples that had been fortified with zinc had a somewhat different carbohydrate composition. According to research by Kale *et al.* (2015),⁴² there were notable variations in the amount of carbohydrates in soaked and raw rice. The reason for the decrease in the amount of carbohydrates after soaking could have been due to amylose leaching during the process of water heating, as suggested by.⁴³

In raw rice and rice fortified with zinc, the average fat level was 0.87 and 0.82%, respectively. The findings demonstrated that fortification has no effect on the fat content of raw or zinc-fortified rice. According to a,³⁹ the soaking technique had no effect on the amount of fat in rice. The estimated fat content values were in close agreement with the values for other varieties of rice published by.⁴⁴ The percentage of fibre in raw rice and rice enriched with zinc was 1.23 and 2.36%, respectively. The findings showed that following the soaking process, the fibre content increased. Similar findings were reported by,⁴² who hypothesized that additional rice ingredients leached to the soaking solution as a result of the rice being soaked at a high temperature.

Both raw and zinc-fortified rice had a total energy content of 377.63 and 342.7 kcal/100 g, respectively. There was decrease in energy value of fortified rice, it causes due to decreased protein, carbohydrates and fat content of fortified rice as mentioned above.

Conclusion

The study successfully developed a zinc fortification method for IGKV-R1 paddy rice, achieving optimal zinc uptake through precise control of soaking temperature, time, and zinc oxide concentration. The ideal conditions identified were soaking at 70°C for 3 hours with 300 mg/100 g of zinc oxide, resulting in a zinc uptake of 15.18 mg/100 g in polished rice. Analysis showed that higher zinc concentrations

significantly improved uptake compared to soaking temperature and duration. Zinc-fortified rice demonstrated improved milling quality, with head rice yields increasing due to the loosening of the paddy husk during soaking and steaming. Physico-chemical properties of the fortified rice indicated slight changes; ash and fiber content increased, while protein and carbohydrate content decreased. The fortified rice's moisture content remained stable, and the overall energy value decreased due to lower protein, carbohydrate, and fat levels. These results are consistent with existing literature, which attributes nutrient loss to leaching during the soaking process. The findings highlight the potential of zinc fortification to enhance the nutritional profile of rice, making it a viable strategy to address zinc deficiency in populations reliant on rice as a staple food. Future research should explore long-term storage stability and bioavailability of zinc in fortified rice to fully understand its benefits.

Acknowledgement

The authors are grateful to the Department of Agricultural Processing and Food Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India for providing the laboratory facilities throughout the experimental work.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors declare no conflict to interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects or any material that requires ethical approval.

Informed Consent Statement

The authors give their consent for the publication of identifiable details to be published in the Journal.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not applicable.

Author Contributions

- **R H Sabalpara:** writing – original draft – review & editing
- **Shadanan Patel:** review, editing & finalizing
- **Dharmendra Khokhar:** Reviewed the manuscript

References

1. Tulchinsky, T. H. Micronutrient Deficiency Conditions: Global Health Issues. *Public Health Reviews*. 2010;32(1), Article 1. <https://doi.org/10.1007/BF03391600>
2. Gödecke, T., Stein, A. J., Qaim, M. The global burden of chronic and hidden hunger: Trends and determinants. *GFS*. 2018;17:21–29. <https://doi.org/10.1016/j.gfs.2018.03.004>
3. World Health Organization Guideline: Fortification of Rice with Vitamins and Minerals as a Public Health Strategy. *WHO*. 2018. <https://iris.who.int/handle/10665/272535>
4. Antony, A. C., Vora, R. M., Karmarkar, S. J. The Silent Tragic Reality of Hidden Hunger, Anaemia, and Neural-Tube Defects (Ntds) in India. *The Lancet Regional Health - Southeast Asia*. 2022; 6. <https://doi.org/10.1016/j.lansea.2022.100071>
5. Steiger, G., Müller-Fischer, N., Cori, H., Conde-Petit, B. Fortification of rice: Technologies and nutrients. *Annals of the New York Aca of Sci*. 2014;1324(1), 29–39. <https://doi.org/10.1111/nyas.12418>
6. Peña-Rosas, J. P., Mithra, P., Unnikrishnan, B., Kumar, N., De-Regil, L. M., Nair, N. S., Garcia-Casal, M. N., Solon, J. A. Fortification of rice with vitamins and minerals for addressing micronutrient malnutrition. *Cochrane Database of Systematic Reviews*, 2019; (10). <https://doi.org/10.1002/14651858.CD009902.pub2>

7. L R, P., Rao P., Gudi, N. Understanding barriers and facilitators for rice fortification in India. *FOODS Spectrum*.2023; <https://nuffoodsspectrum.in/2023/04/05/understanding-barriers-and-facilitators-for-rice-fortification-in-india.html>
8. National Family Health Survey India -5. National Family Health Survey 2019-2021. *National Family Health Survey*. 2021; https://main.mohfw.gov.in/sites/default/files/NFHS-5_Phase-II_0.pdf
9. Aparna, P., Muthathal, S., Nongkynrih, B., Gupta, S. K. Vitamin D Deficiency in India. *Journal of Family Medicine and Primary Care*. 2018; 7(2), 324–330. https://doi.org/10.4103/jfmpc.jfmpc_78_18
10. Black R.E., Allen L.H., Bhutta Z.A., Caulfield L.E., De Onis M., Ezzati M. Maternal and Child Undernutrition: Global and Regional Exposures and Health Consequences. *Lancet*. 2008; 371:243–260.
11. Stephenson L.S., Latham M.C., Ottes E. A. Global Malnutrition. *Parasitology*. 2000; 121:S5–S22.
12. Kotecha P.V. Micronutrient Malnutrition in India: let us say 'no' to it now. *Indian J Community Med*. 2008; 33:9–10.
13. Hambidge K.M., Krebs N.F. Zinc Deficiency: A Special Challenge. *J Nutr*. 2007; 137:1101–1105.
14. Hotz C., Brown K. Assessment of the Risk of Zinc Deficiency in Populations and Options for its Control. *Food Nutr Bull*. 2004;25:S94–S203.
15. Gibson R.S., Yeudall F., Drost N., Mtitimuni B., Cullinan T. Dietary Interventions to Prevent Zinc Deficiency. *Am J Clin Nutr*. 1998; 68:484S–487S.
16. Prasad A.S. Zinc Deficiency in Humans: Effect on Cell Mediated Immunity. In: *Nutrition Goals for Asia-Vision 2020*. Nutrition Foundation of India, New Delhi. 2003; pp.349-358.
17. Hettiarachchi M., Hilmers D.C., Liyanage C., Abrams S.A. Na2EDTA Enhances the Absorption of Iron and Zinc from Fortified Rice Flour in Sri Lankan Children. *J Nutr*. 2004; 134:3031–3036.
18. Brown K.H., Peerson J.M., Rivera J., Allen L.H. Effect of Supplemental Zinc on the Growth and Serum Zinc Concentrations of Prepubertal Children: A Meta-Analysis of Randomized Controlled Trials. *Am J Clin Nutr*. 2002;75:1062–1071.
19. Abrams S.A., Mushi A., Hilmers D.C., Griffin I.J., Davila P., Allen L. A Multinutrient-Fortified Beverage Enhances the Nutritional Status of Children in Botswana. *J Nutr*. 2003;133:1834–1840.
20. Rerkasem B., Cakmak I., Huang L., Zinc Fortification of Whole Rice Grain through Parboiling Process. *Food Chem*. 2010;120:858–863.
21. Cakmak I. Enrichment of Cereal Grains with Zinc: Agronomic or Genetic *Biofortification Plant Soil*. 2008;302:1–17.
22. Kennedy G., Burlingame B., Nguyen N. Nutrient Impact Assessment of Rice in Major Rice-Consuming Countries. *International Rice Commission Newsletter*. 2002;51, 33–42.
23. Piccoli N. B., Grede N., de Pee S., Singhkumarwong A., Roks E., Moench-Pfanner, R., Martin, W. B. Rice Fortification: Its Potential for Improving Micronutrient Intake and Steps Required for Implementation at Scale. *Food and Nutrition Bulletin*. 2012;33(4), S360–S372. <https://doi.org/10.1177/15648265120334S312>
24. Ministry of Consumer Affairs, Food & Public Distribution. 15 States have been identified for implementing Centrally Sponsored Pilot Scheme on Fortification of Rice & its distribution through Public Distribution System. 2020. <https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1669677>
25. Rao Jagannadha P.V.K. Pneumatic Parboiling of Paddy, M.Tech. Thesis. IIT, Kharaghpur, India. 1991.
26. AOAC. Association of Official Analytical Chemists, Official Methods of Analysis 18th ed. Washington, DC, USA. 2005.
27. AOAC. Association of Official Analytical Chemists, Official Methods of Analysis 17th ed. Washington, DC, USA. 2000.
28. Fujihara S., Sasaki H., Aoyagi Y., Sugahara T. Nitrogen-to-protein Conversion Factors for Some Cereal Products in Japan. *Journal of Food Science*. 2008;73(3):204-209.
29. Asibey-Berko E., and Tayie, F. A. K. Proximate analysis of some under-utilized Ghanaian vegetables. *Ghana Journal of science*. 1999;39, 91-96.

30. Design Expert version, 13. Stat – Ease, Inc. MN USA
31. ICMR–NIN. Indian Council of Medical Research–National Institute of Nutrition, <https://www.nin.res.in/>
32. Chiang P. Y., Yeh, A. I. Effect of soaking on wet-milling of rice. *Journal of Cereal Science*. 2002; 35(1), 85-94.
33. Champagne E., Wood D., Juliano B., Bechtel D. The Rice Grain and its Gross Composition. T, Elaine (ed). 3rd, In: *Rice Chemistry and Technology*. 2004; 77-107.
34. Kale S. J., Jha S. K., Nath, P. Determination of Optimum Degrees of Milling for Raw and Parboiled Basmati (PB1121) Rice Using Principal Component Analysis. 2017.
35. Chanu C. S., Shivaleela H. B., Ravindra U. Physicochemical and Cooking Properties of Rice (Sambha masuri) individually Fortified with Iron, Zinc and Calcium. *Int. J. Curr. Microbiol. App. Sci*. 2020; 9(1), 315-327.
36. Vani, G. Fortification of Rice with Micronutrients (Iron and Folic Acid) through Parboiling. M.Tech. Thesis. Acharya N.G Ranga Agricultural University, Bapatla, India. 2021.
37. Shaker A. M. H., Taha F. A., Abdel Fattah S. S. Influence of some Processing Methods on Chemical Composition of Lentil, Faba Bean and Faba Bean Dishes. *Bulletin of the National Nutrition Institute of the Arab Republic of Egypt*. 1995; 15(2), 46-52.
38. Afify A. E. M. M., El-BELTAGI H. S., Abd El-Salam S. M., Omran, A. A. Effect of Soaking, Cooking, Germination And Fermentation Processing on Proximate Analysis and Mineral Content of Three White *Sorghum Varieties (Sorghum bicolor L. Moench)*. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*. (2012); 40(2), 92-98.
39. Ebuehi O. A. T., Oyewole A. C. Effect of Cooking and Soaking on Physical Characteristics, Nutrient Composition and Sensory Evaluation of Indigenous and Foreign Rice Varieties in Nigeria. *African Journal of Biotechnology*. 2007; 6(8).
40. Scherz H., Senser F and Souci S.W. Food Composition and Nutrition Tables, 6th ed. CRC Press/Medpharm, Boca Raton, FL, USA. 2000; 1182.
41. Juliano B.O. Factors Affecting Nutritional Properties of Rice Protein. *Trans Nat Acad Sci technoy*. 1995; 7:205-216.
42. Kale S. J., Jha G. K., Sinha J. P Lal S. B. Soaking Induced Changes in Chemical Composition, Glycemic Index and Starch Characteristics of Basmati Rice. *Rice Science*. 2015; 22(5):227-236.
43. Singh N., Kaur L., Sandhu K. S., Kaur J., Nishinari K. Relationships Between Physicochemical, Morphological, Thermal, Rheological Properties of Rice Starches. *Food hydrocolloids*. 2006; 20(4), 532-542.
44. Heinemann R. J. B., Fagundes P. L., Penteadó E. A., Lanfer-Marquez, U. M. Comparative Study of Nutrient Composition of Commercial Brown, Parboiled and Milled Rice from Brazil. *Journal of Food Composition and Analalysis*. 2005; 18: 287-296.