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# Development of Micronutrient Fortified Extruded Rice Analogues

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***Authors' contributions***

*This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Fortified rice analogues can be manufactured using broken rice flour to suit the nutrient needs of target malnourished populations whose staple food is rice. The purpose of the study was to investigate the feasibility of fortifying rice analogues with iron and zinc. The fortificant mix was formulated to furnish 6.34 mg of iron and 2.10 mg of zinc per 100 g of broken rice flour. Iron fortificant used as micronised ferric pyrophosphate (MFPP) and zinc fortificant as zinc oxide (ZNO). Fortified extruded rice analogues were developed by extrusion technology. The physical properties of the fortified rice analogues were analysed. The length and weight of the fortified extruded rice analogues were 6.0 to 6.1mm and 0.034 to 0.035 g. The bulk density was ranged from 0.90 to 0.96 g/ml. The water absorption index was ranged from 2.31 to 2.33g/g and soluble loss was found to be 0.13 to 0.14 g/g. The physical properties of the rice analogues was found to be non significant ($p<0.05$) between the treatments ($p<0.05$). Colour measurement revealed that rice analogues fortified with MFPP had significant ($p<0.05$) colour differences, compared to analogues fortified with ZNO. However, MFPP, when combined with ZNO, had produced visual appearance closest to the unfortified rice analogue. The iron and zinc content of the unfortified broken rice flour (before extrusion) was 0.80 mg and 1.35 mg/100g. The iron and zinc content of the corresponding fortified rice analogues (after extrusion) were 7.13 mg and 3.35 mg/100g thus recording an iron and zinc retention of 99.85 and 99.70% respectively hence no significant difference ($p<0.05$) was found between fortified rice flour and fortified rice analogues. Sensory analysis revealed, no significant

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difference ($p<0.05$) for aroma, moistness, stickiness and texture, while the significant difference for appearance, firmness and overall acceptance. The study revealed that the rice analogues fortified with MFPP and ZNO could be used in food fortification programs and also could serve as a micronutrient enriched food to target malnourished populations whose staple food is rice.

*Keywords: Rice; analogues; extrusion; micronutrient; fortificant.*

## 1. INTRODUCTION

The World Health Organization (WHO) estimate that more than two billion people suffer from micronutrient deficiency globally. Unlike protein-energy undernourishment, the health impacts of micronutrient deficiency are not always acutely visible hence it is termed ‘hidden hunger'. Iron deficiency affects more than 2 billion people in virtually all countries [1]. Most affected are women and pre-school-age children, but anaemia is also seen in older children and men. Anaemia in infants and children is associated with retarded physical growth, reduced resistance to infections and slow development of learning abilities. In adults, it causes fatigue and reduced work capacity and may cause reproductive impairment. Blood loss in childbirth is very dangerous for anaemic women and is the main cause of about 20 percent of maternal deaths. Maternal anaemia also leads to foetal growth retardation, low infant birth weight and increased prenatal mortality (death in the first week of life). Zinc deficiency contributes substantially to the morbidity and mortality of young children throughout the world. The global prevalence of zinc deficiency was estimated at 31%, ranging from 4-73% across sub regions [2].

Among the different strategies to overcome micronutrient malnutrition, food fortification is most economical and effective. The selection of the appropriate food for use in fortification requires that the food to be consumed in significant quantities by the target population, the added nutrients do not cause sensorial changes, and most of all the fortified food should be affordable. Globally rice is an important staple food for more than three billion population. Particularly in Asia where people eat about 150 kg of milled rice per year and therefore has much potential as a food fortification vehicle. However, milled rice is not a rich source of micronutrients, because most of them are lost during the milling of the kernels. Hence, fortification of rice with essential micronutrients is one of the best solutions to providing people whose diet consists mainly of rice. The low-cost raw material broken rice could be utilised for rice fortification hence it is cost advantage and also addresses the micronutrient deficiencies [3].

There are numerous rice fortification technologies are currently available including extrusion, coating and dusting for micronutrient fortification in rice [4,5]. The major problems encountered with coating technologies are related to colour, taste, and a loss of micronutrients during washing, as well as during cooking of the fortified rice. During dusting, micronutrients in the form of fine particles are blended with the bulk rice. This method makes use of the electrostatic forces between the rice surface and the micronutrients. Nevertheless, there is a segregation risk [6]. Extrusion technology is the most preferable and novel method for the production of fortified rice and the final product have more acceptable in appearance, color and sensory acceptability and also added nutrient is stable and retain after rinsing, washing and cooking hence the added micronutrient are embedded and consequently do not separate from the rice. Studies on development of fortified rice analogues found that the overall retention of fortified iron, zinc, vitamin B12, and folic acid was between 75% and 100% and was unaffected by cooking method in fortified rice developed by extrusion technology. Similar technology has been successfully introduced and has made substantial progress in India, Mexico and other developing countries [7,8].

Fortification of rice with chemical fortificants generally results in deterioration of colour and flavour which is attributed to the chemical nature and solubility of the fortificant and its interaction with other components in the rice. Hence it was also considered of interest to evaluate the quality of the micronutrient fortified rice analogues carrying iron in form of micronised ferric pyrophosphate (MFPP) and zinc in the form of zinc oxide (ZNO). The present study envisages the manufacture of fortified extruded rice analogues which could serve as a nutrient delivery vehicle for micronutrients like iron and zinc. The objectives of the present work is to develop micronutrient fortified extruded rice analogues by extrusion technology and to analyse its physical properties, cooking properties, colour profile, nutrient retention and sensory attributes.

## 2. MATERIALS AND METHODS

### 2.1 Formulation of Broken Rice Flour and Micronutrient Mix

Broken rice flour was thoroughly mixed with a mineral premix formulated by Fortitech, in a blender. The treatment combinations were $T_1$ (control - without fortificants, $T_2$ (iron fortificant - Micronised Ferric Pyrophosphate - MFPP), $T_3$ (zinc fortificant - Zinc Oxide - ZNO) and $T_4$ (MFPP+ZNO). The micronutrient premixes were formulated to provide 6.34 mg of iron and 2.10 mg of zinc per 100 g of broken rice flour on dry weight basis. The micronutrients levels used were intended to compensate for expected losses during extrusion and cooking substantially. The formulation for the development of fortified extruded rice analogues furnished in Table 1.

### 2.2 Extrusion Conditions

Low temperature short-time (LTST) extrusion cooking was conducted using a single-screw model extruder (La Monferrina, Italy). For preparation of the fortified extruded rice analogues with desirable internal and apparent good texture, the blended broken rice flour and fortificants were tempered by adding a predetermined amount of water (30%) at 40°C by spraying and mixed in a mixer thoroughly for 30 min to adjust the feed moisture content to 14%, for moisture equilibrium. The operating conditions were fixed at 500 rpm shearing forces for the cutter; 20 kg/h feed rate; 4.5 mm diameter of the die. The temperature profile in the barrel zone towards rice shaped die was 60°C. The extrudates were collected when the operation conditions were at constant state, cooled at room temperature, dried overnight in tray drier at 60°C before packing.

### 2.3 Physical Characteristics

Bulk density was determined using a modification of a reported method [9]. Ten gram of weighed rice analogues was filled into a 25 ml graduated cylinder. The cylinder was tapped on the bench top until no more settling was observed. The weight of the analogues was taken and bulk density was calculated with the given formulae,

Bulk density (g/ml) = (Weight of sample / Volume of the sample after tapping) x 100

### 2.4 Determination of Water Absorption Index (WAI) and Soluble Loss

WAI and WSI were determined in triplicate following the method described by Carine et al. [10]. One gram of sample was suspended in 20 ml of distilled water in a tared 50 ml centrifuge tube and stirred with glass rod, kept in water bath for 30 min at 30°C temperature. Subsequently, the dispersions were centrifuged at 2000 rpm for 10 min using a centrifuge. The supernatants were collected into dry test tubes and stored overnight at 110°C for evaporation.

WAI = (Weight of sediment / Weight of dry solids) x 100

Soluble loss = (Weight of loss / Weight of sample) x 100

### 2.5 Colour Measurements

Colour measurements were performed on both the uncooked fortified and unfortified rice analogues using a Hunter lab colour meter (Lovi bond tinto meter). L-values correspond to lightness/darkness with higher values corresponding to more lightness. *a* and *b* values correspond to an object's colour dimensions, with a-values describing a sample's red to greenness, while b-values describe a sample's yellow to blueness. Larger *a* values indicate more redness and larger *b* values indicate more yellowness.

**Table 1. Formulations used for development of fortified extruded rice analogues**

| S. No | Treatments | Rice flour (g) | MFPP (mg) | ZNO (mg) |
|---|---|---|---|---|
| 1. | $T_1$ | 100 | - | - |
| 2. | $T_2$ | 100 | 6.34 | - |
| 3. | $T_3$ | 100 | - | 2.10 |
| 4. | $T_4$ | 100 | 6.34 | 2.10 |

The parameter, ΔE, defined as $\Delta E = [(L_1-L_2)^2 + (a_1-a_2)^2 + (b_1-b_2)^2]^{1/2}$, was used to determine the overall colour difference between each of the fortified sample and the unfortified control.

## 2.6 Cooking Properties of Fortified Extruded Rice Analogues

The prepared fortified extruded rice analogues were studied for cooking properties such as including cooking time, cooked weight, percent rehydration and cooking loss.

### 2.6.1 Cooking time

One gram of dried fortified extruded rice analogues was cooked with occasional stirring in a beaker containing 60ml boiling water. The optimum cooking time was evaluated by squeezing the analogues between two glass slides after every 30s and observing the time of disappearance of white core of rice analogues, which indicated the cooking time [11].

### 2.6.2 Cooked weight

The rice analogues were cooked in boiling water for their respective cooking time as per the determined cooking time. Then cooked analogues were rinsed with 20ml distilled water and drained for 2 min. Cooked weight was determined by weighing wet mass of rice analogues [11].

### 2.6.3 Percent rehydration and cooking loss

Both percent rehydration and cooking loss were determined by the method of [12]. For the determination of percent rehydration, rice analogues were cooked their respective cooking time. The cooked rice analogues were then washed with water and drained for 2 min. Weight was then taken to determine the percent rehydration. The cooking water and washing water were collected separately in pre-weighed petridishes and were dried in an oven at 105°C till constant weight was obtained. The residues were weighed after cooling in desiccators to determine the cooking loss. The cooking loss was calculated by measuring the amount of solid residues remained in the cooking and rinse water after drying. Percent rehydration and cooking loss were calculated by the following equations,

Rehydration (%) = {(Weight of cooked analogues – weight of uncooked analogues) / Weight of uncooked analogues} x 100

Cooked weight = (Weight of wet analogues/ Weight of dry analogues) x 100

Cooking loss = (Weight of dried residues / Weight of uncooked analogues) x 100

## 2.7 Nutrient Analysis

For determination of iron and zinc concentration, flour samples were collected randomly from three different portion of the fortificant mixed flour immediately after the mixing was complete. The collected samples were analyzed for iron and zinc content to ensure uniform mixing of the fortificants. The uniformity of distribution of MFPP and ZNO was of particular interest because of the possibility of settling of during the mixing process. The retention of iron and zinc were analyzed in Atomic Absorption Spectrophotometer (AAS) [13]. The nutrient analysis of the dried fortified rice analogues was carried out for protein by Micro Kjeldhal method [14]. Fat was extracted by refluxing with petroleum ether in a soxhlet apparatus [15]. Fiber was estimated by fibra plus equipment and the residue obtained after digestion with acid and alkali was dried in crucible and weighed. The difference in weight of the crucible before and after ashing of the digested residues was taken as weight of the crude fibre [16] and total ash [17] were determined. Carbohydrate content was determined by difference method [18,19]. Amylose [20] and starch content was determined [21].

## 2.8 Sensory Analysis

Sensory evaluation was carried out by fifteen semi-trained judges using a 9-point Hedonic rating scale [22] for sensory attributes like aroma, appearance, firmness, moistness, stickiness, texture and overall acceptability.

## 2.9 Statistical Analysis

Data were assessed by analysis of variance (ANOVA) using SPSS program version 16.0 and means were separated by Duncan's multiple range test with a probability ($P < 0.05$) [23].

# 3. RESULTS AND DISCUSSION

## 3.1 Physical Characteristics

The mean physical parameters of fortified extruded rice analogues are given in Table 2.

**Table 2. Physical characteristics of fortified extruded rice analogues**

| S. No | Characteristics | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|---|---|---|---|---|---|
| 1. | Length (mm) | 6.1±0.05$^{ab}$ | 6.1±0.05$^{c}$ | 6.0±0.05$^{a}$ | 6.0±0.05$^{a}$ |
| 2. | Weight (g) | 0.035±0.00$^{ab}$ | 0.034±0.00$^{a}$ | 0.035±0.00$^{d}$ | 0.035±0.00$^{ac}$ |
| 3. | Bulk density (g) | 0.91±0.00$^{b}$ | 0.96±0.00$^{c}$ | 0.90±0.00$^{a}$ | 0.95±0.00$^{c}$ |
| 4. | F-Value | NS | NS | NS | NS |
| 5. | CD | 0.48 | 0.55 | 0.60 | 0.52 |

*Values are means ± SDs of triplicate determinations. Means for each characteristic followed by the same letter within the row are not significantly different at p<0.05 by LSD test. NS-Non significant, * - Significant*

The length and weight of the fortified extruded rice analogues were 6.0 to 6.1mm and 0.034 to 0.035g and was found to be non significant among the different treatments. Bulk density is a major physical property of the extruded product. The bulk density, which considers expansion in all direction, was ranged from 0.90 to 0.96 g/ml for the fortified extruded rice analogues. These values are coinciding with the bulk density of 0.75g/ml of the rice bran based rice analogues [24]. In the present study observed that added fortificants in the formulations has not influenced the bulk density of the analogues and there was no significant difference was found between the treatments. It was also evident that the bulk density of the extruded rice analogues could not be varied with the addition of fortificants and could be varied only if change in temperature of the extruder and moisture content of the feed [25].

## 3.2 Water Absorption Index (WAI) and Soluble Loss

WAI, an indicator of the ability of fortified extruded rice analogues to absorb water, depends on the availability of hydrophilic groups which bind water molecules and on the gel-forming capacity of macromolecules. The WAI (Table 3) was found to be non significant among the four formulations which ranged from 2.31 to 2.33 g/g. The Water Absorption Index (WAI) of the rice analogues produced from broken rice flour and soybean flour varied from 2.99 to 3.73 g/g [26]. It is also evident that the water absorption capacity of rice analogues produced from cassava flour, taro flour and green bean flour was between 0.8 and 1.84 times [27]. These values are consistent with the fortified extruded rice analogues developed in the present study. Soluble loss is used as a measure for starch degradation and it was found to be 0.13 to 0.14 g/g. No significant difference was observed between the treatments, because addition of fortificants could not influence the soluble loss of the extruded fortified rice analogues. Nevertheless the smallest amount of soluble loss in the present study might be due to the hydrophilic polysaccharides present in the rice flour [28].

**Table 3. Water Absorption Index (WAI) and soluble loss of fortified extruded rice analogues**

| S. No | Sample | WAI (g/g) | Soluble loss (g/g) |
|---|---|---|---|
| 1. | $T_1$ | 2.32±0.01$^{a}$ | 0.14±0.00$^{b}$ |
| 2. | $T_2$ | 2.31±0.03$^{a}$ | 0.13±0.01$^{b}$ |
| 3. | $T_3$ | 2.32±0.03$^{a}$ | 0.14±0.01$^{b}$ |
| 4. | $T_4$ | 2.33±0.02$^{a}$ | 0.14±0.01$^{b}$ |
| 5. | F-Value | NS | NS |
| 6. | CD | 0.46 | 0.61 |

*Values are means ± SDs triplicate determinations. Means for each characteristic followed by the same letter within the same column are not significantly different at p < 0.05 by LSD test. NS-Non significant, * - Significant*

## 3.3 Colour Measurements

Table 4 represents the colour profiles of the fortified extruded rice analogues and unfortified rice analogues (control). The L* value (brightness) of the control ($T_1$ - unfortified rice) analogues were found to be 42.41 and it was significantly reduced when subjected to fortification. Brightness values of the $T_2$ (35.30) were lower than $T_3$ and $T_4$ (41.80 and 38.22).This indicates that the fortification of micronized ferric pyrophosphate could significantly reduce the brightness of the rice analogues. This corroborate well with the study where dispersible ferric pyrophosphate fortified reconstituted rice had decrease in whiteness (L values) and an increase in yellowness (b values) [29]. For the a* parameter, there was an inverse relationship. The a* values of the control ($T_1$) was found to be 2.41 and it increased when subjected to fortification in $T_2$, $T_3$ and $T_4$ (4.90, 2.44 and 5.75).The $T_3$, zinc fortified rice analogues showed lower of a* (redness) values compared to $T_2$ - iron fortified and $T_4$ - iron + zinc fortified rice analogues. Regarding b* values, the $T_2$ showed higher value (13.63) than the other treatments, while the $T_1$, $T_3$ and $T_4$ samples had a lower b* values (9.66, 10.80 and 11.01) thereby indicating that the $T_2$ samples had a more yellowish tinge. It can inferred that the fortification of micronized ferric pyrophosphate resulted in much darker in colour, while zinc oxide fortification resulted in darker less. Overall the L, a and b value of the different treatments of the fortified rice analogues were found to be significantly different. It is also evident that mineral fortificants does not cause effect on colour in extruded rice analogues [30].

## 3.4 Cooking Properties

The fortified extruded rice analogues were assessed for cooking time, cooked weight, percent rehydration and cooking loss (Table 5). The cooking time was found to be 5 minutes for all formulations. Cooking time of rice noodle developed by extrusion technology ranged from 5 to 9 min [31]. The cooked weight of the fortified extruded rice analogues ranged from 2.80 to 2.94 g/g. The percent of rehydration ratio of the fortified extruded rice analogues indicates the degree of hydration which may affect the eating quality. The rehydration percent of the analogues was found to be 278 to 284 %. The rehydration values for fortified extruded rice analogues are consistent with the rehydration capacity (146 to 290%) of the rice extrudates [31,12]. Cooking loss indicates the ability of the fortified extruded rice analogues to maintain structural integrity during the cooking process. High cooking loss is undesirable because it represents high solubility of starch, resulting in turbid cooking water, low cooking tolerance and sticky mouth feel [32]. Cooking loss values of fortified extruded rice analogues were in the range of 0.30 to 0.50 g/g. This result shows that less amounts of solids leached out in the cooking water which indicates the preference for fortification.

## 3.5 Nutrient Analysis

The proximate composition of the fortified extruded rice analogues are tabulated in Table 6. The moisture level of the fortified extruded rice analogues ranged from 11.02 to 11.62 %. However optimum moisture level was found (<14%) in all the fortified extruded rice analogues. The protein, fat and fiber were found to be 5.92 to 6.03%, 0.31 to 0.51% and 0.16 to 0.22% respectively. The amylose and carbohydrate content of the fortified extruded rice analogues was found to be 11.91 to 12.51% and 26.31 to 26.94%. The energy value of all formulations was similar was found to be ranging from 452.12 to 475.53 Kcal.

## 3.6 Nutrient Retention

Table 7 describes that the iron and zinc content of the broken rice flour was 0.80 mg and 1.26 mg/100g. Iron in the form of MFPP was fortified at a level of 6.34 mg/100g and zinc in the form of ZNO was fortified at a level of 2.10 mg/100g into broken rice flour. After addition of fortificants to broken rice flour, the iron and zinc content increased to be 7.14 and 3.36 mg/100g. The mix was extruded and dried to obtain fortified extruded rice analogues. The MFPP and ZNO concentration of the corresponding fortified rice analogues after drying were 7.13 mg and 3.35 mg/100g thus recording a nutrient retention of 99.85 and 99.70% respectively (Table 8). Similar study has been carried out for developing fortified extruded rice products, observed that losses in MFPP and ZNO were 0 and 4%, respectively [33]. In the present study, the losses are less. This indicates that very meagre amount of MFPP and ZNO was lost during extrusion processing, which is expected since they do not degrade as easily as the vitamins. Commonly minerals are heat stable and suitable for fortification with a good nutrient retention capacity during extrusion process.

**Table 4. Colour profile of fortified extruded rice analogues**

| Treatment | L* | a* | b* |
|---|---|---|---|
| $T_1$ –Control | 42.41±0.01$^a$ | 2.41±0.01$^a$ | 9.66±0.03$^a$ |
| $T_2$-MFPP | 35.30±0.01$^b$ | 4.90±0.01$^b$ | 13.63±0.01$^b$ |
| $T_3$-ZNO | 41.80±0.05$^c$ | 2.44±0.03$^a$ | 10.80±0.02$^c$ |
| $T_4$ - MFPP+ZNO | 38.22±0.02$^d$ | 5.75±0.02$^c$ | 11.01±0.02$^d$ |
| F-Value | * | * | * |
| CD | 3.23 | 2.15 | 0.44 |

*Values are means ± SDs of triplicate determinations. Means for each characteristic followed by the different letter within the same column are significantly different at p<0.05 by LSD test. The L* parameter indicates lightness. The a* and b* parameters are coordinates that indicate red (+a*), green (−a *), yellow (+b*) and blue (−b*).*
*NS-Non significant, * - Significant*

**Table 5. Cooking properties of fortified extruded rice analogues**

| Sample | Cooking time (min) | Cooked weight (g/g) | Percent rehydration | Cooking loss (g/g) |
|---|---|---|---|---|
| $T_1$ | 5.0±0.00[a] | 2.94±0.20[c] | 281±2.08[ab] | 0.50±0.01[c] |
| $T_2$ | 5.0±0.00[a] | 2.81±0.01[a] | 278±0.57[a] | 0.44±0.00[b] |
| $T_3$ | 5.0±0.00[a] | 2.80±0.01[a] | 281±2.08[ab] | 0.30±0.00[a] |
| $T_4$ | 5.0±0.00[a] | 2.90±0.01[b] | 284±1.00[c] | 0.48±0.01[c] |
| F value | NS | NS | NS | NS |
| CD | 0.48 | 0.54 | 0.92 | 0.58 |

*Values are means ± SDs triplicate determinations. Means for each characteristic followed by the same letter within the same column are not significantly different at p<0.05 by LSD test. NS-Non significant, * - Significant*

**Table 6. Nutrient composition of fortified extruded rice analogues**

| Samples | Moisture (%) | Protein (%) | Fat (%) | Fiber (%) | Amylose (%) | Carbohydrate (g) | Energy (Kcal) |
|---|---|---|---|---|---|---|---|
| $T_1$ | 11.26±0.02[c] | 6.01±0.01[b] | 0.31±0.01[a] | 0.16±0.00[ab] | 12.06±0.02[b] | 26.71±0.01[b] | 475.53±0.03[d] |
| $T_2$ | 11.11±0.01[b] | 5.92±0.02[a] | 0.46±0.01[b] | 0.18±0.00[c] | 12.51±0.01c | 27.44±0.01[d] | 452.12±0.02[a] |
| $T_3$ | 11.02±0.01[a] | 6.03±0.01[c] | 0.32±0.04[a] | 0.15±0.03[a] | 12.07±0.01[b] | 26.31±0.01[a] | 471.82±0.02[c] |
| $T_4$ | 11.62±0.02[d] | 5.92±0.06[ab] | 0.51±0.02[c] | 0.22±0.02[d] | 11.91±0.01[a] | 26.94±0.02[c] | 462.89±0.02[b] |
| F Value | NS | NS | NS | NS | NS | NS | NS |
| CD | 0.49 | 0.54 | 0.36 | 0.52 | 0.42 | 0.39 | 0.46 |

*Values are means ± SDs of triplicate determinations. Means for each characteristic followed by the same letter within the same row are not significantly different at p<0.05 by LSD test. NS-Non significant, * - Significant*

**Table 7. Iron and zinc content of broken rice flour and MFPP & ZNO fortification level into broken rice flour**

| Sample | Nutrients/100g | | Fortification level/100 g | | Fortified broken rice flour | |
|---|---|---|---|---|---|---|
| | Iron (mg) | Zinc (mg) | Iron (MFPP) mg | Zinc (ZNO) mg | Iron (mg) | Zinc (mg) |
| Broken rice flour | 0.80 | 1.26 | 6.34 | 2.10 | 7.14 | 3.36 |

**Table 8. Iron and zinc retention of fortified extruded rice analogues**

| Nutrients | Treatments | | Fortified rice flour | Fortified extruded rice analogues | % of retention | F value | CD |
|---|---|---|---|---|---|---|---|
| Iron | $T_1$-control | | ≤0.80 | ≤0.80 | NA | - | - |
| (mg/100 g) | $T_2$ -MFPP | | 7.14[a] | 7.13[a] | 99.85 | NS | 0.65 |
| Zinc (mg/100 g) | $T_1$-control | | ≤1.35 | ≤1.35 | NA | - | - |
| | $T_3$ - ZNO | | 3.36[b] | 3.35[b] | 99.70 | NS | 0.43 |
| Iron & Zinc | $T_4$-MFPP&ZNO | MFPP | 7.14[c] | 7.13[c] | 99.85 | NS | 0.54 |
| | | ZNO | 3.36[d] | 3.35[d] | 99.70 | NS | 0.51 |

*Values are means ± SDs of triplicate determinations. Means for each characteristic followed by the same letter within the same row are not significantly different at p<0.05 by LSD test. NS-Non significant, * - Significant*

**Table 9. Sensory characteristics of the fortified extruded rice analogues**

| Attributes | $T_1$ | $T_2$ | $T_3$ | $T_4$ | F value | CD |
|---|---|---|---|---|---|---|
| Aroma | 5.46±0.05[a] | 5.42±0.02[a] | 5.42±0.74[a] | 5.43±0.28[a] | NS | 0.54 |
| Appearance | 6.31±0.07[a] | 6.20±0.04[b] | 6.28±0.03[c] | 6.29±0.07[d] | * | 0.64 |
| Firmness | 5.61±0.21[a] | 5.61±0.42[b] | 5.59±0.41[e] | 5.60±0.68[d] | * | 2.13 |
| Moistness | 6.01±0.06[c] | 5.99±0.02[c] | 6.00±0.06[c] | 6.00±0.01[c] | NS | 1.02 |
| Stickiness | 5.69±0.42[e] | 5.67±0.61[e] | 5.64±0.40[e] | 5.65±0.60[e] | NS | 0.42 |
| Texture | 5.71 ±0.07[d] | 5.67±0.21[d] | 5.70±0.21[d] | 5.71±0.14[d] | NS | 0.41 |
| Overall acceptance | 6.04±0.14[a] | 5.98±0.14[c] | 6.01±0.07[a] | 6.03±0.21[c] | * | 0.53 |

*Values are means ± SDs of triplicate determinations. Means for each characteristic followed by the same letter within the same row are not significantly different and different letter within the same row are significantly different at p<0.05 by LSD test. NS-Non significant, * - Significant*

### 3.7 Sensory Characteristics

The data of different sensory attributes of the fortified extruded rice analogues are presented in Table 9. On comparison of the values for sensory attributes, both the control and the fortified rice samples found to be significantly different ($P<0.05$). For the appearance, MFPP and ZNO fortified extruded rice analogues ($T_4$) had higher score (6.29) when compared with $T_2$ (6.20) and $T_3$ (6.28) respectively. This might be possibly due to the colour masking property of the micronized ferric pyrophosphate. Similar study has been conducted to develop iron fortified extrude rice and reported that iron could alter the colour and appearance of the extruded rice and it did not alter the other sensory characteristics of the fortified rice analogues [34]. Similarly the lower sensory scores was obtained for colour and appearance of the rice analogues fortified with iron fortificant (micronized ferric pyrophosphate) [35]. Overall acceptance of the fortified rice analogues was found to be significantly different and the results showed that $T_4$ had higher value next to the $T_1$, $T_3$ and $T_2$.

## 4. CONCLUSION

Fortified extruded rice analogues showed desirable qualities such as high in bulk density, WAI and low in moisture content and soluble loss. The production of fortified extruded rice analogues except for MFPP ($T_2$) fortified rice analogues were found to be similar in colour and appearance to that of unfortified rice analogues. But when MFPP combined with the ZNO ($T_4$), produced colour appearance closest to the unfortified rice analogues. This would facilitate more consumer acceptance, because appearance and colour are the most important sensory attributes for acceptability of the product. Regarding nutrient retention, fortified extruded rice analogues had 99.85% for iron and 99.70% for zinc respectively. Significant processing loss of 0.1% for iron and 0.2% for zinc was observed in the fortified extruded rice analogues. Based on sensory analysis, fortified extruded rice analogues ($T_4$) had higher sensory scores next to the control. It can be concluded that MFPP in combination with ZNO fortified extruded rice analogues ($T_4$) did not cause significant changes in physical property, cooking quality, colour and sensory attributes of the rice analogues, besides having nutrient dense than the single fortification ($T_2$ and $T_3$), hence it could be concluded that ($T_4$) MFPP in combination with ZNO fortified extruded rice analogues selected for commercialization. The developed fortified extruded rice analogues could serve as a micronutrient fortified food to address micronutrient malnutrition.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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