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Influence of Bioprocessing Methods on 'China Rice' (Gawal R1), and Soyabean Supplementation on the Quality of Complementary Food

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Abstract

The study investigated the influence of malting, solid-state fermentation of "China rice" (GAWAL R1), and soybean supplementation on the proximate, mineral, and amino acid composition, as well as the acceptability of the complementary foods. Paddy was malted, milled, and a portion of the flour was fermented. Similarly, soybeans were processed into flour. A 2 x 2 x 2 factorial design was used, comprising non-complemented rice flour and complemented rice flour with processed soybean (4 samples each). The proximate, mineral, and amino acid composition, as well as the sensory qualities of the samples, were determined. The moisture, protein, ash, fibre, and carbohydrate contents of complementary foods varied significantly ($p < 0.05$). The addition of soybean appreciably ($p < 0.05$) enhanced the mineral content of the complementary food. Germination of rice did not affect the taste of the complementary foods, but fermentation and the combination of fermentation and malting did significantly ($p < 0.05$). The combination of germination and solid-state fermentation did not affect leucine, lysine, isoleucine, valine, tryptophan, methionine + cysteine, threonine, histidine, but reduced phenylalanine + tyrosine. However, most of the essential amino acids were within recommended levels.

Keywords: China Rice; Fermentation; Malting, Germination; Nutrients; Amino Acids

Abbreviations

NMNFRC: Non-Malted Non-Fermented China Rice; $MNFR_C$: Malted Non-Fermented China Rice; MFRc: Malted–Fermented China Rice flour; DMRT: Duncan's Multiple Range Test; CAAS: Chinese Academy of Agricultural Sciences.

Introduction

Complementary feeding is the process of complementing breast milk with adult foods when breast milk is no longer adequate to meet the nutritional requirements of infants, generally at the age of six months, and continues until twenty-three months [1]. Infants may suffer from malnutrition if breast milk can no longer provide adequate nutrients and energy for healthy growth. Malnutrition among children is one of the most important causes of morbidity and mortality in the world, particularly in developing countries [2]. Malnutrition has been directly or indirectly linked to more than half of death cases [2].

Therefore, the need for complementary foods to complement breast milk for infants cannot be overemphasized. Complementary foods have successfully been developed using indigenous raw materials such as cereals like rice, millet, sorghum, maise, acha; legumes and peanuts, sesame, cowpea, soybean, chickpeas, bambara groundnut; while pumpkin, plantain and carrot are the common vegetables [3-13] in use to improve nutrition among the less privileged children.

In recent times, rice has received the most attention, while soybeans are the favoured legume and pumpkin, the chosen vegetable. Common rice cultivars grown in the West African region include FARO 44 and China rice (GAWAL R1), both of which yield more than the local variety. On the other hand, soybeans have been widely used (in most parts of the world) for completing cereal-based food products. Soybean (Glycine max), a leguminous plant, has a high protein content and is very cheap [14]. Soybeans, known for their high protein content, would be an ideal source for protein substitution in starchy foods.

Additionally, the most effective and common methods used to improve the bioavailability of nutrients in food include, among others, malting and fermentation. Fermentation plays an essential role in ensuring food security, enhancing livelihoods, and improving people's nutrition and social well-being. Malting is a vital strategic technology that has been shown to improve the bioavailability of both macro- and micronutrients in plant-based foods [14]. To enhance the quality of cereal-legume-based complementary foods, a combination of fermented and malted rice supplemented with soybeans would be an essential approach for developing high-quality rice-based complementary foods. Varietal products, such as those reported [15] for malted and fermented rice (FARO 44), would add more variety to children's diets.

On the other hand, influence of malting and fermentation on microbiological, essential dietary minerals and amino acids composition [15], proximate composition [16] and rheological properties [17] of FARO 44 rice-soybean based complementary foods have been reported, but that of China rice-soybean blends are under reported; therefore, China rice cultivar which has been cultivated along with FARO 44 needs to be evaluated with the afore said parameters. Specifically, Ihedinachi, et al. [13] assessed the nutritional qualities of complementary food produced from malted rice, soybean and pumpkin pulp flour. Bristone, et al. [16] determined the "Influence of Malting and/or Fermentation on Proximate Composition of FARO 44 Rice plus Soybean Based Complementary Foods". Besides these, Bristone, et al. [17] documented the "Rheological Properties of Malted and/or Fermented FARO 44 Rice Plus Soybean-Based Complementary Foods". However, information on Chinese rice regarding the aforesaid methods and parameters is inadequate. Therefore, there is a need to obtain the effect of malting, a combination of solid-state fermentation and malting of Chinese rice, on the nutritional quality of rice-soybean-based complementary food.

Materials and Methods

Sources of Materials

Chinese rice (In Nigeria, the rice cultivar often referred to as "China rice", called Gawal R1) and soybean (Glycine max) were obtained from recognised distributors in Nigeria.

Cleaning and Production

Cleaning and germination of rice as described by Bristone, et al. [15] and Gasinski, et al. [18]. Milling and solid-state fermentation of rice were carried out according to standard procedures [16,17,19-22]. However, one hundred and twenty grammes (120 g) of raw rice flour (RRF) was added to 60.75 ml [16] and was gently mixed for 2 minutes. While soybean was processed into flour as described by Badau, et al. [7] and Bristone, et al. [16].

Complementary Food Formulations

The protein content of the non-complemented rice flours and that of soybean were first determined, and these values were used as a basis for calculating the appropriate mixing ratios. The quantity of rice to soybean in the mixtures was computed using a material balance [16]. This was done to obtain 16% protein in each sample, as recommended by the United Nations Protein Advisory Group [23]. The first four (4) samples were non-complemented rice, comprising Non-Malted Non-Fermented China Rice (NMNFRC), Malted Non-Fermented China Rice ($MNFR_C$), Non-Malted Fermented China Rice ($MNFR_C$), and Malted–Fermented China Rice flour (MFR_C). The second set of samples (4) consisted of rice products supplemented with soybeans. They were designated as Non-Malted Non-Fermented China Rice Complemented with Soybean ($NMNFR_CS$), Malted Non-Fermented China Rice Complemented with Soybean ($MNFR_CS$), Non-Malted Fermented China Rice Complemented with Soybean ($MNFR_CS$), and Malted–Fermented China Rice Complemented with Soybean (MFR_CS) as shown in Table 1.

Formulations	Ingredients					Mass Balance (g)	Protein g/ sample
	Non-malted non-fermented China rice ($NMNFR_c$)	Malted non-fermented rice ($MNFR_c$)	Non-malted fermented rice ($NMFR_c$)	Malted-fermented rice (MFR_c)	Soybean (S)		
I	187.97				0	187.97	16
II		192.77			0	192.77	16
III			169.31		0	169.31	16
IV				183.91	0	183.91	16
V					40.99	40.99	16
VI	75.8	-	-	-	24.2	100	16
VII	-	74.94	-	-	25.06	100	16
VIII	-	-	77.86	-	22.14	100	16
IX	-	-	-	75.93	24.07	100	16

Table 1: Formulations of complementary foods from blends of malted, fermented, and malted and fermented China (Gawal R1) rice flours and soybean.
Quantity of rice, soybean, rice and soybean alone to obtain 16 g protein per sample

Analysis

Determination of moisture, protein (total N × 6.25), ash, fat (Soxhlet extraction method), ash (incineration in a muffle furnace for 24 h at 550 °C) and crude fiber (sample digestion with diluted acid and alkali) as described by Chinma, et al. [24], while energy by Atwater factor {Protein: 4 kcal/g (17 kJ/g), Fat: 9 kcal/g (37 kJ/g); Carbohydrates: 4 kcal/g (17 kJ/g)} as described by FAO [25]. Magnesium (Mg), calcium (Ca), zinc (Zn), potassium (K), iron (Fe), Copper (Cu), and manganese (Mn) in the samples were determined using an atomic absorption spectrophotometer. In contrast, Phosphorus (P) was determined by the photometric method [22]. Amino acid composition was determined by using Applied Biosystem Phenyl Thiohydantoin (PTH) Amino Acid Analyser (Model 120A, PTH Applied Biosystems Inc., USA) [15]. Amino acid score was calculated using the ratio of a gram of the limiting amino acid in the food to the same amount of the corresponding amino acid in the reference diet multiplied by 100. The scoring patterns were based on the FAO/WHO [26] method, as reported by Caire-Juvera, et al. [27].

Sensory analysis was conducted using selected panellists of 21 mothers (20-35 years of age). The sample and the testing place were prepared using standard methods [7,28]. A 9-point Hedonic descriptive scale (from "1 = dislike extremely to 9 = like extremely") was used to rate sensory attributes of samples [7,28].

Statistical Analysis

Statistical analysis was conducted on the raw data generated from the study. One-way analysis of variance (one-way ANOVA) and separation of means by Duncan's Multiple Range Test (DMRT) at a 5% significance level were performed by using IBM SPSS Statistics version 22.

Results and Discussion

Proximate Composition

Table 2 shows the proximate composition of the formulated rice-based complementary food products. The protein, fat, ash, crude fibre, moisture and carbohydrate contents ranged from 8.30 ($MNFR_c$ to 9.45% ($NMFR_c$), 1.07 ($NMNFR_c$) to 2.12% (MFR_c), 0.78 ($MNFR_c$) to 0.92% ($NMNFR_c$), 0.93 (MFR_c) to 1.37% ($NMNFR_c$), 3.92 ($NMFR_c$) to 8.53% ($MNFR_c$), and 79.36 ($MNFR_c$) to 83.31 (MFR_c) %, respectively. $NMNFR_c$ had the lowest energy (362.94 Kcal) while the highest energy was recorded by MFR_c (387.12 Kcal). Among the ingredients used for complementary formulations, soybeans had the highest ($p < 0.05$) protein, fat, ash and crude fiber contents.

Malting and the combination of solid-state fermentation significantly ($p < 0.05$) reduced the protein content of China rice, but fermentation alone had no effect. The effect of malting and fermentation varied substantially with the proximate composition of malted and fermented rice. However, protein, fat, carbohydrate, and energy values increased, while ash, crude fiber, and moisture content decreased. Similarly, the proximate composition of the formulated rice products varied significantly ($p < 0.05$) except for protein (Table 3). The results obtained in this study are in line with the reports of other scientists [16].

It has been shown that the addition of soybean flour to all rice samples improved their proximate composition (Table 3) significantly ($p < 0.05$). It was shown in their average total (8.30 to 16.36 g/100 g protein, ash (0.78 to 1.62 g/100 g), crude fiber (0.93 to 2.63 g/100 g), moisture (8.31 to 8.53 g/100 g), carbohydrate (68.57 to 83.31 g/100 g), and energy (362.94 to 388.88 KJ). Therefore, as can be seen, children will consume a large quantity of non-complemented rice to obtain 16% protein, compared with soybean-complemented products. This has the potential to benefit from consuming protein-complemented starchy products, especially in a society where cases of protein-energy malnutrition are pronounced.

Mineral Content

Zinc, Calcium, Potassium, phosphorus and Manganese contents varied significantly ($p < 0.05$) among the samples Table 2. However, Iron, Magnesium and contents did not differ significantly ($p > 0.05$) among the formulated samples. The addition of soybean significantly ($p < 0.05$) improved the mineral content of the complementary food Table 3 compared with when only China rice was used Table 2. Sensory Scores of Complementary Food Formulations.

Ingredients					
Parameter	**Non-malted - non fermented rice (NMNFR$_c$)**	**Malted - non fermented rice (MNFR$_c$)**	**Non-malted fermented rice (NMFR$_c$)**	**Malted-fermented rice (MFR$_c$)**	**Soybean**
Proximate composition					
Protein (%)	8.65^{b}	8.30^{c}	9.45^{b}	8.70^{c}	$39{,}03^{a}$
Fat (%)	1.07^{b}	1.91^{f}	1.77^{g}	2.12^{e}	10.45^{a}
Ash (%)	0.92^{b}	0.78^{c}	0.85^{b}	0.79^{c}	3.97^{a}
Crude Fibre (%)	1.37^{bc}	1.13^{cd}	1.05^{cd}	0.93^{d}	5.80^{a}
Moisture (%)	8.31^{a}	8.53^{a}	3.92^{c}	4.15^{c}	4.00^{c}
Carbohydrate (%)	79.68^{c}	79.36^{c}	82.97^{b}	83.31^{ab}	33.78^{d}
Energy (Kcal/100 g)	362.94^{b}	367.83^{b}	385.60^{a}	387.12^{a}	388.80^{a}
Energy (KJ/100 g)	1541^{b}	1560^{b}	1636^{a}	1642^{a}	1649.74^{a}
Mineral content (mg/100 g)					
Iron	0.88^{b}	0.76^{b}	0.88^{b}	0.77^{b}	6.84^{a}
Zinc	0.53^{c}	9.41^{a}	0.53^{c}	0.47^{c}	4.10^{b}
Calcium	8.80^{b}	7.60^{bc}	8.27^{bc}	7.73^{bc}	58.92^{a}
Magnesium	9.68^{b}	8.36^{b}	9.46^{b}	8.51^{b}	48.62a
Potassium	40.04^{b}	34.58^{cd}	39.13^{b}	35.19^{cd}	264.31^{a}
Phosphorus	78.52^{b}	63.09^{d}	77.06^{b}	69.29^{cd}	519.88^{a}
Copper	0.13^{b}	0.12^{b}	0.13^{b}	0.12^{b}	0.32^{a}
Manganese	0.44^{a}	0.38^{bc}	0.43^{a}	0.39^{bc}	2.90^{d}

Table 2: Proximate composition and mineral content of China (Gawal R1) rice (malted, fermented, malted and fermented) and soybean[1].
[1]Each value is a means of quadruplicate determination.
[2]Mean values in a row for each category not sharing common superscript letters are significantly ($p < 0.05$) different

Proximate Composition/Mineral Content	Formulations[3]			
	VI (NMNFR$_C$S)	VII (MNFR$_C$S)	VIII (NMFR$_C$S)	IX (MFR$_C$S)
Proximate composition				
Protein (%)	16.00^a	15.99^a	16.02^a	16.00^a
Fat (%)	3.42^d	4.14^{ab}	3.77^c	4.21^a
Ash (%)	1.70^a	1.62^{ab}	1.43^b	1.60^{ab}
Crude fibre (%)	2.63^a	2.49^{ab}	2.27^c	2.24^c
Moisture (%)	7.32^b	7.45^b	3.97^{cd}	4.15^c
Carbohydrate (%)	68.94^g	68.57^g	72.58^e	71.75^f
Energy				
Kca/100 g	370.52^d	375.47^c	388.17^a	388.88^a
KJ/ 100 g	1570.44^d	1590.56c	1645.00^a	1647.48^a
Mineral (mg/100 g)				
Iron	2.46^a	2.54^a	2.33^a	2.38^a
Zinc	1.48^a	1.43^a	1.39^b	1.43^a
Calcium	21.56^a	21.27^a	20.20^a	20.84^a
Magnesium	20.05^a	19.43^a	18.90^a	19.10^a
Potassium	97.70^a	95.64^b	92.07^b	93.71^b
Phosphorus	183.29^a	179.50^b	174.64^c	177.22^b
Copper	0.18^a	0.17^a	0.17^a	0.17^a
Manganese	1.07^a	1.05^a	1.01^a	1.02^a

Table 3: Proximate composition and mineral content of complementary food formulations from blends of rice (malted, fermented, malted and fermented) and soybean[1,2]

[1]Each value is a mean of quadruplicate determinations.

[2]Mean values in a row not sharing common superscript letters are significantly ($p < 0.05$) different

[3]Formulations: VI (NMNFR$_C$S); Non-malted - non fermented China rice-based food product complemented with soybean, VII (MNFR$_C$S); Malted - non fermented China rice-based food product complemented with soybean, VIII (NMFR$_C$S); Non-malted fermented China rice-based food product complemented with soybean, IX (MFR$_C$S); Malted-fermented China rice-based food product complemented with soybean.

The sensory attributes of complementary food formulations from mixtures of non-malted, malted, fermented, and malted-fermented China rice (Gawal R1), and soybean flours are presented in Table 4. Germination of China rice did not affect the taste of the complementary food formulations, but fermentation, and the combination of fermentation and malting, did. The aroma, texture, and consistency of complementary food formulations from mixtures of malted and fermented China rice and soybeans did not differ significantly from those of the control. However, the combination of malting and fermentation significantly reduced these parameters ($p < 0.05$). However, colour was not affected by any of the processing methods of complementary food formulations. The overall acceptability of complementary food formulations has been affected by fermentation, and the combination of malting and fermentation of China rice.

Formulations[3]	Sensory Attributes[2]						
	Taste	Aroma	Colour	Texture	Consistency	Overall Acceptance	Total
VI (NMNFR$_C$S)	6.14^a	5.95^{ab}	6.29^a	6.05^a	6.00^a	6.52^a	36.95
VII (MNFR$_C$S)	6.43^a	6.62^a	6.76^a	6.10^a	6.29^a	6.67^a	38.87

VIII (NMFR$_C$S)	5.62^{b}	5.57^{ab}	6.29^{a}	5.76^{ab}	5.38^{ab}	5.52^{b}	34.14
IX (MFR$_C$S)	5.52^{b}	5.24^{e}	6.52^{a}	6.00^{a}	5.71^{ab}	5.62^{b}	34.61

Table 4: Sensory scores of complementary food formulations from blends of rice (malted, fermented, malted and fermented) and soybean[1]

[1]Each value is the mean of 21 times the determinations.

[2]Mean values in a column not sharing common superscript letters are significantly ($p < 0.05$) different

[3]Formulations: VI (NMNFR$_C$S); Non-malted - non fermented rice-based food product complemented with soybean, VII (MNFR$_C$S); Malted - non fermented rice-based food product complemented with soybean, VIII (NMFR$_C$S); Non-malted fermented rice-based food product complemented with soybean, IX(MFR$_C$S); Malted-fermented rice-based food product complemented with soybean.

Amino Acid Composition

The amino acid profile of the complementary food was affected by malting, solid-state fermentation, the combination of malting and solid-state fermentation, and the addition of soybean Table 5. Germination significantly ($p < 0.05$) reduced the essential amino acids (leucine, lysine, isoleucine, valine, tryptophan, methionine + cysteine, threonine and histidine) but did not affect phenylalanine + tyrosine. Similarly, fermentation alone reduced the levels of essential amino acids (leucine, lysine, isoleucine, phenylalanine + tyrosine, valine, tryptophan, methionine + cysteine, threonine, and histidine). The combination of germination and solid-state fermentation did not affect leucine, lysine, isoleucine, valine, tryptophan, methionine + cysteine, threonine, and histidine but reduced phenylalanine + tyrosine. Fortunately, most of the essential amino acids encountered in the study were within recommended values. Similar trends were observed for non-essential amino acids Table 5.

	Formulations				
Amino Acid	**VI (NMNFR$_C$S)**	**VII (MNFR$_C$S)**	**VIII (NMFR$_C$S)**	**IX (MFR$_C$S)**	***Recommendation (mg/100 g)**
Essential Amino Acid (mg/100 g)					
Leucine	7.69^{a}	6.49^{b}	6.09^{b}	7.42^{a}	7
Lysine	6.77^{a}	5.82^{b}	5.57^{c}	6.64^{a}	5.5
Isoleucine	3.93^{a}	3.22^{b}	3.03^{c}	3.74^{a}	4
Phenylalanine + Tyrosine	8.78^{a}	7.21^{ab}	6.67^{b}	5.26^{c}	6
Valine	4.45^{a}	3.72^{b}	3.52^{b}	4.22^{a}	5
Tryptophan	1.22^{a}	0.90^{bc}	0.81^{c}	1.00^{ab}	
Methionine + Cysteine	2.79^{a}	2.25^{b}	2.05^{c}	2.76^{a}	3.5
Threonine	3.56^{a}	2.89^{b}	2.73^{b}	3.40^{a}	4
Histidine	3.01^{a}	2.70^{b}	2.44^{c}	2.94^{a}	2.6
Total EAAs	42.2	35.2	29.39	37.38	37.5
Non-Essential Amino Acid (mg/100 g)					
Alanine	4.03^{a}	2.74^{b}	2.85^{b}	3.96^{a}	
Glutamic acid	16.59^{a}	13.33^{b}	13.87^{b}	16.38^{a}	
Glycine	3.42^{a}	2.42^{c}	2.82^{b}	3.29^{a}	
Serine	5.01^{a}	4.29^{b}	2.82^{c}	4.42^{b}	
Aspartic acid	11.05^{a}	9.75^{c}	9.88^{bc}	10.88^{a}	
Proline	3.87^{a}	3.36^{c}	2.85^{d}	3.66^{b}	
Arginine	7.06^{a}	6.02^{b}	5.61^{b}	6.98^{a}	
Total NEAAs	51.03	41.91	40.7	49.57	

Table 5: Amino acid composition of complementary food formulations from blends of rice (malted, fermented, malted and fermented) and soybean[1]

[1]Each value is a means of triplicate determination.
[2]Mean values in a row not sharing common superscript letters are significantly ($p < 0.05$) different
[3]Formulations: VI (NMNFR$_C$S); Non-malted - non fermented rice-based food product complemented with soybean, VII (MNFR$_C$S); Malted - non fermented rice-based food product complemented with soybean, VIII (NMFR$_C$S); Non-malted fermented rice-based food product complemented with soybean, IX (MFR$_C$S); Malted-fermented rice-based food product complemented with soybean, *FAO/WHO [29]

Amino acids are the basic unit of protein, which is needed for healthy growth, development and body maintenance [30,31]. Amino acids play a significant role in regulating multiple processes related to gene expression, including modulating the functions of proteins that mediate messenger RNA (mRNA) translation [31]. If amino acids are deficient, protein synthesis does not occur, protein deficiency diseases set in, and death may result [31]. In fact, without essential amino acids in our diets, there could have been no human or animal life.

In this study, it was observed that the amino acid composition of rice improved significantly upon the addition of soybean, compared with the amino acid composition of milled rice reported in the literature [32]. Studies by Asma, et al. [33] on development of weaning food from sorghum supplemented with legumes and oil seeds, and those of Ijarotimi and Keshinro [34] on formulation and nutritional quality of infant formula produced from germinated popcorn, Bambara groundnut and African locust bean flour as well as nutritive values of three potential complementary foods based on cereals and legumes blends investigated by Marian [35] showed low levels of amino acids compared to this study. Similarly, reports by Onabanjo, et al. [36] on complementary foods from cassava and soybean revealed lower levels of amino acids than in this study. Therefore, children consuming an appropriate combination of rice and soybean as complementary food would have a greater advantage than those consuming other alternatives of cereals and legumes combination.

Amino Acid Scores

Table 6 shows the amino scores for four weaning food formulations analysed in this study, based on the essential amino acid content and the pattern for children aged 1-2 years (% of the FAO/WHO UNU recommendation) as reported by Caire-Juvera, et al. [27].

	Formulations[2]			
Essential Amino Acid	**VI (NMNFR$_C$S)**	**VII (MNFR$_C$S)**	**VIII (NMFR$_C$S)**	**IX (MFR$_C$S)**
Leucine	109.86	92.71	87	106
Lysine	123.09	105.82	101.27	120.72
Isoleucine	98.25	80.5	75.75	93.5
Phenylalanine + Tyrosine	146.33	120.17	111.17	87.5
Valine	89	74.4	70.4	84.4
Methionine + Cysteine	79.71	64.29	58.57	78.86
Threonine	89	72.25	68.25	85
Histidine	115.77	103.85	93.85	113.08

Table 6: Amino acid scores (%) of complementary food formulations from blends of rice (malted, fermented, malted and fermented) and soybean[1]
[1]Each value is a mean of triplicate determinations.
[3]Formulations: VI (NMNFR$_C$S); Non-malted - non fermented rice-based food product complemented with soybean, VII (MNFR$_C$S); Malted - non fermented rice-based food product complemented with soybean, VIII (NMFR$_C$S); Non-malted fermented rice-based food product complemented with soybean, IX (MFR$_C$S); Malted-fermented rice-based food product complemented with soybean

A lower score for any of the essential amino acids designates the limiting quality of the amino acid, and it gives an indication of the percentage protein quality relative to the reference amino acid as described by Asma, et al. [33]. Asma, et al. [33] reported that leucine was the most limiting amino acid in most blends (58-75%), contrary to the current findings. Also, mostly lysine, threonine, valine and tryptophan are the limiting amino acids in their study. Marian [35] found that the most limiting amino acids were tryptophan, phenylalanine, and tyrosine. The current study is much better in amino acid scores. However, amino acids may be limited in some diets but may fulfil their functions in the body due to their nutritional bioavailability [37-40].

Conclusion

China rice paddy was malted, fermented, malted-fermented, and milled into flour. Complementary food formulations were produced by blending each flour with soybean flour. Proximate composition, mineral content, and acceptability of the complementary were influenced by malting, fermentation, and fermentation-malting of China rice.

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