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REVIEW

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Rice: a potential vehicle for micronutrient fortification

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Abstract

The choices of consumer towards food have been changed. Consumer prefers to eat food which is not only safe but also nutritious. Now a day, they like to eat the food which promote their health and help in minimizing nutrition related health hazards. Rice is a staple food in many countries, but most emerging issue is that rice is deficit in minerals. Rice ranks second among cereals in dietary uses around the world. Rice is deficit in iron (Fe) zinc (Zn) and these are important micronutrients for infants, men and women. Fortification of rice with iron and zinc would help to minimize nutrient deficient disorders among humans. Present study is aimed to introduce nutrients rich rice for consumers and also to encourage food-fortification organizations for diverting their focus on rice fortification. In south Asian countries, micronutrient deficiency especially Fe and Zn deficiency is very common. The rice because of its use as a staple food can be utilized as a carrier medium for transporting micronutrients from plants sources to human beings. Hence, rice fortification with microminerals can prove as a miracle for the virtual eradication of nutrition related diseases in humans.

Keywords: Rice fortification, Parboiling, Malnutrition, Health improvement, Fortification technologies, Milling problems

Introduction

Cereals are consumed all over the world and are rich source of vitamins. Majority of world population rely on cereals to fulfill their energy needs. Cereals are staple food for human consumption and are being processed in a spectrum of products that are of great economic importance. Among cereals wheat, rice and corn are important in terms of dietary uses [1]. Incidence of numerous age-related maladies such as diabetes, cancer and cardiovascular diseases can be prevented by the regular consumption of whole grains cereals coupled with sufficient physical activity [2].

Wheat is most common cereal available all over the world and has higher demand in whole world due to its health benefits. It is most sustainable cereal crop and is utilized in variety of food products. Wheat has been fortified with microminerals mainly with iron, especially in developing countries to overcome malnutrition [3]. Likewise, rice is consumed in large quantities all over the world and many countries are completely dependent on rice to fulfill caloric need of people. Rice is staple food for over half of the world population. Hence, both wheat and rice are deficient in essential minerals and consumed world widely. A lot of research work has been carried out on wheat fortification with micronutrients. So, it has become inevitable to boost up mineral content of rice in parallel to wheat [4].

Rice is one of the leading crops of world and is second only to wheat in term of production and food based uses. About 90% of world's rice is produced and consumed in

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Asia [5]. About 870 million people are estimated to suffer from chronic undernourishment globally, the vast majority of whom live in developing countries where rice is closely associated with food security. Rice production and consumption are among the highest in Asian populations. Therefore, rice is of special importance for nutrition of large reaches of population in Asia Pacific region and Africa [6]. A variety of food products are made from rice such as noodles, cakes, bread and other commercial and traditional foods nearly all over the world. It is a valuable source of nutraceutical and nutritional substances for human health. Due to higher consumption of rice in terms of different products a serious kind of health related issues has become visible on human health [7].

Due to its dietary uses, higher digestibility and commercial importance; rice is considered as queen of cereals. But, due to its limited mineral profile, the introduction of fortification techniques is an effective strategy to engage communities which are at higher level of health risks. There is a big need for joint effort on fortification program and dietary diversification to increase micronutrient share among staple foods [8]. Rice is a source of vitamins profoundly thiamine; but, thiamine is lost during processing and leads to beriberi in rice consumers. Rice has been found effective in a number of diseases i.e. hypertension and lowering of blood cholesterol level. On nutritional basis, rice is a rich source of carbohydrates, but moderate in protein and is good source of vitamins, namely thiamine, niacin and riboflavin [9]. Minerals play a key role in body regulatory and metabolic functions but during processing a tremendous loss of micronutrients occur leading to different medical complexities [10, 11].

Micronutrient deficiencies particularly for vitamins probe severe diseases and symptoms in human beings. These micronutrient oriented alterations leads to impairment in energy metabolism, cognitive functions, bone deformations and immune system related disorders. The most common vitamin oriented insufficiencies in different communities of world are for folate (in pregnant women), vitamin D, Vitamin C in children, adults and old age individuals [12].

Moreover, rice fortification would boost up overall health potential by optimizing micronutrient needs of end users. Among population, pregnant and lactating women, infants, young children and adolescent girls are tried to be targeted. An outstanding product's performance differing from other products made be available in market in future. Fortification of rice is an effectual strategy to tackle micronutrient imperfection. Fortification is considered as one of realistic, cost effective and result oriented approach. Fortification is an intentionally/deliberate addition of useful ingredients in limited amount with the aim to improve nutritional profile. This fortification program has been executed to address threat of mineral and vitamin insufficiencies in targeted areas [13, 14].

Rice is vehicle for fortification of micronutrients and holds its own position among cereals, as diet among Pakistani population. It is also second one after wheat in production and consumption in Pakistan. Its contribution to GDP of Pakistan is about 0.7%. In Pakistan, consumption of rice especially in urban communities is increasing day by day [15].

Worldwide food fortification scenario

By going in past but not more than two decades; every private organization, national authorities and international agencies were talking about food security to address shortage of food which was in prediction among coming years. They made great achievements in this regard and remain succeeded in their aims to prevent food shortage. To bring tremendous increase in production they move towards intensive agricultural practices which resulted in more production but leaving agricultural land exhausted in nutrients which leads to decrease in mineral content in food commodities. Talking about present scenario ample quantity of food is available but its nutritional quantity diminished alarmingly. So, in recent decade focus of private organization, national authorities and international agencies is to produce nutrient rich food. Same outcomes can be repeated as in past with strong commitment and collaboration with different agencies belonging to different school of thoughts [16, 17]. The impact of malnutrition is described in Fig. 1.

Food fortification & malnutrition

Numerous food items are being subjected to fortification namely cereals, vegetable oils, beverages and dairy products. Presently, 87 countries have made legislation to mandate fortification for every milling and processing industry. Main fortificants which are being focused are minerals and vitamins and they have gain great socioeconomic importance due to their immense benefits. Different kind of acceptable, feasible and economical strategies are used to increase mineral content of food. The term food fortification is the deliberate addition of micronutrient in food to increase nutritional stature of food to address nutritional deficiency disorders which occurs due to poor diet. It is most productive, effective and long term approach used to enhance micronutrient status of malnourished communities [18, 19]. The fortified food is economically feasible and is in ample access for poor people. Hence, fortification can alter their habits without altering their habits. Wheat, rice and maize are the most commonly used cereals and they are popular with respect to fortification significances among researchers

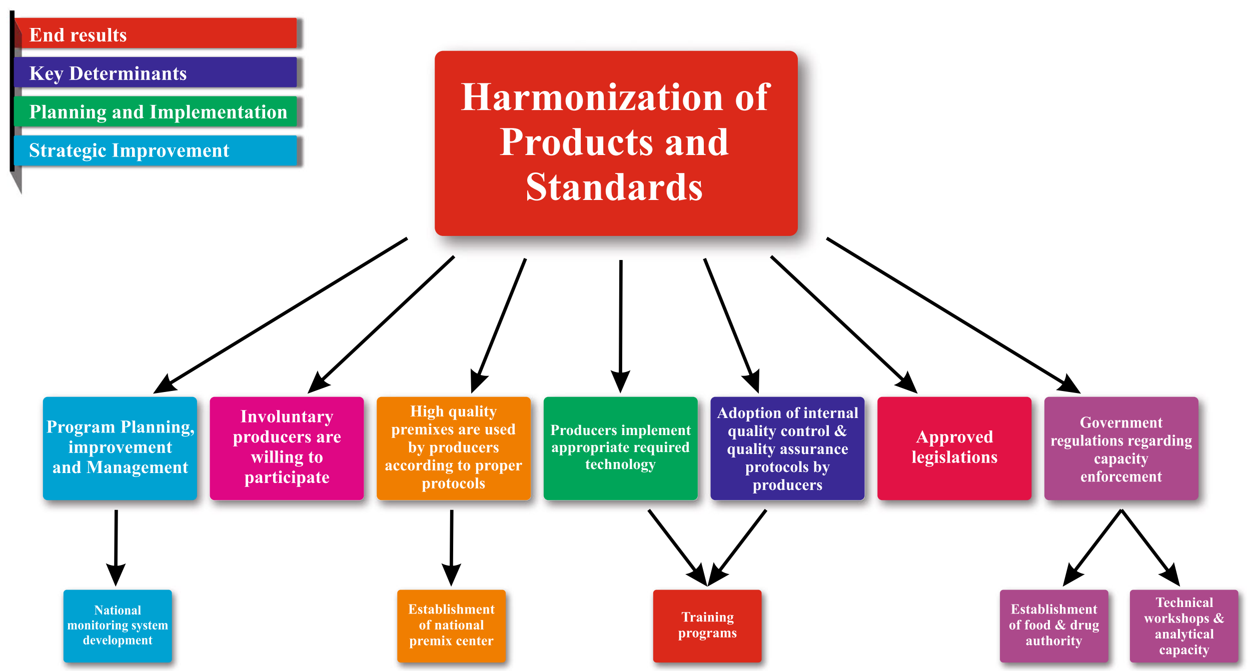

Fig. 1 Harmonization of Products and Standards for fortification

and stakeholders due to recognition, affordability and availability [20]. Fortification of food is a subset of food processing. According to Codex Alimentarius, food fortification is defined as addition of one or more essential nutrients in food whether these nutrients are present in food or not in the specific or targeted, voluntary and mandatory communities [21] Mass fortification or universal fortification refers to fortification of foods that are consumed by entire segments of the population e.g. fortification of rice or wheat flour. It is most preferred approach when majority of people is at highest risk for a scrupulous nutrient deficiency. Targeted fortification is for specific group of population. For example, infants have a severe kind of risk for becoming susceptible to nutrient deficiency diseases. So, when we are targeting infant then there is a need to set nutrient requirements keeping infant formulas in consideration [22, 23].

Mass fortification is usually denoted as voluntary fortification and is not mandated by government agencies for fortification of food but some private companies add nutrients voluntarily to facilitate nutrition e.g. breakfast cereals which are fortified in many countries. Governments make mandatory food fortification in certain areas which are of severe need for fortification program. In this type of fortification technique no concern is made that fortification targets infants, men and women. Mass fortification never requires any statistical support for verification whether fortification is needed or not [24].

Market-driven fortification is a third kind of fortification which is adopted by private organizations mainly industries keeping business point of view and only to maximize their profit by campaigning that we are adding minerals and vitamins etc. They also support their fortified foods by describing and advertising their benefits of usage. The only concern in this type of fortification is marketing but health concern is second one in this regard [25].

From technical point of view food fortification is quite feasible and simple for most foods. However, for gaining effective results it is not mandatory to hire trained and technical personnel for fortifying food. The only and only key for successful and consistent fortification program is that it must be centralized, cost effective and feasible. For a sustainable and long term fortification there should be an efficacious program. Public communities must be educated about fortification benefits [26].

Fortification as a technique has the potential to significantly improve nutritional value of large number of susceptible populations. The World Bank has published a report on food fortification program; that there is no substituent technology which provides such an ample opportunity to elevate nutritional status of consumers at a very low cost. Fortification is an ideal technique than other technologies because of its long term

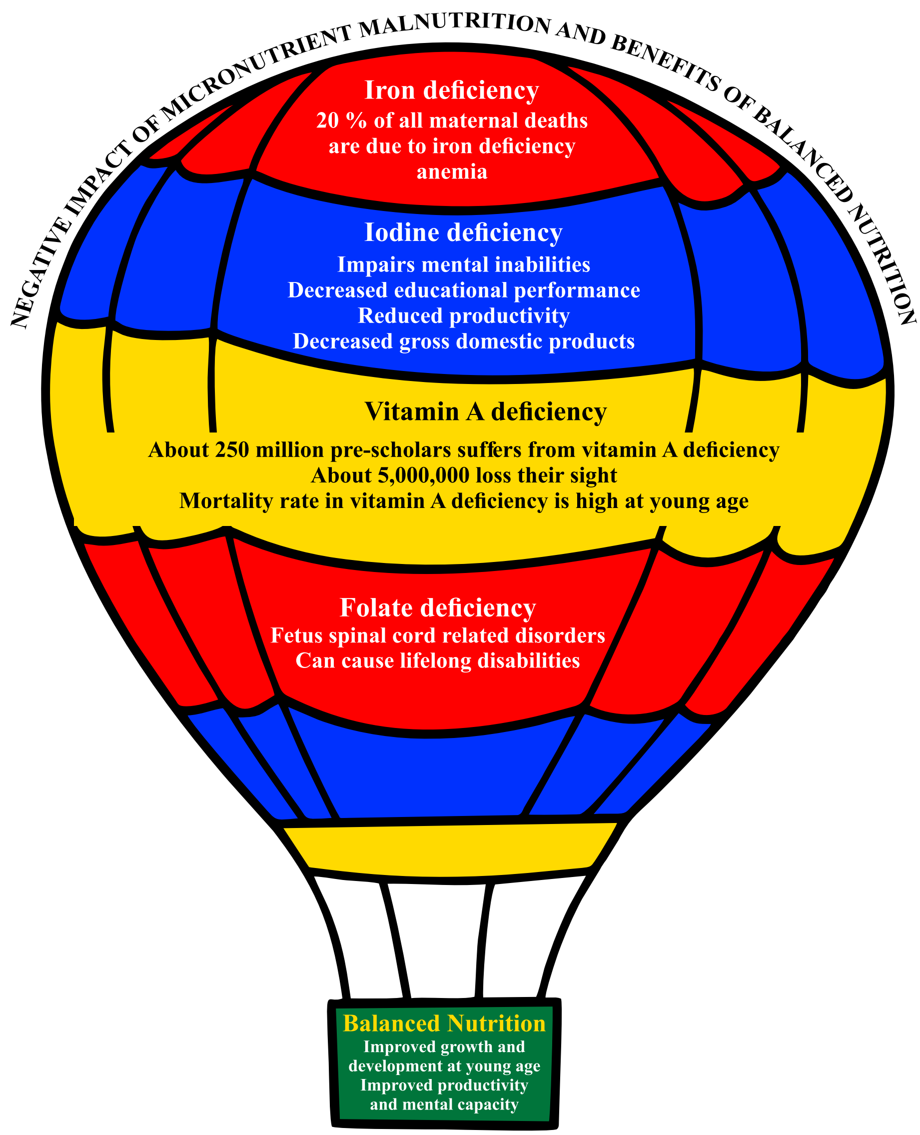

Fig. 2 Malnutrition Vs Balanced Nutrition

benefits, worldwide applications and acceptance among researchers [27].

Multiple-fortification is more effective tool in improving nutritional status than supplementation with single micronutrient. Fortification of rice with more than one micronutrient simultaneously is effective strategy for combating micronutrient deficiencies. Rice is a vehicle for fortification of micronutrients and holds great promise for alleviating micronutrient deficiencies in populations that consume rice based diets [28].

Numerous studies have been conducted to evaluate the fortify rice with mineral but sole and sole objective was to boost up rice's nutritional profile which is consumed in immense amount as a traditional food in many countries. For children micronutrients powder is being formulated which are single dose packets containing multiple minerals and vitamins. This micronutrient powder is sprinkled over semi-solid or solid food. Formulation of micronutrient powder is a big intervention in food fortification program for home usage but it has one drawback that it has some kind of acceptability issues i.e. taste preferences in some consumers. Micronutrient powder finds good results in infants ageing below two years because at this age infant have no taste likes and dislikes. So, there is a big need to nourish our future mentally and physically because in turn we can see prosperous future of our country [29]. The approaches for facilitating fortification programs are explained by following Fig. 2.

Methodology De-hulling of rice

The de-hulling and polishing are important operations in rice processing. The de-hulling and polishing extent, effect nutritional status of rice particularly on minerals (iron, phosphorus, zinc, magnesium and copper etc.) and distribution of nutrient within the kernel [30]. During milling, rice is subjected to high pressure and abrasion to remove brown layer of bran. Milling losses, during milling are approximately 5–10% [31]. Milling of brown rice is main cause of loss of nutrient and affect nutritional properties of rice's kernel. During milling process loss of magnesium, phosphorus and iron is observed [32]. The proportion of bran in rice is 6–7% by weight and amount of endosperm is about 2–3%. Commonly, white rice is named as milled rice and during production of white rice approximately 8–10% of weight losses occur [33]. Extent of milling leads to changes in nutrients, lipids, protein, physical, pasting properties and sensory qualities of rice. Rice is low in mineral and vitamin content and losses occur during milling process [34].

Milling of rice

Rice go through different stages and forms during processing. The normally found forms of rice are brown rice, rough rice, white rice and polished rice. Rough rice is composed of 20% hull which is removed during de-hulling. The proportion of bran and germ is about 10% and 70%, does starchy endosperm constitute the major part of rice's kernel. Brown rice is derived from paddy rice which is de-hulled to remove extraneous portion of hull. The layers of bran or germ remain intact on brown rice surface therefore; brown rice is more nutritious than white or polished rice. Rice can be grinded into flour which is used in different food products such as snacks, breakfast cereals and as a thickener for baby foods. Rice flour functional properties strongly influence process ability and quality attributes of end product. The extent/degree of milling strongly influences pasting properties of rice which are quantified by using Brabender Amylograph and a Rapid Visco Analyzer (RVA). The estimation of removal of bran during milling is denoted as degree of milling. Mostly, rice is consumed in milled or white form which is produced by removing husk and bran layers. Usually, rice protein and lipid content resides in bran portion; whereas, starch is located in endosperm [35, 36].

In Asia, it is assumed that consumption of brown rice is associated with poverty and in old age it was only consumed by sick and elderly people. Whereas, white rice is consumed in abundance with pride and honor of superiority but; in fact, white rice is very low in nutrition. White rice can be produced by removal of outer covering of hull and bran layer. Bran layer is rich source of vitamins and fiber content which is essential part of daily intake. Sometimes, white rice is blended with glucose and talc powder which is fatherly processed into rice flour to form different rice products [37].

During milling immense losses of minerals and vitamins are reported. Milled rice contains approximately 4–8 mg of iron per kg which is not sufficient to meet human body requirement. Unfortified rice consumed as a diet is not able to provide adequate amount of dietary iron. It is a challenge to develop effective and suitable method to reduce iron deficiency. Rice kernel is mostly consumed in intact form; so, proper techniques and methods are devised to solve fortification issues [38].

On the average, milling of 100 kg paddy rice yields approximately 60–65 kg white rice. Out of which 10% are broken grains, 10 kg is broken germ and bran and 20 kg is hull. Milling of paddy rice is highly desirable unit operation to impart organoleptic properties to rice but in turn a lot of nutritional losses are observed due to removal of bran. The concentrations of different vitamins which are residing in outer layer of rice kernel are 2–10 times higher than white rice. In some developed countries including United States America (USA) enrichment of white rice is being carried out with iron, thiamine, niacin and other minerals and vitamins to fulfill losses during milling process [39].

Rice fortification technologies

To fortify rice different technologies are being employed. Micronutrients addition in rice depends on type of fortification and strategies that are involved in fortification. The types of fortification technologies are parboiling, dusting and extrusion technology. These techniques are found effective in increasing mineral content of rice and are discussed below;

a) **Parboiling**

Parboiling process is a hydrothermal technique which involves three main steps; soaking steaming and drying. Approximately, 15% of milled rice is parboiled world widely. The leading countries of parboiled rice producer are Bangladesh, Sri Lanka, India, Thailand and West Asia. The contribution of these countries in production and consumption is about 90% of the total parboiled rice [40]. The prevalent cause of micronutrient deficiency is the limited use of variety of foods which is main concern for many individuals in developing countries [41].

Parboiling of paddy is most important postharvest process of rice which is normally used to maintain quality. A variety of factors are responsible for determining quality related attributes of parboiled rice. Prolonged parboiling itself is a leading cause of loss in essential constituents in paddy rice. Parboiling has good and advantageous effects on physiochemical properties of rice because it cause reduction in breakage during handling but remarkable increase in water absorption, cooking time and thiamine content has observed [42, 43].

Parboiling of rice is developed to improve quality characteristics for consumers because parboiled rice has superior aroma, texture and cooking qualities as compared to brown and white rice. To address essential micronutrient deficiency different techniques are introduced. Among fortification's techniques parboiling is prominent one which is being used at domestic and industrial level for a long time as a primitive technique. Fortification of rice during parboiling process is found suitable to contribute significant increase in iron content upto 140 mg/kg of dry weight [44].

Parboiling can be advantageous for improving milling, nutritional, organoleptic and quality characteristics of rice. Moreover, it also increases head rice yield and reduces nutritional losses during polishing process [45]. During soaking process contaminants associated with rice's kernel are removed. Parboiling prevents the development of undesirable flavor and yellow color during processing and storage [46]. The role of water in parboiling process is to soften the endosperm of rice's kernel and steaming cause gelatinization of rice's starch which is ultimate and leading cause of rice texture development. Parboiling not only facilitate easy milling but also results in beneficial increase in taste and aroma of rice which makes the parboiled rice more palatable to eat. But, parboiling has one limitation that mycotoxins may develop in paddy rice due to prolonged soaking [47].

b) **Dusting technology**

Dusting or coating is an important technique to preserve minerals which are lost during milling and washing operations. Suspension of nutrient is sprayed on rice's surface which sticks on outer layer of bran. But, before cooking excess washing results in loss of micronutrients. Another problem or disadvantage, which may arise are alterations in color and taste of dusted rice. However, some commercial premixes are available which claim that they are stable against washing and cooking conditions. Dusting technology has advantage because of lower investment as compared to extrusion technology [48]. In dusting technology tempering of rice is done for about 30–40 min at ambient temperature (20–25 °C). After this, sample is dried at 50 °C for 30–60 min. The fortificant is applied on rice surface by spraying fortificant solution. This process has been adopted in a few countries. This process has a limitation that dusted rice must be subjected to minimum washing before cooking [49].

iii) **Extrusion technology**

Extrusion is a versatile, feasible and very efficient technology in food processing. During extrusion process raw flour undergo many chemical and structural modifications, such as starch gelatinization, complex formation between lipids-amylose, protein denaturation and degradation reactions. The trend of extrusion cooking technology is increasing tremendously in the production of many food products such as breakfast cereals, flat breads, baby foods, meat snacks and modified starches. Minute variations in processing conditions can affect quality of end product. The factors affecting product quality are extruder type, feed moisture, screw configuration, temperature profile, screw feed rate and screw speed. The rice flour is being utilized as an attractive ingredient in extrusion industry because of its remarkable characteristics such as appealing white color, bland taste, hypoallergenicity and ease in digestion [50, 51].

In Extrusion Technology extruder is being used having hammer mill, single or double screw, mixer and drier at a temperature of (70–100 °C) which gradually increased to 100–140 °C. High pressure is applied as dough passes through the screw of extruder. Extrusion technology is a rather expensive technology as compared to parboiling and dusting because it involves few disadvantages as preparatory operations namely, milling, dough making and extrusion process. But, this loss can be compensated to some extent by utilizing broken rice's kernels which are damaged during threshing and other processing operations as they are available in market at considerable lower price. In short extrusion technology has some limitations like high cost of extruders which results, 15–20% increase in price of extruded rice [52]. The vitamins and minerals fortifications trends on worldwide basis are discussed below in Table 1.

Rice fortification

Micronutrient deficiency is caused by inadequate intake of minerals in diet and other factor which is necessary to describe is that; some food constituents act as inhibitors. These inhibitors bind minerals and make unavailable for human use. The examples of inhibitors are phytates, drugs and other chemicals that develop interactions with minerals and decrease their bioavailability [73].

Table 1 Cereals Fortification with Vitamins & Minerals

Sr. No.	Cereal	Fortification		Fortification Method	Country	Citation
		Mineral	Vitamin			
1	Rice	Iron, Zinc	Vit A, B1, B12	Hot Extrusion tech.	Bangladesh	[53]
					Nepal	[54]
2	Rice	–	Vit A, B9,	Parboiling (Soaking with limited water)	USA	[55]
3	Rice	Iron,Zinc	Vit A, B3, B6, B9, B12	–	Nepal	[56]
4	Rice	Zinc	–	Parboiling	Bangladesh	[57]
5	Rice	Iron	Vit B9, Beta-carotene	Parboiling	Sydney, Austrailia	[58]
6	Rice	Calcium, Iron	–	Parboiling (Soaking with limited water)	USA	[59]
7	Rice	Iron, Zinc	Vit A, B1, B3, B6, B12	Cold, Hot Extrusion	South Asia (Cambodia, Vietnam)	[60]
8	Rice	–	Vit B5	Sonication	Philippines	[61]
9	Rice	–	Vit B9	Ultrasonication	Philippines	[62]
10	Wheat Flour	Iron, Zinc	–	Fe and Zn Sulphate Fortificants	California, Davis	[63]
11	Wheat Flour	–	Vit B 9	–	Chile	[64]
12	Wheat Flour	Calcium, Iron, Zinc	–	Mixing with fortificant salts	Pakistan	[65]
13	Wheat Flour	Iron	–	Mixing with Fortificant salt	Northern China	[66]
14	Rice, Wheat	Iron	Vit A, B9	Forticant mix	India	[67]
15	Wheat Flour	Iron, Zinc	Vit B9, B12	Forticant mix	Yaoundé, Douala, Cameroon	[68]
16	Maize Flour	Iron	–	Iron Fortificant mixes.	Kenya	[69]
17	Maize flour	–	Vit A, B1, B2, B6	Vitamin Fortificants	South Africa	[70]
18	Wheat Flour	–	Vit B9	Vitamin fortificant	Australia	[71]
19	Wheat Flour	Iron	Vit A	Fortificants mix.	India	[72]

In south Asia, approximately 95.4% people are suffering from zinc deficiency. The existing food commodities require dietary modifications to alleviate Zn deficiency [74]. Zinc has a significant effect on immune system of human beings. In zinc deficient persons, resistant against pathogen is decreased and they are more prone to diseases. The persons who are susceptible to zinc deficiency show symptoms of impaired taste and smell, depressed immunity, frequent infections, dermatitis, diarrhea and mental disturbances [75, 76].

Fortification of iron results in considerable increase in iron concentration in rice. In experimental studies rice was fortified with 250–450 mg/kg of iron the optimum level of iron which suggested for fortification is 250 mg/kg. At this level of fortification rice possess maximum consumer acceptability, pre-cooking appearance, cooking quality and sensory attributes [77].

Zinc fortification during parboiling process results in considerable increase in zinc concentration in polished rice and its bioavailability increases. Zinc is required for different biological functions including DNA synthesis, cell division and gene expression. It is required for activity of many enzymes in biological systems [78]. Whole paddy rice is fortified with 50–400 mg/kg which resulted in 1.3–4.5 times increase in zinc concentration as compared to unfortified rice [79, 80]. The outcomes of minerals and vitamins deficiencies are explained in Table 2.

Cooking and textural properties of rice

Main factor influencing the liking and disliking of rice among consumers in many countries is rice's kernel shape, whiteness, flavor, aroma, amylose content, taste and other properties of cooked rice. The properties of rice's starch like gelatinization, gelling ability and amylose content strongly influence the eating habits and cooking characteristics of rice [115]. To assess cooking quality of rice an analysis can be performed to measure gelatinization temperature of rice's starch. Normally, gelatinization temperature of rice's starch ranges from 55-79^{o} C depending upon starch granule size, shape, structure and rice variety. There is existence of strong relationship between cooking attributes and amylose content of rice's starch. Environmental conditions can strongly influence the cooking quality and starch behavior of rice [116].

Cooking time and gelatinization temperature have positive correlation with each other. But, there is no evidence to support or describe relationship between gelatinization temperature and texture of cooked rice. Hence, gelatinization temperature and amylose content have negative correlation with each other i.e. when amylose content will increase then

Table 2 Mineral & Vitamin Deficiency Consequences

Sr. No	Micronutrient	Consequences	Citation
1	**Iron**	Iron deficiency anemia (IDA), fatigue, neuromuscular symptoms, mental illness, epithelial manifestations, and cardiopulmonary symptoms	[81] (Soliman, Amer, & Soliman, 2019)
		Anemia in hemodialysis patients	[82] (Motonishi, Tanaka, & Ozawa, 2018)
		Negative symptoms in schizophrenia patients	[83] (Kim et al., 2018)
		Anemia, Plummer Vinson syndrome, angular stomatitis, pica, glossitis and restless leg syndrome most commonly in pregnant females Cognitive impairment and behavioral problems in infants	[84] (Moll & Davis, 2017)
2	**Zinc**	Neuronal dysfunction, growth retardation, skin lesions (*Acrodermatitis enteropathica*, poor appetite, cell-mediated immune dysfunction and neurosensory disorder Autism Spectrum Disorders (ASD) Attention deficit hyperactivity disorder (ADHD) Mood Disorders, such as depression, anxiety and aggression, Schizophrenia (SCZ), and Spinocerebellar ataxia type 2 Hypogonadism in males	[85] (Hagmeyer, Haderspeck, & Grabrucker, 2015; Pfaender & Grabrucker, 2014; Prasad, 2013; Yasuda & Tsutsui, 2016)
		Impairment, sexual dysfunction, cutaneous lesions, inflammatory and gastrointestinal disorders	[86] (Maxfield & Crane, 2020b)
		Alopecia, diarrhea and impaired immune function in infants and children	[87, 88] (Ackland & Michalczyk, 2016; Kambe, Fukue, Ishida, & Miyazaki, 2015)
3	**Calcium**	Ca Paradox Disease that leads to muscular dystrophy, hypertension, diabetes mellitus, malignancy, arteriosclerosis and alzheimer's disease	[89] (Fujita & Palmieri, 2000)
4	**Vitamin D**	Rickets, osteoporosis and osteomalacia	[90] (Glorieux & Pettifor, 2014)
5	**Selenium**	Keshan disease, Keshin-Beck disease and myxedematous cretinism	[91] (Westermark, 2021)
		Epilepsy, multiminicore disease and cardiovascular disease (CVD)	[92] (Amankwah & Han, 2018)
		Immune system disorders, inflammatory disorders, impaired fertility, cardiovascular diseases, cancer and diabetes mellitus	[93] (Sarwar et al., 2020) [94] (Kieliszek, Bano, & Zare, 2021)
6	**Iodine**	Endemic goiter Mental manifestation, growth retardation and increased miscarriages during pregnancy Hypothyroidism	[95] (Cakmak et al., 2017 [96]; Tulyathan, Laokuldilok, & Jongkaewwattana, 2007)
7	**Vitamin A**	Night blindness (nyctalopia) Keratomalacia Impaired immune functions	[97] (Norsa et al., 2019) [98] (Godswill, Somtochukwu, Ikechukwu, & Kate, 2020)
		Lung dysfunction, pulmonary disease and respiratory diseases Increased risk of asthma and severe wheezing	[99] (Timoneda et al., 2018)
8	**Vitamin B1 (Thiamine)**	Beriberi (Korsakoff syndrome and Wernicke encephalopathy)	[100] (Wiley & Gupta, 2019)
9	**Vitamin B2 (Riboflavin)**	Normocytic anemia, Angular cheilitis Eye irritation and itching Increased eye sensitivity to light Watery eyes	[101] (Godswill et al., 2020)
10	**Vitamin B3 (niacin)**	Pellagra (4Ds: Dementia, Dermatitis, Diarrhea and Death)	[102] (López & Otero, 2021)
11	**Vitamin B5 (Pantothenic acid**	Its deficiency is very rare Apathy, fatigue and itchiness	[103] (Godswill et al., 2020)

Table 2 (continued)

Sr. No	Micronutrient	Consequences	Citation
12	**Vitamin B6**	Its deficiency is very rare Electroencephalographic abnormalities Impaired immune function and convulsive seizures Depression	[104] (Parra, Stahl, & Hellmann, 2018)
13	**Vitamin B7 (Biotin)**	Its deficiency is rare Detrimental effects on skin health and hair growth	[105] (Godswill et al., 2020)
14	**Vitamin B9 (Folate)**	Neural tube defects (NTDs) in infants	[106] (Moll & Davis, 2017)
15	**Vitamin B12 (Cobalamins)**	Megaloblastic anaemia Neuropsychiatric manifestations Ataxia, and cognitive decline Atrophic glossitis Infertility and persistent spontaneous abortions Pernicious anaemia	[107] (Moll & Davis, 2017; Xie et al., 2021)
16	**Vitamin C (Ascorbic Acid)**	Scurvy	[108] (Maxfield & Crane, 2020a)
17	**Vitamin D**	Rickets	[109, 110] (Allgrove & Shaw, 2015; Lin et al., 2020)
18	**Vitamin E**	Progressive neurologic disorder Spinocerebellar ataxia Heart muscle cardiomyopathy	[111, 112](Euch-Fayache, Bouhlal, Amouri, Feki, & Hentati, 2014; Traber, 2014)
19	**Vitamin K**	Fat malabsorption diseases (bleeding gums, nosebleeds, heavy menstrual bleeding in women, and sensitivity to bruising)	[113] (Haddadin et al., 2019)
		Chronic kidney disease (CKD)	[114] (Cozzolino et al., 2019)

gelatinization temperature would decreased and vice versa. Some rice varieties have low cooking time but high gelatinization temperature. There is no evidence to support that any single variety in which both gelatinization temperature and cooking time are high simultaneously [117].

In rice's starch, ratio of amylose and amylose content are very significant in influencing the eating and cooking properties of rice because amylose content is a main factor in determining cooking and eating quality of rice. Water absorption, volume expansion and elongation ratio are key factors for contributing rice cooking quality. Although, physiological properties of rice are greatly varies by amylose content. Different rice varieties are classified by scientist into three categories on the basis of amylose content [118].

The quantity of amylose in rice's starches fall in the range of 15–35%. After cooking of rice flakiness and stickiness appears which is due to high amylose content. The leading cause of rice becoming dry is high amylose content which results in hardening and becoming less tendering of cooked rice. Moderate amylose content is consider good for getting good quality attributes of cooked rice in the whole world [119].

The determining factors of cooking quality are amylose content, solubility of amylose and chain length of amylopectin molecule and gelatinization, melting temperature of amorphous and crystalline region of amylopectin molecules. In rice, protein thought to be influenced the stickiness and surface hardness. The rice with high protein content is much firmer than low protein content. The main protein in stored grain is oryzenin and other proteins includes; prolamins, globulins and albumins. Oryzenin is primarily made up of inter- and intra-molecular subunits which are linked by disulphide bridges. During storage content of oryzenin increases which inversely correlates the stickiness of rice [120].

Sensory properties of rice

Sensory evaluation is defined as "direct assessment of rice eating quality based on human five senses". After qualifying sensory evaluation test, rice sample attain approximately 75% acceptance and preferences among consumers. Sensory evaluation procedure is a scientific approach in which human senses like vision, smell, taste and touch are brought in utilization to assess sensory properties of food. Post-harvest handling has strong effect on sensory properties of cooked rice [121].

Good sensory properties are of great concern for consumer because it is consumed in bulk and is staple food over half of the world population. Nowadays, consumer marketplace and consumers are demanding rice of peculiar aroma and flavor for taste satisfaction and textural attributes. To fulfill consumer needs enough knowledge about similarities and differential about textural and flavor properties of rice is needed. Moreover, comprehension about these sources of similarities and differential is very important. Cooking attributes and sensory properties are affected by different aspects mainly by post-harvest conditions of paddy rice during drying and storage conditions [122].

Agronomic practices, environmental conditions and production conditions in field potentially influence flavor and textural properties of rice. Some cultivars's textural and flavor characteristics are stable against environmental alterations. To control variations in flavor and textural properties for producer and processor is tough job to do because they have to accumulate enough knowledge about genetics of rice cultivars and different post-harvesting factors which are affecting texture and flavor [123].

To assess acceptance among rice consumers fortified rice are compared with commercial rice. On comparison, it was found that there is no considerable difference between conventional unfortified rice and fortified rice. Non-definable difference was found in sensory and physical properties of fortified rice [124]. Extruded rice was compared with unfortified rice and conclusion was made that there is no difference between uncooked fortified and unfortified rice. Similarly, to find distinction between cooked fortified and unfortified rice is also difficult [125].

Post-harvest conditions are main contributing factor in determining sensory properties of rice. These post-harvest conditions includes; storage duration, moisture and temperature of rice. Sensory characteristics of cooked rice include; mass cohesiveness, surface roughness, grain hardness, stickiness, adhesion and chewability. Stickiness of rice's kernel decreases with increase in temperature during storage. Different kinds of instrumentations are being employed to determine the stickiness of rice [126].

Aroma is of great importance in eating quality of rice. During storage a peculiar kind of aroma is developed which is of great importance due to its acceptability among rice consumers. In different Asian countries aromatic rice is preferred and fetch higher price as compared to non-aromatic rice [127]. It is assumed that in some communities the rice without aroma is a liked food without salt [128].

Mostly, basmati varieties of rice in Pakistan are aromatic. These varieties have moderate amylose content, strong aroma long grains and moderate starch-gelatinization temperature. High temperature during storage strongly influences the aromatic flavor of rice inversely. Optimum moisture is a main contributing factor in determining consistency in aroma of rice. When rice is consumed at 12% moisture content possess good aromatic attributes as compared to moisture content either low or high than optimum moisture content [129].

Malnutrition consequences

On global basis, approximately two billions people are affected by micronutrient deficiency which leads to malnutrition. Malnutrition in human beings is caused by minerals and vitamins deficiencies which are usually known as "Hidden Hunger" because many people are affected by it, and does not show any physical symptoms. The lack of minerals and vitamins leads to anemia, blindness and other severe maladies. It is not necessary that hidden hunger is directly related to hunger but to nutritionally incorrect foods. Diseases which are caused by minerals deficiencies have no clinical symptoms but cause many people to live below their physical and mental health. Hidden hunger is caused by excessive eating of starchy foods such as rice, wheat flour and corn. Starch provides enough amount of calories but not able to provide sufficient amount of minerals. Hidden hunger is form of malnutrition which cause mental impairment and stunted growth in infants and children. This undermines adults' productivity and effect socio-economic progress of nation [130].

Micronutrient deficiency is caused by inadequate intake of minerals in diet and other factor which is necessary to describe is that; some food constituents act as inhibitors. These inhibitors bind minerals and make unavailable for human use. The examples of inhibitors are phytates, drugs and other chemicals that develop interactions with minerals and decrease their bioavailability [131].

The communities which cannot afford diversified diet and rely on rice as staple food then fortification is a cost-effective strategy to address micronutrient gap which is experienced by poorer socioeconomic group. Presently, food fortification program has garnered tremendous interest and arguing for a significant micronutrient-related interposing. Food fortification has been ranked 3rd among international developmental priorities with respect to need and significance [132].

Malnutrition is due to distinctively underfeeding; but, it is regrettable to say that it has still existence in developing countries. Major proportion of malnutrition is not directly related to extreme hunger or shortage of food. It can be caused by eating poor profiling foods which are already deficient in essential constituents. Unfortunately, mineral and vitamin deficiency have no clinical symptoms which leads to failure of diagnosis and ultimate adverse consequences. A malnutrition person lives its life below physical and mental potential [133].

The consequences of malnutrition are in the form of impaired growth of brain and physical inabilities in young children. It also induces fetus aberration; women death during pregnancy or shortly after birth and it severely affects productivity of adults. Children can easily fall victim to malnutrition causing stunted mental and physical growth which found a solid base for restarting of poverty. The root cause of malnutrition is quite simple. When daily meal plan is simply based on starchy foods such as rice, corn and wheat flour then expectations about sustainable nutrition are not true to ensure good health. The only and only, balanced diet can provide essential minerals and vitamins when variety of foods are consumed including vegetables, fruits, pulses, eggs, milk and possibly many foods of animal origin. People do not consume such kind of foods because of many reasons; cost, religious issues, regional traditions and ignorance etc. To tackle this kind of situation when a lot of factor conjoining at one spot then fortification is the sole way to approach these severe issues and malnutrition [31, 134].

Conclusion

In Pakistan an alarming kind of situation has developed in concern with micronutrients deficiencies which are leading to severe sort of metabolic and medical incompatibilities among nation. Rice does not provide enough micronutrients for optimal health. The authors suggest to help to minimize nutrient deficient disorders among humans by fortification of rice with iron and zinc, in rice-consuming countries like Pakistan that can seize the momentum and lead the way in building effective and sustainable rice fortification programs, by parboiling, dusting/coating and extrusion technologies. The evolution of cost-effective technologies, combined with supportive results on effective nutrient fortification levels, makes rice fortification safe, feasible, effective, and sustainable. Strong advocacy is needed further to drive the public-private partnerships and the government mandates that help to ensure long-term success of fortification program. Moreover, nutrition, health and general well-being should receive priority after rice fortification. The potential impact of improving micronutrient health in Asia, particularly in Pakistan would be a landmark. The time is right – there is a great momentum and need to move forward with rice fortification techniques for a growing number of national health organizations.

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