International Journal of Innovation Scientific Research and Review
Vol. 04, Issue, 07, pp.3065-3082, July 2022
Available online at http://www.journalijisr.com
SJIF Impact Factor 4.95

ISSN: 2582-6131

Research Article

WHITE, AND BROWN RICE- NUTRITIONAL VALUE AND HEALTH BENEFITS: ARSENIC TOXICITY IN RICE PLANTS

[1,] * Ravindra B. Malabadi, [2]Kiran P. Kolkar, [1]Raju K. Chalannavar

[1]Department of Applied Botany, Mangalore University, Mangalagangotri-574199, Mangalore, Karnataka State, India.
[2]Department of Botany, Karnatak Science College, Dharwad-580003, Karnataka State, India.
*E-mail: mlbd712@rediffmail.com

Received 17th May 2022; Accepted 18th June 2022; Published online 30th July 2022

ABSTRACT

This literature review paper highlights the dietary importance, arsenic toxicity, and nutritional value of brown, white, basmati and pigmented rice varieties. Rice is one of the most widely consumed cereals in the world rich in dietary fiber, bioactive compounds such as **Melatonin**, and **Gamma - amino-butyric acid (GABA)**. However, the edible brown rice is rarely consumed as the most human populations prefer the white polished rice for reasons connected to appearance, taste, palatability, ease of cooking, tradition, safety, and shorter shelf of brown rice which limits the market potential. **Rice** generally contains **more arsenic** than any other grains because of its **anaerobic** growing environment and unique physiology. **Brown rice** accumulates **more arsenic** than white rice because arsenic accumulates in the outer hard bran layer of the grain which is removed to make the **white rice**. Arsenic contamination is also reported in white rice. This also depends on the geographical location of the rice growing area. If the rice is grown in arsenic contaminated water with high arsenic levels, then brown rice accumulates **high arsenic** which is toxic to human health. Washing rice with water for 4 to 5 times before cooking could reduce arsenic levels in rice. **Pigmented varieties of rice** are considered valuable for their health benefits due to the presence of **Melatonin** but consumption is very less. India is the largest producer and exporter of basmati rice in the world. **Basmati rice** has a medicinal value and consumption is very high. Indian **Basmati** rice is a premium quality grain loved by people across the world. The chemical compound responsible for aroma in basmati rice is **2-acetyl-1-pyrroline** and hence unique among other aromatic long grained rice.

Keywords: Arsenic toxicity, basmati rice, bran layer, brown rice, cancer, pigmented rice, India, white rice.

INTRODUCTION

Rice (*Oryza sativa*) belongs to Poaceae or Gramineae is one of the most important cereal food crop and stable human food in most of the Asian countries (1-21, 23-102). Rice is the most widely consumed cereals in the world (1-21, 23-102). Rice is a staple food, and also a major contributor to dietary glycaemic load (1-54, 55-102). The major producers of rice are China, India, Indonesia, and Thailand (1-102). **India ranks second** in the production of rice in the world next to China accounting for 24.5% of overall world rice production (1-21, 23-102). India is one of the major centers for rice production particularly the aromatic royal Basmati rice (1-21, 165-176). **Basmati**, the unique aromatic quality rice is a natures gift to Indian sub-continent. India, the world's **second-largest** producer and biggest exporter of rice, harvested a record **of 121.46 million** metric tons of rice grains in 2020-21, up 2.2% from the previous year. With the likely record output during the year 2020-2021, the export prices of Indian rice may decline. So far the rise in exports of rice are primarily due to a fall in the average export prices of Indian rice. During 2020-21, India has exported 13.1 million metric tons of rice so far, as against **5.1 million metric tons** in 2019-20. Another good news is that India's food grains, consisting of rice, wheat, pulses and coarse cereals, has **recorded** a production of **316.06 million** tonne (mt) for the 2021-22 crop year (July-June). Historically, rice was cultivated widely in the river valleys of South and Southeast Asia 10,000 years ago and it is believed to have originated probably in India (2). Domestication of **rice in India** is mainly attributed to the Indus valley civilization 3000–1500 BC (2). However, the evidence of rice cultivation in India has been pushed to 4000 years ahead with the discovery of rice grains and early pottery found in the site of **Lahuradewa, Uttar Pradesh**, **India** situated in the middle Ganges plains dating to 6409 BC (2).

India is one of the major centre's for rice production and largest countries in terms of energy consumption from agriculture and rice comprises a major part of it (2, 3, 4). Rice is rich in genetic diversity, with thousands of varieties grown throughout the world (2, 3). At present, India is home to **6000 rice** varieties (2, 3, 4-102). Originally, India had more than **1,10,000 varieties** of rice until 1970, which were replaced by the high yielding semi dwarf cultivars during the Green revolution with its emphasis on monoculture and hybrid crops (2, 3, 4, 5, 6-102). **Rice grain** is a major source of carbohydrates, protein as well as other essential nutrients for billions of people worldwide, especially in developing countries (2-102). Paddy comes in many different colors, including **brown, red, purple** and **even black**. The colourful varieties of rice are considered valuable for their health benefits (1-21, 23-102). The unpolished rice with its bran has high nutrient content than milled or polished white rice. However, rice consumers prefer to consume polished white rice, despite the fact that brown rice contains valuable nutrient content (1-102).

Medicinal value of Rice

Ancient Asian civilizations have long been valued the importance of rice in sustaining human health and nutrition. India has a wealth of medicinal plants including rice, the most of which have been traditionally used in **Ayurveda**, and **Unani** systems of medicines by tribal healers for generations (1-21). Rice is a great

***Corresponding Author: Ravindra B. Malabadi,**
1Department of Applied Botany, Mangalore University, Mangalagangotri-574199, Mangalore, Karnataka State, India.

source of complex **melatonin, carbohydrates, minerals, vitamins** and **proteins** (1-102, 196-199). **Rice** is an excellent food included in a balanced diet. Rice has **no fat, no cholesterol** and is **sodium free** (1-21, 22-103). Rice mineral content, starch quality, **glycemic index**, and antioxidant activity has made rice unique among cereals (1-102). It has been found that in comparison with other sources (wheat, potato, and maize), rice starch is completely absorbed by the human body (1-21, 23-103). Rice can therefore, be described now as a functional food. Rice-based oral rehydration solutions (ORS) have been proved effective in decreasing stool output and improving intestinal absorption in acute diarrhea (1-21, 23-103). Rice extracts were found to decrease intestinal losses by actively inhibiting chloride channels (21). Rice is the **least allergic food** and is recommended for people affected with the **Irritable bowel syndrome** (22).

Colored rices (red, brown, yellow, green, purple and black) have been extensively studied and their anthocyanins or colored pigments, **melatonin** and flavonoids are associated with antioxidant properties (21, 196-199). However, white rice is preferred for reasons connected to appearance, taste, palatability, ease of cooking, tradition, safety, shelf-life, lack of awareness about its health benefits and availability (1-102). Glycemic index studies of rice reported the values ranging from 64 to 93 (1-28, 29-102). However, the most rice varieties are of **high glycemic index** (1-28, 29-102). Rice **starches** with a higher amount of amylose are more resistant to human digestion (1-28, 29-102). In addition to the amylose content of **paddy rice**, post-harvest processing such as milling, paraboiling, quick-cooking, home cooking and cooling processes can influence starch digestibility (1-28, 28-103). The amino acid profile of rice showed that it is high in **glutamic** and **aspartic acid** while **lysine** is the **limiting amino acid** (1-28, 29-102). A nutrition rich in brown rice may help in appetite control and weight loss due to higher fiber content compared to white rice. This also aids in the reduction of **LDL cholesterol** (1-28, 29-102).

PROCESSING OF RICE

Rice grain during processing steps such as drying, milling, and packaging after harvest to be convenient for consumption (1-21, 23-102). The harvested unprocessed rice is known as paddy rice and needs to undergo milling for human consumption (28). As a part of the processing, the protective hull is removed, leaving only the actual rice kernel which is called **as the** brown rice (1-28, 29-102). Paddy rice comes in many different colors, including brown, red, purple, green, yellow and even black (1-28, 29-102). The first step of the milling process removes the husk from the whole rice grain or paddy to obtain the whole brown rice grain that contains the outer **bran layer** with commonly brown color (1-21, 23-102). The second step removes the outer bran layer to obtain the polished or white rice (1-7). The bran layers consist of pericarp, aleurone, subaleurone layer, and germ, which contains large amounts of nutrients and bioactive compounds (1-21, 23-102). However, the removal of the outer bran layers during polishing or milling resulted in polished grain or flour with the lower content of nutrients and bioactive compounds (1-8). **Brown rice** is a wholegrain cereal, and is known to have beneficial effects on human health (1-28, 29-102). Recent epidemiological studies have shown that the consumption of whole grains can reduce the risk of metabolic disorders, cardiovascular diseases, and some types of **cancer** (1-28, 30-102).

Rice varieties

Rice is rich in genetic diversity with thousands of varieties grown in the world (1-102). There are different types of rice available worldwide which generally fall under the category of short, medium, and long grain size (28). Among the 40,000 varieties of rice cultivated worldwide, only two major species are cultivated widely—*Oryza sativa* or the Asian rice and *Oryza glaberrima* or the African rice (1-120). The cultivation of *Oryza sativa* is practised worldwide. However, the cultivation of the *Oryza glaberrima* is confined to Africa (2). *Oryza sativa* has two major subspecies: the Indica, long-grain rice and the Japonica, round-grain rice. Japonica rice is mainly cultivated and consumed in Australia, China, Taiwan, Korea, the European Union, Japan, Russia, Turkey and the USA (1-21, 23-102).

Indica rice varieties are grown widely in Asia (2). These varieties also comprise of the fragrant ones which are priced as premium. The principal fragrant varieties are Hom Mali from Thailand and the various types of Basmati exclusively grown on the Himalayan foothills of India (in the states of Haryana and Punjab, UP, Bihar) and Pakistan (in the state of Punjab) (2, 165-176). The Indian rice varieties cultivated widely are Basmati, Joha, Jyothi, Navara, Ponni, Pusa, Sona Masuri, Jaya, Kalajiri (aromatic), Boli, Palakkad Matta, etc. The coloured variety includes Himalayan red rice; Matta rice, Kattamodon, Kairali, Jyothy, Bhadra, Asha, Rakthashali of Kerala; Red Kavuni, Kaivara Samba, Mappillai Samba, Kuruvi Kar, Poongar of Tamil Nadu, etc (2).

Moreover, rice varieties can also be categorized as Indica, Japonica, glutinous, and aromatic (1-28, 29-102). Indian Basmati rice is very famous throughout the world (29-102, 165-176). Glutinous rice is common in Japan (1-28). It is a short-grain variety whereas most of the aromatic cultivars are long-grain rice (1-28, 29-102). Different cultures have different preferences regarding the taste, texture, color and stickiness of the rice varieties they consume, and many countries have signature rice recipes such as sushi, paella, risotto, and curry. Many other food products are made from rice such as noodles, sweets, cakes, cookies, snacks, and beverages (1-28, 30-102).

In USA, the wild rice (*Zizania* sp.*)* is an annual cross-pollinated species that grows natively in the northern part of the Mid-West region of the United States (Minnesota, Wisconsin, and Michigan primarily) (180-183). Next to the annual species (*Z. aquatica*, *Z. palustris*) perennial species (*Z. texana* (Texas wild rice), *Z. latifolia*) exist, the latter one being cultivated in Asia (180-183). Wild rice traditionally was the most important food eaten by Native Americans in the Great Lakes region where it grew (180-183). The grain of cultivated wild rice is somewhat similar to the grain of white rice (*Oryza sativa*), though it is longer and its color after processing is between black and brown. After harvesting, wild rice is dried, parched, winnowed, milled, and treaded (180-183).

Top 10 Largest Rice producing states in India

India is a leading exporter of rice in the world. India produces Basmati as well as other types of rice. India is the 2nd largest rice producer and the largest exporter of rice worldwide. Rice production in India is expanded from 53.6 million tons in FY 1980 to 121 million metric tons in FY 2020-21. This rice produce is then sent to different nations by leading exporters of food grains from India. The top 10 Indian states that grow rice are; **1) West Bengal**- Highest rice producing state in India. Close to half of its agricultural land is under rice cultivation. It is the largest rice producing state. **2**) **Uttar Pradesh**- Uttar Pradesh ranks on the 2nd position in the country and the largest producer of paddy in India. **3**) **Andhra Pradesh**- Ranking on the 3rd position and known as the Rice bowl of India. **4) Punjab** ranks on the 4th position and Basmati Rice is grown in Punjab. **5**) **Tamil Nadu**. **6**) **Bihar. 7**) **Chhattisgarh -** Chhattisgarh ranks on the 7th position and rice is widely cultivated (21). Biodiversity Unit, Department of Genetics and Plant Breeding, College of Agriculture, IGKV, Raipur is maintaining more than 23,000 rice germplasm accessions (21). The deep red colored and long-sized rice of Chhattisgarh and Jharkhand are reported to be more nutritious than the red, white, and coarse-grained rice (21). **8**) **Odisha. 9)**

Assam- Assam ranks on the 9th position and four main categories of rice cultivars grown in Assam are ***Sali*** rice (winter rice), ***Boro*** rice (summer rice), ***Bao*** rice (deepwater rice) and ***Ahu*** rice (autumn rice), having various traits like stickiness, color difference, waxy and non-waxy and specific aroma (47). **10) Karnataka-**At the 10th position, Karnataka produces around 39.55 lakh tons of rice. It has a yield of more than 2,700 kg/hectare and accounts for more than 3% share in India.

Brown rice: Phytochemistry

Generally, higher amounts of nutrients such as protein, fat, vitamins, and minerals were found in **brown rice** compared to those in white rice (1-21, 23-102). Brown rice also has lower glycemic index as compared to other grains including white rice. Brown rice is the best rice to consume due to uncountable benefits it provides. Brown rice is high in soluble fiber and less in calories (1-21, 23-102). Furthermore brown rice grain has shown a greater content of bioactive compounds such as **Melatonin**, phenolic acids, falvonoids, γ- oryzanol, **Gamma aminobutyric acid (GABA)**, α-tocopherol, and γ- tocotrienol (1-21, 23-102, 196-199). However, the total flavonoids content in brown rice ranged from 75.90 to 112.03 mg catechin equiv./100 g. Trans-ferulic acid was the predominant phenolic acid in brown rice (1-102). In addition, only α- and γ -tocopherols and -tocotrienols were detected in brown rice with α- tocopherol and γ -tocotrienol being the predominant (1-21, 23-102).

Ferulic acid, p-coumaric acid, and isoferulic acid were the main bound phenolic acids in the light rice samples. However, ferulic acid, p-coumaric acid, and vanillic acid were the main ones in the pigmented rice samples (1-21, 23-102). The higher content of phenolics and total flavonoids were found in brown rice than in white rice (1-21, 23-102). In addition, the content of phenolics varied depending on rice cultivar (1-21, 23-102). The content of bioactive compounds in brown rice is influenced by processing method and conditions (1-21, 23-102). The levels of ferulic, coumaric, syringic, and caffeic acids significantly increased after germination (1-1-21, 23-102). Furthermore, cooking of brown rice with a pre-soaking step significantly enhanced the levels of tocopherols, tocotrienols, and γ -oryzanol compared to un-soaked brown rice (1-1-21, 23-102). Therefore, **brown rice** based food products with high bioactive compounds content can be obtained by choosing appropriate processing methods such as soaking and germination (1-1-21, 23-102). Brown rice is also rich in phosphorous, magnesium, thiamin, selenium, manganese, niacin and vitamin B 6 (1-21, 23-102). This is because these nutritional components are highly concentrated in the outer bran layers of rice grain (1-21, 23-102). Brown rice is found to be healthiest and minerals rich food commodity (1-21, 23-102). Due to its appearance, color and texture it is rarely used. Brown rice has a meek nutty flavours and may become rancid more rapidly, but it is extreme more nutritious as compared to processed white rice (1-21, 23-102). Brown rice is the whole grain rice and is high in fiber contents (1-1-21, 23-102).

One **common trait** between white and brown rice is that they are both **gluten free** and contain **no trans fat or cholesterol** (1-21, 23-102). The primary phenolic compound found in brown rice is trans-ferulic acid, a hydroxycinnamic acid that exists in the bound form (11-21, 23-102). The second major phenolic acid found in brown rice is trans-p-coumaric acid which is a hydroxycinnamic acid derivative with its bound form making up about 98% (11-21, 23-102). Another component that is widely found is cis-ferulic acid, an isomer of trans-ferulic acid, which is found abundantly in the bound form (1-21, 23-102**). Magnesium** plays an important role in human body, as it works as a cofactor of more than 300 enzymes (1-21, 23-102). About 21% of the daily value of **magnesium** can be obtained by consuming a cup of brown rice (1-21, 23-102).

Plant lignans are one type of phytonutrient that is found widely in **brown rice**, which are then converted to mammalian lignan, called enterolactone (1-21, 23-102). Inositol hexaphosphate is a naturally-occurring molecule found in brown rice (1-21, 23-102). This compound has demonstrated anti-cancer properties (1-21, 23-102). Selenium is a trace mineral, which is found abundantly in brown rice (1-21, 23-102). The function of **selenium** is to induce DNA repair and combine in damaged cells to promote apoptosis, which is the self-destruction of the cells in the body to remove damaged and worn out cells (1-21, 23-102). **Selenium** also functions as a cofactor of glutathione peroxidase, which is an enzyme used in the liver to detoxify many possible harmful molecules (1-21, 23-102).

Ferulic acid and **p-coumaric** acid are found in the highest quantity in white rice, brown rice and germinated brown rice (1-21, 23-102). The high levels of phenolic compounds in germinated brown rice are due to the increase in the free forms with alkaline hydrolysis, and this is because of the dismantling of the cell wall during germination (11-21, 23-102). Flavones are the most common **flavonoids** found in brown rice, and tricin is the major flavonoid, accounting for more than 75% of the flavonoids in brown rice (1-21, 23-102).

Brown rice: Storage conditions

The uncooked white rice can be safely stored at ambient temperature for a long time if protected from insects and contaminants (1-1-21, 23-102). However, shelf life of the uncooked brown rice is shorter than that of polished white rice because **the oil** is highly concentrated in the **bran layers** (1-21, 23-102). The naturally occurring **lipase enzyme** in brown rice breaks down the oil in the bran layers and cause rancidity and off flavour (1-1-21, 23-102). Therefore, optimization or modification of storage conditions is important to maintain qualities of brown rice during storage (1-1-21, 23-102).

Brown rice: Nutritional value and health benefits

Brown rice may become white rice when the bran layer is exposed of in the milling process (1-21, 23-102). The brown rice or their derived extracts and fractions have shown several potential health benefits such as antioxidant, anti-diabetic, anticancer, neuroprotective, and cholesterol lowering effects (1-21, 23-102). **The oil present in brown rice is as good as it increases good cholesterol and lowers blood pressure and bad cholesterol** (1-21, 23-102). It is not commonly used in Indian households since many are ignorant of its health benefits, and secondly because it is costlier than white rice (1-21, 23-102). Due to the carbohydrate present in brown rice, the digestion of fibre is very slow leading to a controlled and slow release of sugar into the blood (1-21, 23-102). Carbohydrates, mainly starch, are the major component of both the whole brown rice grain and refined white rice (1-21, 23-102).

The brown rice was found to contain greater content of nutrients such as protein, lipids, minerals, and vitamins than that in the refined white rice (1-21, 23-102). Generally, cereal grains are a major source of the dietary carbohydrates (1-60). Starch is highly concentrated in the inner endosperm of rice kernel (1-21, 23-102). In addition, the brown grain is rich in dietary fiber compared to white rice and the dietary fiber is highly concentrated in the outer bran layer (1-21, 23-102). Therefore, eating of brown rice may be healthier than white rice especially for obese and diabetic people (1-21, 23-102).

Protein is the second major component of rice after starch. Rice protein composed of four protein fractions, including albumin (water-soluble), globulin (salt-soluble), glutelin (alkali-soluble), which represents the dominant protein in brown, and white rice and prolamin (alcohol-soluble), a minor protein in all rice milling fractions

(1-21, 23-102). Protein is highly concentrated in the outer bran layer of rice grain, which makes the protein concentration of brown rice higher than that of white milled rice (1-21, 23-102). Furthermore, rice flour is commonly incorporated into gluten-free cereal food products because of hypoallergenicity of its protein (1-21, 23-102). Therefore, replacing white rice with brown rice in the human diet is expected to provide more protein and amino acids, which is important for health and well-being (1-21, 23-102).

Lipids are the third major component of brown rice, next to carbohydrates and protein (1-21, 23-102). Fats or lipids are mainly concentrated in the outer bran layer of brown rice, up to 20% by mass (db). Therefore, the lipids content of brown rice is greater than that of milled rice (1-21, 23-102). On the other hand, brown rice is a rich source of unsaturated fatty acids such as oleic and linoleic acids (1-21, 23-102). Therefore, brown rice can be a good source of healthy fatty acids for people who utilize rice as a stable food in their daily diet (1-21, 23-102). The brown grain contains a greater content of minerals compared to white rice (1-21, 23-102). This is also because minerals are highly concentrated in the outer bran layer of rice, which is removed during milling (1-21, 23-102). Brown rice contains different vitamins such as vitamin B and vitamin E (1-21, 23-102). The concentrations of vitamins in brown rice is greater than that of white rice because vitamins are highly concentrated in the rice bran (1-21, 23-102). Therefore, the consumption of brown as stable food instead of white rice may help in the prevention **of malnutrition-related diseases**, which resulted from the deficiency of minerals or vitamins (1-21, 23-102). Brown rice and its derived fractions or extracts have shown **antioxidant activity** based on *in vitro* assays and *in vivo* trials (1-21, 23-102). The increase in antioxidant activity of brown rice could be attributed to germination enhances the content of bioactive compounds. However, the lower antioxidant activity of white rice compared to brown rice could be attributed to the removal of the outer bran layer during milling (1-21, 23-102).

The whole brown rice grain and or its processed products showed a potential **antidiabetic** activity based on *in vitro* assays or *in vivo* trials (1-21, 23-102). Brown rice or its processed products have showed **antiobesity and cholesterol lowering** effects (1-21, 23-102). Several studies have found that brown rice grain and its fractions have potential **anticancer and anti-inflammatory** effects (1-21, 23-102). Therefore, rice bran was suggested as an active rice fraction for the protection against colon 1,2-dimethylhydrazine early **carcinogenesis** and as a novel dietary supplement for **colon cancer prevention** (1-21, 23-102). Extracts derived from brown rice showed potential **neuroprotective** effects against **neurodegenerative diseases** (1-21, 23-102). Therefore, germinated brown rice and its processed products may help in prevention of **Alzheimer's and Parkinson's diseases** (1-21, 23-102). Therefore, the brown rice diet was suggested to be useful for the protection of **bone mass** and structure against **osteoporosis** (1-21, 23-102).

Germinated brown rice and or its processed products are convenient for gluten sensitive people (1-21, 23-102). Germinated brown rice has also showed other potential health benefits such as **uterine modulatory** and **antidepression** effects (1-21, 23-102). The enhancement of **sperm quality** may be attributed to the action of antioxidant substances in brown rice such as *γ* -oryzanol and *α*-tocopherol, or vitamin E (1-21, 23-102). Therefore, germinated brown rice was suggested for the treatment of depression without adverse effect on **male reproduction** (1-21, 23-102). Furthermore, a study with human subjects showed a **slower gastric emptying** rate for brown rice compared to white rice regardless of the variation in amylose content and *in vitro* starch digestion rates (1-21, 23-102). Therefore, the slower rate of gastric emptying for brown rice may indicate a lower glycemic index compared to that of white rice (1-21, 23-102).

The **lower digestibility** of brown rice compared to white rice may be attributed to the high resistant of the bran layer in brown rice to water penetration into rice kernels during digestion, which limit textural degradation and lead to lower mixing and mass transfer efficiency (1-21, 23-102). In addition, the high content of phenolic compounds such as phytic acid in the outer bran layer may contributes to the **decreased digestibility** of brown rice through partial inhibition of digestive enzymes such as pepsin and amylase, which play an important role in digestion of protein and starch (1-21, 23-102).

Brown rice noodles showed a higher **antioxidant activity** than that of white rice noodle, which can be attributed to the greater content of bioactive components such as phenolic compounds and dietary fiber of brown rice (1-21, 23-102). The germination of brown rice for 48 hr resulted in flour and bread with higher protein content, lipids content, and bioactive compounds (GABA and polyphenols) content, antioxidant activity, as well as reduced phytic acid content and glycemic index compared to other germination durations (1-21, 23-102). Other baked products such as biscuits, cake, and crackers were also developed from brown rice or blend of brown rice with other ingredients (1-21, 23-102). Biscuits prepared from wheat flour mixed with varying amounts of brown rice flour showed greater contents of ash, fat, and crude fiber compared with biscuits prepared from wheat flour only (1-21, 23-102). Therefore, different highly acceptable and healthy food types can be produced from brown rice by optimization of processing conditions (1-21, 23-102). The new rice varieties bio-fortified with nutrients such as iron, zinc, and beta-carotene have been produced, useful for improving deficiencies such as **anemia**, stunted growth, and **xerophthalmia** in some populations (1-21, 23-102). It is clear that benefits are maximum if rice is consumed in its wholegrain version as brown rice (1-21, 23-102).

TYPES OF BROWN RICE

Rough rice can be separated into husk and brown rice through a threshing process. The components in brown rice that was hulled from rough rice are **bran layers** (6–7%), an embryo (2–3%) and an endosperm (about 90%) (1-21, 23-102). Brown rice can be further separated into polished rice, commonly called white rice, which is obtained by removing the bran. Minor differences may exist in the degree of milling (1-21, 23-102). Brown rice has a nutty flavour, chewier than white rice, but more **easily goes rancid**, as well (1-21, 23-102). The difference between **brown rice and white rice** can be obtained through milling (1-29). White rice contains mainly the starchy endosperm (1-21, 23-102). The removal of rice bran leads to a loss of nutrients (1-21, 23-102). During milling, about 85% of the fat, 15% of protein, 75% of phosphorus, 90% of calcium and 70% of B vitamins (including B1, B2 and B3) are removed (1-21, 23-102).

There are **two types of brown rice**, which are germinated and non-germinated (1-21, 23-102). Germinated brown rice is obtained by immersing the brown rice grain in water to initiate germination (1-21, 23-102). The benefits of **germinated brown** rice are that the nutrients found in brown rice are more easily digested and the texture of brown rice is better (1-21, 23-102). Germination has been employed to improve the texture of cooked brown rice (1-21, 23-102). It also initiates numerous changes in the composition and chemical structure of the bioactive components. Germination could induce the formation of new bioactive compounds, such as **gamma-aminobutyric acid (GABA**) (1-21, 23-102). The consumption of germinated brown rice is increasing in many Asian countries because of its improved palatability quality and potential health-promoting functions (1-21, 23-102). Brown rice is a rich source of various bioactive compounds, such as -oryzanol, tocopherol, tocotrienol, amino acids, dietary fibres and minerals (1-21, 23-102). It is less consumed than white rice because its cooking is more difficult

than white rice due to its slow water absorption, and the **palatability quality** of brown rice is **inferior** to white rice (1-21, 23-102).

Limitations of Brown rice consumption

1. Within any one type of rice, **brown rice** contains **more arsenic** than white rice because arsenic accumulates in the bran, which is the hard outer layer of the grain seen in brown rice (103-160). Arsenic accumulates in the grain's outer layers, which are removed to make white rice (120-160). This also depends on the geographical location of rice growing area. If the rice is grown in arsenic contaminated water with high arsenic levels, then brown rice accumulates **high arsenic** which is toxic to human health (103-160). This is due to rice being the only major cereal crop grown under flooded conditions (103-160). **Arsenic contamination** in **groundwate**r is an issue that affects millions of people around the world.
2. Brown rice contains more **phosphorus** and **potassium** than white rice. People with kidney disease may need to limit these nutrients in their diet. This is because **kidney disease** makes the kidney less able to properly regulate the levels of these nutrients in the body. If potassium levels become too high, for example, it can lead to other health concerns such as **heart attack**. In this case, white rice may be better than brown rice (1-21, 23-102).
3. The lower consumer acceptability or preference of brown rice compared to the polished white rice. The brown rice **promoting consumer education programmes** have been completely failed in India. This is mainly due to the high customer demand for the white rice and not for brown rice.
4. The **lower acceptability** of brown rice can be attributed to its astringent taste and nutty flavour caused by phenolic compounds, volatiles, and dietary fibre, which are mainly concentrated in the outer bran layer. Also, the presence of the fiber-rich bran in brown rice gives it chewer texture and **darker color** than white rice.
5. Brown rice needs longer cooking time and the texture of the cooked brown rice is **harder** than that of the polished white rice.
6. Another important challenge for brown rice comes from the fact that the shelf-life of brown rice is shorter than white rice at ambient temperature because of the oxidation phenomena of lipids present in the germ and bran layers. The short **shelf-life** of the whole brown rice grain is mainly attributed to **oxidation during storage** because of the **high oil content** in the outer bran layer. The naturally occurring **lipase enzyme** in brown rice breaks down the oil in the bran layers and cause rancidity and off flavour. Efficient and cost-limited storage and packaging techniques to extend shelf-life and stability of wholegrain brown rice are also necessary.
7. The quality of brown rice during storage is also affected by other factors such as storage temperature, packaging type, rice variety, pre-treatments, and whether cooked or not. Therefore, efficient and low-cost processing and packaging techniques to extend shelf-life and stability of brown rice during storage are also needed.
8. The experimental studies evaluated the potential health benefits of brown rice based on *in vitro* assays or in animal models. However, it is well known fact that the results of the *in vitro,* in animal, and in human studies are not always consistent. Therefore, future research should focus on the evaluation of brown rice in human subjects to provide high-quality scientific evidence about its health benefits.
9. The lack of consumer knowledge about health benefits of the whole brown rice is a key challenge for its commercialization. Therefore, there is a need for strategies to improve the knowledge of consumers about the relationship between the consumption of brown rice and well-being to promote its utilization as food.
10. However, the edible brown rice, **is rarely consumed** as most populations prefer the white polished rice for reasons connected to appearance, taste, palatability, ease of cooking, tradition, safety, shelf life, and lack of awareness about its benefits and availability which **limits market potential**.
11. Cooking quality and sensory attributes of brown rice needs to be improved by applying innovative processing technologies. The chemical composition of brown rice is very relevant for human nutrition. Cultivation techniques and post-harvest processing should aim at reducing the contaminants in brown rice as much as possible. **Shorter shelf life of brown rice** should be extended by suitable processing and packaging techniques.

Pigmented varieties of rice

Rice is categorized into **seven color** classes based on bran color: white, green, black, yellow, red, brown, purple, light brown, speckled brown, variable purple (1-21, 23-102). Studies have shown that pigmented or darker colored cereal grains, such as red and purple, have higher amounts of some phytochemical compounds than non-pigmented varieties (1-21, 23-102). Paddy comes in many different colours, including brown, red, purple, yellow, green, white and even black (1-5). **Pigmented rice** has a variety of colored grains like yellow, green, brown, red, purple and black (5). Due to rich in antioxidant nutraceuticals, pigmented rice varieties have higher demand in the Indian market due to medicinal value of rice (1-5, 7-21). **Pigmented varieties of rice** are considered valuable for their health benefits and grown mainly in Indian states, Karnataka, Tamil Nadu, Kerala, West Bengal, Chattisgarh, Odisha, Maharashrta, Telangana, Jammu and Kashmir, Himachal Pradesh, Arunachal Pradesh, Manipur, Assam, and Jharkhand, India (5).

Furthermore, comprehensive evaluation of traditional rice collections (pigmented & non-pigmented) investigated mainly in South Asian countries like Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka and deposited in IRRI rice gene bank (5).

Exclusively **pigmented rice** are rich in polyphenols (250-1075 mg/100g) with having high free radical scavenging ability (69-93% by DPPH assay) (5). Most abundant phenolics in black/purple rice are **anthocyanins**; while **pro-anthocyanidins** are predominant in **red/brown** rice varieties (5). Pigmented rice varieties are rich in pigments which are majorly **antioxidants or functional bio-actives** (5). Other than bio-actives, **pigmented rice** is also reported to have higher contents of total dietary fiber, vitamin B compared to white rice (5). The major fatty acids of pigmented rice are **palmitic acid, oleic acid and linoleic acid** (5). Pigmented rice are rich in antioxidants like **anthocyanins, pro-anthocyanidins, tocopherols, carotenoids** etc, efficiently chelate the free radicals which are the hidden reasons behind life style disorders (5).

Over the decades, white grained rice varieties are preferred and the wild growing ancestors having coloured grain have been only grown and consumed due to its cultural and therapeutic significance (5). White rice makes a major contribution to the calorific intake of Asian and African populations, but its nutritional quality is poor compared to that of **pigmented** (black, purple, red orange, or brown) variants (5). The compounds responsible for these color variations are the **flavonoids anthocyanin** and **proanthocyanidin,** which are known to have nutritional value (162). The rapid progress made in the technologies underlying genome sequencing, the analysis of gene expression and the acquisition of global 'omics data, genetics of grain pigmentation has created novel opportunities for applying molecular breeding techniques to improve the nutritional value and productivity of **pigmented rice** (1-22, 162).

Supplementing with the **pigmented rice**/extracts significantly reduced the body weight gain, lipid accumulation in the liver and adipose tissue in animal models as well as in clinical trials (5). Recent work demonstrated that **pigmented rice bran** extracts are helpful in attenuating **inflammation** and **inflammation** induced **cancer progression** (5). **Red rice** was characterized by a high quantity of **oligomeric procyanidins** (0.2 mg/g) with more than 60% of total phytochemicals found in the rice seeds (5). **Procyanidins** are high molecular weight polymers or complex flavan-3-ol polymers that consist mainly of **catechin, epicatechin, gallocatechin,** and **epigallocatechin** units that can also be found in rice germ and bran (5). **Most** of the nutrients found in rice grain accumulated in the outer aleurone layer and embryo, the endosperm being composed of primarily starch (162). The process of de-hulling and milling discards the most micronutrients, fatty acids, anti-oxidants, and fiber. As a result, diets over-reliant on **white rice** risk deficiencies for several nutritional factors (162).

Black rice farmers are hugely benefitted with the market potential of crude and pure black rice powder which are used as **natural colorant** as well as for supplements (5). However, poor consumer preferences due to **palatability issues** (eating and cooking qualities) being a **major limitation**. Therefore, breeding/genetic engineering efforts are in the need to escalate the status of this wonder grain (5). Several **pigmented rice varieties** have been used to extract **nutraceuticals**, and these seem to hold a promise in terms of potential pharmaceutical utilization in the new global business era (5). But currently this is handicapped by the lack of efficient high throughput extraction methods, which have not been tackled (5). The unpolished rice with its bran has high nutrient content than milled or polished white rice (1-5). **Anthocyanins** are responsible for the black-purple pigmentation in rice grain. The **variation seen in pigmentation intensity** has been taken to imply that the trait is under polygenic control, involving as yet unidentified genes (1-5). **Anthocyanins** and **proanthocyanidins** are the two major classes of bioactive phenolic compounds that have been identified in cereal grains which are mainly present in the pericarp of pigmented varieties (28). The most abundant anthocyanins were identified as **cyanidin 3-glucoside** in **black** and **red ric**e (28). They are flavonoids and well recognized as **antioxidants** for their health-beneficial effects such as reduction in the risk of **obesity, diabetes, cardiovascular diseases,** and **certain types of cancer** (28). While several health benefits were shown to possess to consume **pigmented rice**, its texture and palatability is found to be poor and thus its **acceptance rate is lower**.

Detection of Melatonin in Rice

Melatonin is an indoleamine neurohormone (biogenic indoleamine) structurally related with tryptophan, serotonin, indole-3-acetic acid (IAA) (196-199). Melatonin regulates various aspects of plant physiological processes, including seed germination, shoot and root growth, flowering time and circadian rhythm, fruit ripening and flavouring, and others (196-199). It improves plant growth and development under multiple abiotic or biotic stress conditions (196-199). **Melatonin** was detected in various **rice products** composed of polished, whole grain, aromatic, black, black glutinous, red, and parboiled rice (196-199). All kinds of pigmented rice grains showed high levels of melatonin (>100 μg kg^{-1}), and the highest levels of **melatonin** were found in **red rice** (196-199). The consumption of food sources of melatonin is associated with health benefits, significantly increasing serum concentrations and raising the antioxidant capacity in humans, being therefore considered a nutraceutical (196-199). Melatonin has been detected in notable amounts for example in tomatoes, olives, barley, rice and walnuts (196-199).

Arsenic toxicity

Toxic metal exposure through diet is a public health concern (103-160). As a result, food safety is an issue that threatens human health and agricultural trade (103-154-160). **Arsenic** is a naturally occurring element that is present in air, soil, water, and food (120-160). **Arsenic** exists in many chemical forms and the forms fall broadly into two categories with public health relevance: **inorganic** and **organic** (103-177). Inorganic forms are considered as a primary **toxic form of arsenic** (103-160). Arsenic is a toxic element that is found in soil and water sources throughout the world (110-160). Arsenic can be found naturally in volcanic rock. Man-made sources include pesticides (132). The common organic arsenic species (predominantly, **Dimethylated Arsenic-**DMA) found in terrestrial ecosystems can also be toxic (136-137, 138-160).

Human activities, such as **burning of coal**, oil, gasoline, and **wood; mining**; and the use of arsenic compounds such as medicinals, herbicides, and wood preservatives [primarily chromated copper arsenate (CCA)] have contributed to the arsenic environmental burden (103-155). The highest levels of total arsenic in food are generally found in **fish**, crustaceans, and seaweed, where the arsenic occurs primarily in organic forms, such as **arsenobetaine** and **arsenocholine**, and **arsenosugars**, which have been considered to be of little toxicological concern (103-160). Arsenic also has been released into the environment through the use of **pesticides** and **poultry fertilizer** (**Chicken**s can be fed arsenic) (103-153). Therefore, arsenic is in soil and water (103-153). The primary forms of arsenic found in drinking water are forms of inorganic arsenic; **arsenite**, and **arsenate** (103-155). Naturally occurring arsenic-contaminated **groundwater** has severely affected people in Holocene sediment flood-plain regions of Southeast Asia, most notably the West Bengal state, India, Bangladesh, and in certain arid regions, such as Inner Mongolia, China, and the Atacama Desert (Chile), where people have been **chronically exposed** to the elevated arsenic in drinking water (137-138-160). The International Agency for Research on Cancer, Agency for Toxic Substances and Disease Registry, and the US Environmental Protection Agency (EPA) all classified inorganic **arsenic** as a **human carcinogen** (103-154-160).

US-**FDA's Total Diet Study (TDS**) measured total arsenic in a variety of foods. Excluding seafood, the highest mean levels of total arsenic among the foods analyzed for the Total Diet Study (TDS) are in rice grain and rice products (e.g., rice cereal) (103-160). Other potential sources of arsenic exposure include fruit juices, fruits, meats, vegetables, beer, wine, flour, corn, and wheat (103-153) as well as drinking water (137-160). In humans, inorganic arsenic is extensively **methylated**, and its metabolites are excreted **primarily in the urine** (103-160). Age, gender and smoking may contribute to the large individual variations in **arsenic methylation** in humans (137-160).

Arsenic Toxicity in Rice plants

One food known to be particularly **high in arsenic is rice**, a staple for much of the world's population (103-160, 184-195). **Rice** is particularly **an** efficient **scavenger of arsenic**, it takes up **ten times** as much as other cereal grains because it is the only grain traditionally grown in fields that are under water (103-154-160, 184-195). Rice grown throughout the world contains **arsenic**, particularly US-grown rice (103-160, 184-195). Rice tends to absorb arsenic more readily than many other plants (103-160, 184-195). Brown rice has **80 percent** more **inorganic arsenic** on average than white rice of the same type (103-160, 184-195). Though the amount and forms of arsenic found in different rice cultivars vary, the average levels of inorganic arsenic detected in **rice are high enough** to raise

questions about potential health impacts, including for children (103-160, 184-195). When rice is grown in an area with naturally **high levels of arsenic**, the problem becomes much worse (132, 103-154-160, 184-195). In various geographical region, arsenic has a similar chemical structure to phosphate and silicon, allowing it to sneak through the same pathways that plants use to absorb these important nutrients. Once inside, the arsenic becomes embedded in the **roots, shoots, leaves** and particularly important for human health the **seeds** (103-160, 184-195).

Rice generally contains **more arsenic** than any other grains because of its **anaerobic** growing environment and unique physiology (103-154-160, 184-195). In flooded rice paddies, arsenic is brought into the plant by its **silicon transporters**, and then used in place of silicon to strengthen the plant stem and husks, including the part of the plant that is consumed as food (103-156). **Flooding** makes soil conditions **anaerobic**, which causes arsenic to convert from bound and stable forms into more mobile ones (103-154). It accumulates most in the **husk**, the outer covering of the seed (bran layer) that is left intact in **brown rice** (103-153, 184-195). **Arsenic accumulates** in different parts of the **rice plant**, especially in the outer part of the grain, the **bran layer**. To make white rice, the outer bran layer of the rice grain are polished off, and with them goes some of the arsenic (103-160). Because, more of the fibrous outer bran layers of the grain are left in brown rice, the **brown varieties** tend to have **higher levels of arsenic** than **white rice** of the same type (103-160, 184-195). There is a wide variation in total inorganic arsenic concentrations across different types of rice and growing locations (103-160, 184-195).

In comparing across types and locations, inorganic arsenic concentrations appear to be lowest in sushi rice from the US and **basmati rice** from California, India, or Pakistan (103-153, 184-195). Brown basmati from California, India, or Pakistan is the best choice. **Basmati rice from India, Pakistan, or California, and sushi rice from the U.S. had the lowest levels of total inorganic arsenic compared with other types of rice** (103-160). Rice that is grown organically takes up arsenic the same way conventional rice does, so do not rely on organic to have less arsenic (103-160). Within any one type of rice, **brown rice** contains **more arsenic** than **white rice because arsenic accumulates in the bran**, which is the hard outer layer of the grain seen in **brown rice** (103-160). **Arsenic** accumulates in the grain's outer bran layers, which are removed to make white rice (120-160, 184-195). Brown has more nutrients, though, so it is better not to switch entirely to white. Removal of this bran layer produces white rice, thereby eliminating a portion of the arsenic (103-160). However, the bran also contains nutritious fiber and vitamins, so even though brown rice on average contains more inorganic arsenic, brown rice also provides more nutrition (103-160, 184-195).

Basmati rice is always the best choice, because it appears to have the **lowest levels of inorganic arsenic**, but the averages are for all origins combined, and depending on where that rice comes from, it can have very different levels (103-160). The same technique could also help the rice companies elsewhere to lower arsenic levels in baby cereals and other products that use pre-cooked rice (103-158). Rice-based baby foods often contain high levels of arsenic, a double-whammy for small children, who consume proportionately more of the substance for their body size (103-160, 184-195). Also in this analysis, brown rice of a particular type always had **higher levels of inorganic arsenic** than white rice of the same type (140-160, 184-195).

Rice is known to accumulate more metals and a much **higher arsenic concentration** than other such as wheat and barley cereals (103-153, 184-195). As a staple food, particularly in the Asian populations, rice could be a major source of toxic metals intake (103-160). **Toxic metals** are both naturally occurring and/or introduced through anthropogenic activities into soils where the crops are grown (103-153, 184-195). The metals are absorbed and accumulated in the edible plant parts and enters the food chain (103-153). Plants vary considerably in their ability to take up and **accumulate arsenic** (103-153). Compared with other cereals, such as wheat and barley, **rice has much higher levels of arsenic** (103-153, 184-195). The **elevated arsenic** is due to **rice** being the only major cereal crop grown under **flooded conditions**, leading to high arsenic availability and high concentrations close to the root (137-138). **Arsenic** is taken up by plants through pathways for nutrients (106-160). This has resulted into a high arsenic availability by causing the reduction of immobile arsenate in non-flooded soils to the more mobile arsenite (103-153, 184-195). This leads to both arsenate and arsenite building up in high concentrations close to the root. Both arsenate and arsenite are **analogs** of the plant micronutrients phosphate and silicic acid, and plants have evolved efficient mechanisms of capturing them from soil solution (137-138, 184-195).

How to remove arsenic toxicity in Rice plants

Some rice strains accumulate 20-fold less arsenic than others. This suggests that certain varieties may have developed a way of **blocking** its uptake, offering hope that plant **breeding** could give the same powers to other strains (103-153). Pinson and her colleagues studied more than 1,700 strains of rice from around the world (103-154-160). They found that some varieties from the United States contained significantly **less arsenic** than other rice varieties grown using the same soil and water (103-154). Even more revealing, when they **crossed** some of these low-arsenic strains with high-arsenic varieties, exactly one fourth of the second-generation plants that had **low arsenic** accumulation (103-154-160). Following the logic of simple **Mendelian genetics**, **these** findings suggested that a **single gene** is involved in the **trait** (103-160). However, the researchers have yet to figure out what gene it is, how it works, or even which of the plant's 12 chromosomes it can be found on (120-159).

Other studies in Spain and the United States have flagged several genes and regions that may be involved in **arsenic accumulation**. Another way to prevent arsenic from accumulating in rice is to **block** its pathway from the **roots to the grains** (103-154-160). The way rice is grown and processed offers other opportunities for intervention. It is also possible to cultivate the grain in dry soils that are moistened only by rain. This method, known as **upland rice cultivation**, reduces the arsenic load by a factor of 30 compared with **traditional flooded** rice paddies (103-160). Milling removing the husk and turning brown rice into white also removes much of the arsenic, which accumulates in the outermost bran layers of the grain. As a result, **brown rice contains 10- to 20-fold more arsenic** than white, but it also contains many beneficial nutrients such as fiber and niacin. Perhaps the easiest solutions of all lie in the kitchen. Instead of using equal parts water and rice when cooking, using **three times** more **water** than grain, and rinsing before and after cooking, can reduce the amount of arsenic by up to 30% (103-132, 133-154).

WHO Guidelines for Arsenic in Rice

In July 2014, the World Health Organization (WHO) set worldwide **guidelines** for what it considers to be safe levels of arsenic in rice, suggesting a maximum of 200 micrograms per kilogram for white rice and 400 μg kg^{-1} for brown rice (103-154-160, 184-195). The situation is especially dire in Bangladesh, where rice is the national staple food and the water is naturally high in arsenic. Here as many as **100 million** people suffered from acute **arsenic poisoning** from multiple sources (103-160). The problem of contaminated rice is not limited to Asia. A 2012 study by the US-

based advocacy group **Consumers Union** also found worrying levels of **arsenic in rice** sold in the United States (103-153). Some samples contained arsenic at more than twice the safe limit recommended by the WHO (103-160, 184-195). The group suggested eating no more than two or three servings of rice each week (140-160). But eating less rice is not an option in many parts of the world where the food is an irreplaceable part of the culture, diet and lifestyle (103-160). A variety of metals can accumulate in rice, including **cadmium, lead and mercury** (103-161). But arsenic (strictly a metalloid, not a metal) is the **biggest problem**, partly because it naturally occurs worldwide in soil and water (103-154). It is especially common in the rocks of the Himalayas, from where the Ganges and other great rivers carry it to the heavily populated plains of south and southeast Asia (103-154). Most of the world's arsenic is locked up in mineral compounds underground, but mining and coal burning have released many tonnes into the environment (103-154-160).

US-Consumer Reports: Arsenic Toxicity in Rice

About 85% of rice in the US is locally produced while the rest is imported from Asia, including India, China, Thailand, and Pakistan (103-154). Rice in the US is mainly produced in the southern states (Arkansas, Louisiana, Mississippi, Missouri, and Texas), which accounts for 80% of the production while California state produces 20% (103-154-160). Short and medium grain rice types are mainly grown in California for domestic and export purposes whereas the southern states primarily produce the long grain rice (103-154-160). **Arsenic** concentrations in rice from the US is found to be higher than other countries (103-153). Studies have shown that arsenic concentrations in rice differ by state within the US, suggesting varying metal contamination in the environments; for example, rice produced in Texas and Arkansas contained more arsenic than rice grown in California (103-160). In general, limited sampling indicated that rice grown in the South Central US (Arkansas, Missouri, Louisiana, and Texas) contains more arsenic than rice grown in California (103-178). In general rice labeled from the U.S. or from Arkansas, Louisiana, or Texas tended to have the highest levels of total inorganic arsenic compared with rice from elsewhere (103--178).

According to the **Consumer Reports**, the American non-profit **organization**, which came out with an extensive report on the arsenic content in different rice varieties in **2012**, reveals that rice varieties which have their **husk removed** and polished **white rice** might have **lesser** arsenic content. It also revealed that **basmati rice** from India and sushi rice grown in the US have the **lowest inorganic arsenic content**, while arsenic in brown rice, brown basmati rice and **black rice** (or forbidden rice) is much higher. However, a **2017** study insists that basmati rice grown in northwest parts of India have higher arsenic content and should be screened before consumption. Therefore, cook a cup of rice in **six cups of water** until done, and **drain out the excess water**. This method, popular in eastern parts of India, is effective in removing all toxic substances from rice and remember the 1**:6 ratio** (103-160).

Arsenic Toxicity in Rice: Effect on Human Health

Exposure to low and high levels of arsenic (As), lead (Pb), and cadmium (Cd) can cause **cancerous** and **non-cancerous effects** (103-153-160). According to The U.S. Food and Drug Administration's Center for Food Safety and Applied Nutrition (FDA-CFSAN) conducted a quantitative risk assessment which examined the **lung cancer** and **bladder cancer**, and provided the best evidence of low-dose cancer effects (103-153-160). **Arsenic toxicity** has been attributed to **skin, lung, kidney,** and **bladder cancers**. Cadmium and Pb toxicity have been linked to lung, prostate, and **kidney cancers** (103-160). Human exposure to these toxic metals can occur through occupation, air pollution, or diet. Dietary exposure is the most common route through which these toxic metals enter the human body (103-153-160). **Arsenic contamination** in **groundwate**r is an issue that affects millions of people around the world. Naturally occurring high concentrations of arsenic in **groundwater** are particularly problematic in regions such as the Ganges Delta, causing serious arsenic poisoning to large populations. Not only limited to drinking-water supplies, the accumulation of arsenic favours the **flooded cultivation practice of rice fields**, thus causing absorption in rice grains farmed for human consumption (103-160). While rice is estimated to contain 10-20 times more arsenic than other cereal crops, food safety assessments in India – currently the world's largest exporter of rice, must be routinely performed to ensure that rice products are non-toxic for human consumption (103-160).

Exposure to **elevated arsenic** in drinking water, for an intermediate period of time (e.g., weeks to months), can result in **gastrointestinal effects**, such as **abdominal pain**, **vomiting, diarrhea,** and **muscular cramping; hematological effects,** such as **anemia** and **leucopenia; peripheral neuropathy,** such as **numbness, burning, or tingling sensations or pain** in the extremities. **Metallic taste, garlic odours in breath and feces**, and salivation may also be present (137-138-160). The main adverse effects reported to be associated with long-term ingestion of inorganic arsenic in humans are **cancer, skin lesions, cardiovascular disease, neuro developmental toxicity, adverse pregnancy outcomes, non-malignant lung disease,** and **diabetes** (103-160). Of these, the greatest strength of evidence for a causal association is for **cancers of the skin, bladder, and lung, for skin lesions, and for ischemic heart disease** (137-138, 140-160). Therefore, people who frequently ate rice with relatively high levels of arsenic were more likely to have cells in their bladders that had damage to chromosomes that could be associated with **cancer** (103-160).

According to the US-FDA report, for brown-rice varieties, the highest predicted lifetime cancer risk is also for **parboiled rice** (103-160). However, there is significant uncertainty in these risk estimates, because they are based on a very small sample size of inorganic arsenic concentrations (103-153). In general, **risk estimates are higher for brown rice** than for white rice, due to the higher levels of **inorganic arsenic in brown-rice** varieties, relative to white-rice varieties (137-138). The levels of inorganic arsenic in rice and rice products ranged from <1 to 545 ppb, and the average for rice grain ranged from 59 ppb (instant) to 160 ppb (brown rice) (103-153).

For white-rice varieties, predicted **cancer risk is the highest for parboiled rice**, at 149 cases per million for a lifetime of daily consumption (up to 50 years old) and 36 cases per million for exposure only during childhood (up through 6 years old) (103-160). These risk estimates can be attributed to the higher average concentrations of inorganic arsenic in parboiled rice, which is most similar to brown rice (103-160). The predicted lifetime cancer risks for long-grain white rice, which has the largest market share (37%), is 136 cases per million for lifetime exposure and 33 cases per million for children (137-138).

Consumption of rice and rice products can be a significant exposure pathway to inorganic arsenic which is a group **1 carcinogen** to humans (103-160). Because of the way rice is grown, it can harbour arsenic, which is a threat to human health (120). The **UK follows** the current European Commission regulations so that inorganic arsenic concentrations must be < 0.20 mg kg^{-1} in white (polished) rice and<0.25 mg kg^{-1} in brown (unpolished) rice (120). However, inorganic arsenic concentration in rice used for infant food production or direct consumption has been set at a maximum of 0.1 mg kg^{-1} (120). Studies have linked chronic arsenic exposure with **cancers of the bladder, lungs, skin and prostate, as well as heart disease** (103-160). In the short term, it can cause gastrointestinal

problems, muscle cramping and lesions on the hands and feet (130-160). The risk of arsenic poisoning is greatest for people who eat rice several times a day, and for infants, whose first solid meals are often rice-based baby food (103-160).

In this context, a study was conducted and evaluated the inorganic arsenic concentrations in different types of rice sold in the UK **and** quantified the health risks to the **UK population** (120). According to this study, arsenic concentrations in 55 rice types marketed in the UK in which this study compared cultivation methods (organic or non-organically grown) and various types of rice (wild, white/polished and brown/unpolished) (120). The total arsenic concentrations in organic white rice were significantly lower than non-organic types, whereas the opposite was true for brown rice (120). However, inorganic arsenic concentration of organically grown rice was significantly higher than non-organically produced rice (120). The order of accumulation of arsenic in different rice types was brown > wild > white (120). **Out of 55 rice types** studied, **28 exceeded infant total arsenic maximum** limit stipulated by the European Commission as unsuitable for the production of baby food products or direct feeding (120). This study also showed that health risks due to rice arsenic consumption are confined mainly to infants in the UK (120). Therefore, this study recommended that consumers could be better informed whether rice and rice products are suitable for infants and young children up to 5 years in the product description labels (120).

Rice Cooking methods to lower arsenic levels

Consumer practices reported that rinsing and altering water cooking volume for rice, can affect the level of inorganic arsenic ingested (150-160). Several studies reported that the **total arsenic content of cooked rice** is strongly dependent on the cooking protocol and the concentration of arsenic in the water is used to prepare the rice (103-160). The available literature provides preliminary estimation that range from 28% to 60% reduction of total inorganic arsenic from rinsing and cooking practices in water containing low arsenic levels (< 3 µg/L) (104-160). However, there is substantial uncertainty in these estimates. Therefore, new research is underway to evaluate not only changes in total inorganic arsenic levels in rice, but also the impact on nutritional content (103-160).

The US- FDA study measured the effects of rinsing rice and cooking rice in variable amounts of water on inorganic arsenic and nutrients in the cooked grain (103-160). **Rinsing rice before cooking** had a minimal effect on the inorganic arsenic content of the cooked grain but also removed enriched iron, folate, thiamin and niacin (104-160). Cooking rice in excess water reduced average inorganic arsenic by 40 to 60% depending on the type of rice and also reduced iron, folate, thiamin and niacin by 50 to 70% in enriched rice (103-160).

Sengupta *et al.* (157) reported that 57% of the **total arsenic** was removed from rice native to India (Boro and Aman rice) that contained 203 – 540 µg/kg total arsenic by using a method of multiple washes (five to six times) until the water is clear, then boiling in a 6:1 water:rice ratio (157). Levels of inorganic arsenic were not provided. About half of the arsenic was lost in the wash water and half in the **discarded** water (157). A second method, which includes the same rinsing step, although the rice is boiled in water in a 1.5–2:1 ratio of water:rice. This method also resulted in a reduction of 28% of the total arsenic content (103-160). A third method, in which unwashed rice was cooked using a rice:water ratio of 1:1.5–2.0 until no discard water remains, did not modify the arsenic content (150-160). The water used in this study contained a small amount of arsenic (< 3 µg/L) (157).

Raab *et al.,* (154) investigated the effect of rinsing, low-volume (2.5:1 water:rice), and high-volume (**6:1 water:rice**) cooking, and steaming (154). Several types of rice were investigated, including polished basmati (white), whole-grain basmati (brown), polished long-grain (white), and whole long-grain (brown) (154). Rinsing raw rice with water removed approximately 15% of total arsenic and 5% – 14% of inorganic arsenic, depending on the type of rice (103-154-160). High-volume water rice cooking effectively removed both total and inorganic arsenic for the rinsed long-grain and basmati rice by an additional 35% and 45% for total and inorganic arsenic content, respectively, compared with uncooked (raw) rice (154). With both rinsing and **cooking with a high volume** of water, inorganic arsenic levels were reduced 51%, 54%, and 60% for polished long-grain, whole-grain basmati, and polished basmati, respectively (154). Although steaming reduced total inorganic arsenic rice content, it did not do so consistently across all types of rice investigated (103-160). **Low-water-volume cooking did not remove arsenic** (140-160). The authors suggested that rinsing is more effective for basmati rice than other types of rice, for reducing total arsenic, and more effective across types of rice, for inorganic arsenic, but more research is needed. Most of the arsenic **is lost in washing was inorganic arsenic** (103-160). This study used double-distilled, deionized water for cooking (154).

Cooking rice with **arsenic-contaminated water** can increase arsenic burden (145-160). This is of greatest concern in regions of the world with high arsenic **groundwater levels**, such as Bangladesh and West Bengal, India (152-155). In a study in which the cooking water contained 40 µg/L (ppb) arsenic, in India (154, 155-160).

In general inorganic arsenic in any type of rice is reduced by rinsing raw rice thoroughly before cooking, using a ratio of **6 cups water to 1 cup rice**, and draining the excess water afterward (107-160). This is a traditional method of cooking rice in Asia (103-160). The modern technique of cooking rice in water that is entirely absorbed by the grains has been promoted because it allows rice to retain more of its vitamins and other nutrients (148-160). But even though after sacrificing some of rice's nutritional value, research has shown that rinsing and using more water removes about **30 percent** of the rice's inorganic arsenic content (103-160). Therefore, cooking rice by repeatedly **flushing it through with fresh hot water** can remove much of the grain's stored arsenic, researchers have found a tip that could lessen levels of the toxic substance in one of the world's most popular foods (130-160).

High levels of arsenic in food have been linked to different types of cancer, and other health problems (103-160). The risk of arsenic poisoning is greatest for consumers who eat rice several times a day (103-160). **In Bangladesh**, where rice is a staple food and the water is also naturally **high in arsenic**, people are particularly vulnerable (104-160). Parboiling facilities in the country process rice **by pre-cooking**, drying and husking the grain (107-160). In the long term, the best strategies for removing arsenic from rice will come from ongoing efforts **to breed low-arsenic strains** and alter growing techniques (103-160).

Detection methods for Arsenic in Indian Rice

Over the past several years, many scientific reports and media articles have been published regarding serious health issues due to the presence of arsenic in Indian rice depending upon the geographical location where the rice is grown (163-170). Various national and international regulatory agencies such as the WHO, Codex, the EU Council Directive, and the Food Safety and Standards Authority of India (FSSAI) – have set up stringent norms to ensure the safety and quality of Indian rice samples that may be subject to arsenic contamination before batches are distributed worldwide (163).

According to the EU Commission Regulation 2015/10006, the maximum concentrations of inorganic arsenic (the sum of As (III) + As (V)) in rice samples that are destined for the production of food for infants and young children is 0.10 mg/kg(163). By contrast, for

non-parboiled milled rice (polished or white rice) and parboiled rice, and husked rice, these values are 0.20 and 0.25 mg/ kg, respectively (163). Similarly, according to the Codex Alimentarius Commission (including the Food and Agricultural Organizations of the United Nations (FAO) and the WHO), the maximum residual levels (MRLs) for polished rice and husked rice are 0.2 and 0.4 mg/ kg, respectively(163).

At Agilent Technologies in India, the team is working closely with various agricultural universities, research institutes and commercial testing labs (CTLs) (such as Bihar Agriculture University (BAU) and Basmati Export Development Foundation (BEDF), for the estimation of different species of arsenic in rice and various food products at low trace levels (163). Experts from Agilent are provided accurate, sensitive, and selective analytical methods for the detection and quantification of arsenic species in rice samples using high-performance liquid chromatography (HPLC) with inductively coupled plasma-mass spectrometry (ICP-MS) (163). Dr. Anupam Dixit and his team at Basmati Export Development Foundation (BEDF) in India specialized in analytical quality evaluations of Indian Basmati rice (163).

Indian Basmati Rice

Basmati occupies a special status in rice cultivation. It is a variety of long, slender grained aromatic rice (165-177). Basmati rice has a unique aroma which is due to the presence of a chemical called **2-acetyl-1-pyrroline** (165-176). Basmati rice was a predominant constituent of the rich and royal menus (165-176). India is the leading producer and exporter of the basmati rice to the global market (165-177). India produces about 74% of the world's basmati rice, and the rest is provided by Pakistan, the Philippines and China. In the international market, rice is traded under two main groups, fragrant and non-fragrant. The fragrant rice in India dominates the trade with its basmati rice (165-177). A huge amount of income generated from export of basmati rice product. It accounts 75% of global Basmati **rice** production (165-176). In the financial year 2018-19, India exported around 4.4 million tonnes of Basmati rice worth of USD 4.7 billion (165-177). Basmati rice from the Indian subcontinent is highly prized in the international market for its unique grain, cooking and eating quality. Basmati rice has a harmonious combination of defined kernel dimensions, appealing aroma, fluffy texture of cooked rice, high volume expansion during cooking, linear kernel elongation with minimum breadth-wise swelling, palatability, easy digestibility and longer shelf-life (165-176).

In the evolution of rice and its genetic differentiation into distinct varietal groups, consumer quality preferences have played a significant role besides agro-ecological factors (165-177). One such varietal group comprising the aromatic *pulao/biryani* rice of the Indian subcontinent is known as “Basmati” which is the highly priced rice in domestic as well as international markets (165-177). Three colour variants have been known in basmati as in many other rice varieties. Basmati surpasses all other scented varieties in shape, appearance, taste and quality (165-177). The basmati rice are differentiated from other aromatic rice in a certain criterion that its length increases twice of their original size after cooking with other characteristics like soft and fluffy texture upon cooking, delicious taste, superior aroma and distinct flavour (165-177). Basmati, like other rice varieties, has red, black and golden husk variants, though at present only golden husked basmati is famous. All the three variants are still grown in Champaran area of Bihar state, India (165-177).

In India, basmati is known as "queen of fragrance" and the nutty, sweet smell of basmati rice is unmistakable. Basmati is a necessary element in Biryani dishes and is the preferred type of rice served with Indian meals (165-177). Typically, the delicately curved, long grained, highly aromatic rice which elongate and cook soft and fluffy were the ones which were traditionally categorized as basmati (165-177). Basmati rice has enjoyed privileged treatment both in domestic and international markets, generating three times higher price. In the export markets, still the traditional tall basmati variety Taroari Basmati followed by Basmati 370 and Type 3 (Dehraduni) has supremacy over other varieties due to their exclusive quality features. The high yielding quality rice is derived from the traditional basmati are regarded as evolved basmati (165-177).

Basmati Rice: Growing region in India

In India, basmati rice is grown in the specific geographical area, at the Himalayan foot-hills confined into few Northern states of India (165-177). In India, Basmati rice is primarily grown in the Indo-Gangetic region of north-western region comprising the seven states Punjab, Haryana, Bihar, Himachal Pradesh, Uttarakhand, Chattisgarh, Jammu and Kathua districts of Jammu and Kashmir, and 27 districts of western Uttar Pradesh (165-177). This region has been earmarked as the Geographical Indication (GI) for basmati rice and the GI status has been conferred to Basmati rice in 2016 (GI No. 145 of the Geographical Indication Registry, Government of India, vide certificate No. 238 dated 15.02.2016) (165-176). Aromatic rice is known for its nut like scent and taste which is caused by the chemical compound **2-acetyle-1- pyrroline** (165-177). The special quality of basmati rice is attributed to unique combination of soil, water and climate, besides the inherent genetics governing these features (165-177). Basmati is one of the unique specialty rice varieties, which has been cultivated for centuries at the foot of Himalayan mountain ranges, India (165-177). Broadly speaking, aromatic rice can be classified into three categories- (1) Basmati (2) Jasmine and (3) Non-basmati/non-jasmine (177). The aromatic basmati rice of Indian Subcontinent clinches a good premium and gets higher price than high quality non-basmati rice (165-177). India, Pakistan and Thailand are the major exporters of aromatic rice. Among these, India and Pakistan are the major suppliers of basmati rice (177). Thailand is the major supplier of Jasmine rice. Foot-hills of Himalayas are considered to be the origin of aromatic rice. Although immense aromatic rice diversity is existing in India, not all aromatic types are recognized as basmati (165-177).

Basmati Rice varieties

The cultivation of basmati in India is confined to traditional basmati growing areas in North-west Indian states including Haryana, Punjab, Uttarakhand and western Uttar Pradesh, Bihar and to some areas of Delhi, Himachal Pradesh and Jammu and Kashmir (165-177). Some of the evolved varieties of Indian Basmati are **1**) Punjab Basmati-1(Bauni Basmati) (1984)- developed by Punjab Agricultural University, Ludhiana. **2**) Pusa Basmati-1 (1989)- developed by The Indian Agricultural Research Institute, New Delhi. **3**) Kasturi (1989) developed by Directorate of Rice Research, Rajendra Nagar, Hyderabad, Telangana. **4**) Haryana Basmati- 1 (1991) -developed by CCSHAU, Rice Research station, Kaul, District Kaithal, Haryana. **5**) Mahi Sugandha (1995)- developed by RRS, Banswara, Rajasthan. **6**) Pusa Basmati 1121 (2005)- The Indian Agricultural Research Institute, New Delhi. **7**) Pusa Basmati-1(Pusa 1460) (2007) by The Indian Agricultural Research Institute, New Delhi. **8**) Vallabh Basmati-22 (2009) by Sardar Vallabh Bhai University of Agriculture and Technology, Modipuram. **9**) Pusa Basmati-6 (Pusa 1401) (2010) by The Indian Agricultural Research Institute, New Delhi. **10**) Punjab Basmati- 2 (2010) by Punjab Agricultural University, Ludhiana. **11**) Basmati CSR-30 (Yamini) (2012) by The Central soil Salanity Research Institute, Karnal, Haryana. **12**) Pusa Basmati-1509 (2013) by The Indian Agricultural Research Institute, New Delhi. **13**) Malviya Basmati Dhan 10-9 (HUBR 10-9) (2013) by Banaras Hindu

University, Varanasi, UP. **14**) Vallabh Basmati (2013) by Sardar Vallabhai Patel University of Agriculture and Technology, Modipuram UP. **15**) Basmati 564 (2015) by Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu. **16**) Vallabh Basmati 23 (2015) by Sardar Vallabhai Patel University of Agriculture and Technology, Modipuram UP. **17**) Vallabh Basmati 24 (2015) by Sardar Vallabhai Patel University of Agriculture and Technology, Modipuram UP (165-177).

Traditional basmati rice varieties are tall, prone to lodging, photoperiod and temperature sensitive and very low yielding. Therefore, their production and productivity were limited. There are 6 Indian Basmati varieties such as 1) **Pusa Basmati-1**, 2) **Basmati-370**, 3) **Basmati-386**, 4) **Taraori Basmati**, 5) **Super Basmati**, 6) **Pusa Basmati-1121** (165-176).

Basmati Rice: Top Indian Brands in market

'**Basmati**' rice is a **premium quality** grain loved by people across the world. From delecious Biryanis to tangy fried rice, basmati rice has been the base for many mouth-watering meals (165-177). The grains are fine, long, soft, and rich in nutrients. While the market is abundant with numerous basmati rice brands, finding the **best Indian basmati rice** may be a little tricky. The best basmati rice is priced between **Rs 100 to Rs 500 per kg.** After packaging, Basmati Rice is available in markets in different brands e.g. Daawat, Tilda, Suraj basmati, Quality Priya, Gia royal Riz basmati, Quality 1121 extra long grain creamy sella basmati, Organic Tattva, Pristine, Nature Land Organics, Golden grain Rozana, Pride of India-Long grain, Charminar, India Gate, Shri- Lal Mahal, Lal Qila, Pansari, Organic India, Pride of India brown basmati, Aeroplane basmati rice, Fortune, Tata Sampann, Elephent, Kohinoor, Vedaka, and Sungold etc. with a very high price value even up to Rs.180-450/Kg. Basmati rice is always aged. It means the grains have to be aged for a long time in the storage units approximately,18-24 months (165-177). This is very time-consuming process and requires particular conditions for ageing and warehousing. This adds to the overhead cost of the rice (165-177).

Basmati Rice: Medicinal value and Health benefits

Basmati rice has a medicinal value. **Melatonin** has been detected in Basmati rice too. Though rice contains high levels of complex carbohydrates and is categorized as a high glycemic index food but basmati has a low glycemic index (176). Basmati is high in Fe and Zn, and helps in their bio-availability (adsorption). Basmati rice makes a **metallo-thionein-like protein** that is rich in **cystine** which aids in iron absorption; gene controlling this activity is being used in the development of **Fe-rich** rice through biotechnology (165-177). The chemical compound responsible for aroma in rice is **2-acetyl-1-pyrroline** present at 0.09 ppm in basmati rice grain which is almost 12 times more than non-basmati rice (165-177). Hence, basmati rice is unique among other aromatic long grained rice. In India, basmati rice is mainly grown for exporting purpose (165-176). Basmati rice has lower saturated fat content, which makes it a healthy option for heart. However, the unsaturated fats present in basmati rice have less bad cholesterol, and it prevents clotting. Moreover, a high amount of fiber provides a healthy cardiovascular system (165-177). Again, the soluble fiber present in basmati rice helps in promoting the movement of material within digestive system (165-177). A lower fibre diet is associated with the problem of constipation. Therefore, people suffering from digestive and constipation problems can be benefited by including basmati rice in their daily routine diet (165-177). Eating 3 ounces of whole basmati rice grains per day may lower the risk for this type of cancer by about 17% (165-177). Basmati rice is high in B vitamins, including **B1 (thiamine**) and **Melatonin**. It has 22% of daily recommended intake in each serving (165-177).

A cup of basmati rice has 20 per cent more fibre as compared to any other Indian rice. Basmati rice has also low Glycemic index and is safe for patients suffering from diabetes (165-177). Basmati rice also helps in giving balanced energy levels. Basmati rice is available in many varieties with varying costs. It has two versions, white and brown. It is a long grain rice, which gives food a royal look (165-177). As compared to any other brown rice, basmati rice contains nearly 20% more fiber. The biggest benefit of fiber is its ability to prevent the formation of cancerous cells. Researchers have found that fibre intake prevents many forms of cancer, especially colon cancer. Moreover, the consumption of whole-grain brown basmati rice effectively prevents breast cancer because fibre helps the body to eliminate estrogen hormones (165-177). It is a well-known belief that rice is the biggest enemy for weight loss. However, basmati rice, particularly boiled one, can benefit weight loss attempts. It is good for dieting and maintaining a healthy weight because of its fibre content (165-177). Fiber breaks down in the body slowly, controls appetite, and makes feel fuller for a long time. Moreover, it has a **high amount of amylose**, a more difficult carbohydrate for the body to digest (165-177).

Basmati Rice: Research work in India

The basmati rice research work is carried out at ICAR-IARI, New Delhi, India has resulted in reducing the crop duration from 160 days in traditional Basmati to 140–145 days in PB 1121, combined with doubling the yield from 2.5 t/ ha to nearly 5.0 t/ha (165-177). This research work has immensely helped in creating an employment in the basmati growing region, which has resulted in the establishment of more modern rice mills and making available better quality basmati rice for the domestic and global market on a regular basis (165-177). It has greatly improved the economics of basmati rice cultivation, and also the entire value chain of the basmati rice industry, especially exporters and consumers thereby ushering in a basmati rice revolution (165-177). Currently, PB 1121 is grown in 70% of the total area under basmati rice cultivation in India (165-176). It is the most common basmati rice variety in rice grain quality research for developing mapping populations, genetic analyses and molecular mapping of basmati quality traits (165-176). Additionally, it has been widely used in the basmati rice breeding program across India, because of its superior quality attributes (165-176). **Pusa Basmati 1121 (PB 1121) is a landmark Basmati rice** variety having Basmati quality traits introgressed from traditional basmati varieties such as Basmati 370 and Type 3 (165-176). It was released for commercial cultivation in 2003 (165-176). It possesses extra-long slender milled grains (9.00 mm), pleasant aroma, and an exceptionally high cooked kernel elongation ratio of 2.5 with a cooked kernel length of up to 22 mm, volume expansion more than four times, appealing taste, good mouth feel and easy digestibility (165-176). Owing to its exceptional quality characteristics, it has set new standards in the basmati rice market (165-176).

Basmati Rice: Challenges

However, basmati rice cultivation is facing several challenges from diseases such as bacterial blight, bakanae, neck blast, and insect pests like brown plant hopper and stem borer(165-176). Therefore, breeding basmati cultivars with resistance to these diseases, pests and other abiotic stresses while maintaining the superior grain quality by reducing chalkiness, improving HRR and better aroma is the major focus for basmati rice improvement (165-176). In this endeavour, PB-1718, a bacterial blight resistant near

isogenic line of PB-1121, has been developed and released for commercial cultivation in 2017(165-176).

CONCLUSION

Rice is a staple food and also a major contributor to dietary glycaemic load. India is one of the major centres for the rice production particularly the aromatic royal Basmati rice. Among different foods, rice has received increasing attention because it is a major component of billions of peoples' diets throughout the world. In addition, the removal of the outer bran layer during rice milling results in a loss of nutrients, dietary fiber, and bioactive components. Therefore, many studies were performed and investigated the potential health benefits for the consumption of whole brown rice grain in comparison to the milled or white rice. India is the leading producer and exporter of the basmati rice to the global market. Rice is a good candidate for the natural sources of antioxidants, other medicinal properties and may hold the potential for the development of rice based functional foods, drugs, food preservative, pharmaceuticals and cosmetic products.

Rice is commonly consumed after polishing or whitening and the polished grain is known **as** high glycemic food because of its high starch content. This literature review highlighted brown rice which contains greater levels of nutrients such as protein, fat, minerals, and vitamins than those in polished or milled white rice. Furthermore, brown rice contains several bioactive compounds such as phenolic acids, flavonoids, *γ* -oryzanol, and **Gamma aminobutyric acid (GABA**). In addition, brown rice, germinated brown rice, and their derived fractions or extracts have shown different biological activities and potential health benefits such as antioxidant, antidiabetic, and anticancer activity. The intake of brown rice or germinated brown rice showed a healthier effect compared to polished white rice. Therefore, brown rice and its processed products were recommended as functional and healthy foods. Several brown rice-based food products such as noodles, bread, and **snacks** were successfully developed as essential food in the Asian countries.

However, **brown rice** contains **more arsenic** than white rice because arsenic accumulates in the bran, which is the hard outer layer of the grain seen in brown rice. Arsenic accumulates in the grain's outer bran layers, which are removed to make white rice (120-160). This also depends on the geographical location of rice growing area. If the rice is grown in arsenic contaminated water with high arsenic levels, then brown rice accumulates **high arsenic** which is toxic to human health. This is due to rice being the only major cereal crop grown under flooded conditions (103-160). **Arsenic contamination** in **groundwate**r is an issue that affects millions of people around the world. Studies have linked chronic arsenic exposure with **cancers of the bladder, lungs, skin and prostate, as well as heart disease** (103-160). In the short term, it can cause gastrointestinal problems, muscle cramping and lesions on the hands and feet. In addition to this, there are some challenges and limitations such as the lower sensory properties and short shelf-life facing the commercialization and consumption of brown rice and its products. Higher concentrations of As, Cd, Pb, Zn, Mn and Cu were found in brown rice samples, revealing the prevalence of these elements in the rice bran. The consumption of brown rice is recommended because of its high fibre content and nutrients. However, brown rice also contains higher levels of toxic element arsenic. This would be more critical in case of consuming rice contaminated with these elements. Therefore, cooking rice by repeatedly **flushing it through with fresh hot water** can remove much of the grain's stored arsenic. Researchers have found a tip that could lessen levels of the toxic substance in one of the world's most popular foods.

The scientific evidence on the health benefits of wholegrain rice comes from compositional, in vitro, or in vivo studies with animal models. Results are very encouraging but more studies involving human subjects are needed to assess and validate the role of wholegrain rice in human nutrition. Therefore, the promotion of wholegrain production and consumption must be tackled at several levels that involve agronomy, biochemistry, processing, storage, marketing, and consumer science. Finally, future rice breeding programs should take into account the preferable consumption of rice as wholegrain rice and focus on the quality traits that are related to arsenic toxicity issue that need to be considered**.**

In conclusion, consumption of white rice is better than brown rice. Brown rice is very healthy but accumulates arsenic provided grown in a area where ground water is contaminated with high arsenic levels. If the rice is grown in arsenic contaminated water with high arsenic levels, then brown rice accumulates **high arsenic** which is toxic to human health. **Rice is particularly** efficient **scavenger of arsenic**, it takes up **ten times** as much as other cereal grains because it is the only food grain traditionally grown in fields that are under water. Brown, and pigmented rice varieties are consumed as healthy food but white rice is more popular and higher market demand. Consumer education campaigns could help in increasing brown rice consumption. The chemical composition of brown rice is very relevant for human nutrition. Cooking quality and sensory attributes of brown rice need to be improved by applying innovative processing technologies. Indian Basmati rice is the best healthy nutritional food for the consumption. However, the price of the basmati rice is very high and poor people cannot afford to buy this expensive rice.

REFERENCES

1. Saleh ASM, Wang P, Wang N, Yang L, Xiao Z. Brown Rice versus White Rice: Nutritional Quality, Potential Health Benefits, Development of Food Products, and Preservation Technologies. Comprehensive Reviews in Food Science and Food Safety. 2019; Vol. 00, 2019. doi: 10.1111/1541-4337.12449.
2. Rathna Priya TS, Nelson ARLE, Ravichandran K, Antony U. Nutritional and functional properties of coloured rice varieties of South India: A review. Journal of Ethnic Foods. 2019; 6:1-11.
3. Devi GN, Padmavathi G, Babu VR, Waghray K. Proximate nutritional evaluation of rice (Oryza sativa L.). J. Rice Res. 2015;8(1):23–32.
4. Umadevi M, Pushpa R, Sampathkumar KP, Bhowmik D. Rice-Traditional medicinal plant in India. Journal of Pharmacognosy and Phytochemistry. 2012;1(1):6–12.
5. Veda Krishnan, Singh A, Sharma S, Bollinedi H, Mabalirajan U, Kota S, Raja S, Singh AK, Praveen S. Nutrient dense pigmented rice: A diet for healthier people. News Bulletin. TB-ICN:236/2019**.** 2020; Published by the Division of Biochemistry**,** ICAR-Indian Agricultural Research Institute, New Delhi, India.
6. Kaur N, Sharma S, Yadav DN, Bobade H, Singh B. Quality characterization of brown rice pasta supplemented with vital gluten and hydrocolloides. Agricultural Research. 2017; 6(2): 185–194.
7. Sharif MK, Butt MS, Anjum FM, Khan SH. Rice bran: A novel functional ingredient. Critical Reviews in Food Science and Nutrition. 2014; 54: 807–816.
8. Pang Y, Ahmed S, Xu Y, Beta T, Zhu Z, Shao Y, Bao J. Bound phenolic compounds and antioxidant properties of whole grain and bran of white, red and black rice. Food Chemistry. 2018; 240: 212–221.
9. Kalman D. Amino acid composition of an organic brown rice protein concentrate and isolate compared to soy and whey concentrates and isolates. Foods. 2014; 3(3): 394–402.

10. Kaur B, Ranawana V, Henry J. The glycemic index of rice and rice products: A review, and table of GI values. Critical Reviews in Food Science and Nutrition. 2016; 56(2): 215–236.
11. Li SC, Chou TC, Shih CK. Effects of brown rice, rice bran, and polished rice on colon carcinogenesis in rats. Food Research International. 2011; 44: 209–216.
12. Mohan V, Spiegelman D, Sudha V, Gayathri R, Hong B, Praseena K, Krishnaswamy K. Effect of brown rice, white rice, and brown rice with legumes on blood glucose and insulin responses in overweight Asian Indians: A randomized controlled trial. Diabetes Technology & Therapeutics. 2014; 16: 317–325.
13. Wu F, Yang N, Tour´e A, Jin Z, Xu X. Germinated brown rice and its role in human health. Critical Reviews in Food Science & Nutrition. 2013; 53(5): 451–463.
14. Amagliani L, O'Regan J, Kelly AL, O'Mahony JA. The composition, extraction, functionality and applications of rice proteins: A review. Trends in Food Science & Technology. 2017; 64: 1–12.
15. Baek JJ, Lee S. Functional characterization of brown rice flour in an extruded noodle system. Journal of the Korean Society for Applied Biological Chemistry. 2014; 57(4): 435–440.
16. Ahuja U, Ahuja SC, Thakrar R, Singh RK. Rice a Nutraceutical. Asian-Agri History. 2008; 12(2):93-108.
17. Babu DP, Subhasree RS, Bhakyaraj R, Vidhya lakshmi R. Brown rice beyond the color reviving a lost health food - A review. American-Eurasian Journal of Agronomy. 2009; 2(2):67-72.
18. Chaudhary RC, Tran DV. Specialty rices of the world - a prologue. In: Specialty Rices of the World: Breeding, Production, and Marketing Chaudhary RC and Tran DV, eds., 2001.
19. Das DK, Oudhia P. Rice as medicinal plant in Chhattisgarh India: A survey. Agricultural Science Digest. 2001; 21(3):204-206.
20. Oudhia P. Medicinal weeds in rice fields of Chattisgarh, India. International Rice Research Notes. 1999; 24(1):40.
21. Chaudhari PR, Tamrakar N, Singh L, Tandon A, Sharma D. Rice nutritional and medicinal properties: A review article. Journal of Pharmacognosy and Phytochemistry. 2018; 7(2): 150-156.
22. Malabadi RB, Kolkar KP, Acharya M, Chalannavar RK. Constipation-A major health disorder: Role of herbal medicine treatment. International Journal of Innovation Scientific Research and Review. 2022; 4(4): 2634-2645.
23. Zahra, N, Jabeen S. Brown rice as useful nutritional source. Pakistan Journal of Agricultural Research. 2020; 33(3):445-453.
24. Patil SB, Khan MK. Germinated brown rice as a value added rice product: A review. J. Food Sci. Technol. 2011; 48(6): 661-667.
25. Kumar S, Mohanraj R, Sudha V, Wedick NM, Malik V, Hu VFB, Spiegelman D, Mohan V. Perceptions about varieties of brown rice: A qualitative study from Southern India. J. Am. Diet. Assoc. 2011; 111(10): 1517-1522.
26. Das M, Banerjee R, Bal S. Evaluation of physicochemical properties of enzyme treated brown rice (Part B). LWT-Food Sci. Technol. 2008; 41(10): 2092-2096.
27. Babu PD, Subhasree RS, Bhakyaraj R, Vidhyalakshmi R. Brown rice beyond the color reviving a lost health food-a review. Magnesium. 2009;187: 10-13.
28. Carcea, M. Value of Wholegrain Rice in a Healthy Human Nutrition. Agriculture. **2021**; 11: 720. (https://doi.org/10.3390/ agriculture11080720).
29. Ravichanthiran K, Ma ZF, Zhang H, Cao Y, Wang CW, Muhammad S, Aglago EK, Zhang Y, Jin Y, Pan B. Phytochemical profile of Brown rice and Its nutrigenomic implications. Antioxidants. **2018**; 7: 71; doi:10.3390/antiox7060071.
30. Kale SJ, Jha SK, Jha GK, Sinha JP, Lal SB. Soaking induced changes in chemical composition, glycemic index and starch characteristics of basmati rice. Rice Sci. **2015**; 22: 227–236.
31. Burlando B, Cornara L. Therapeutic properties of rice constituents and derivatives (Oryza sativa L.): A review update. Trends Food Sci. Technol. **2014**; 40, 82–98.
32. Hegde S, Yenagi N, Kasturiba B. Indigenous knowledge of the traditional and qualified Ayurveda practitioners on the nutritional significance and use of red rice in medications. Indian J. Tradit. Knowl. **2013**; 12: 506–511.
33. Babu PD, Subhasree R, Bhakyaraj R, Vidhyalakshmi R. Brown rice-beyond the color reviving a lost health food—A review. Am.-Eurasian J. Agron. **2009**; 2: 67–72.
34. Tian S, Nakamura K, Kayahara H. Analysis of phenolic compounds in white rice, brown rice, and germinated brown rice. J. Agric. Food Chem. **2004**; 52: 4808–4813.
35. Puri S, Dhillon B, Sodhi NS. Effect of degree of milling (Dom) on overall quality of rice—A review. Int. J. Adv. Biotechnol. Res. **2014**; 5: 474–489.
36. Pengnoi P, Mahawan R, Khanongnuch C, Lumyong S. Antioxidant properties and production of monacolin k, citrinin, and red pigments during solid state fermentation of purple rice (Oryzae sativa) varieties by Monascus purpureus. Czech J. Food Sci. **2017**; 35: 32–39.
37. Shobana S, Lakshmipriya N, Bai MR, Gayathri R, Ruchi V, Sudha V, Malleshi NG, Krishnaswamy K, Henry CK, Anjana RM et al. Even minimal polishing of an Indian parboiled brown rice variety leads to increased glycemic responses. Asia Pac. J. Clin. Nutr. **2017**; 26: 829–836.
38. Shao Y, Bao J. Polyphenols in whole rice grain: Genetic diversity and health benefits. Food Chem. **2015**; 180: 86–97.
39. Das A, Tushar VK, Rangan L. Aromatic Joha rice of Assam-A review. Agricultural Review. 2010; 31(1): 1-10.
40. Deka SD, Sarmah B, Sharma S. Conservation and utilization of indigenous rice varieties for a sustainable livelihood scrutiny. International Journal of Environmental Research and Development. 2014; 4(4): 291-296.
41. Hemavathy J, Prabhakar JV. Lipid composition of rice (*Oryza sativa L.*) bran. Journal of American Oil Chemists' Society. 1987; 64: 1016-1019.
42. Iqbal S, Bhanger MI, Anwar F. Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. Food Chemistry. 2005; 93(2): 265-272.
43. Kashyap A, Mahanta CL. Physical properties and Nutritive value of a popular Assamese breakfast cereal. International Journal of Home Science. 2016; 2(2): 227-231.
44. Verma DK, Srivastav PP. Proximate composition, mineral content and fatty acids analyses of aromatic and non-aromatic Indian rice. Rice Science. 2017; 24(1): 21-31.
45. Verma DK. (2011). Nutritional value of rice and their importance. Farmers' Digest. 2011; 44(1): 21.
46. Vora J, Madhrani N, Sarman A. Biochemical, organoleptic and antimicrobial characterization of Brown Rice (*Oryza sativa*). IOSR Journal of Environmental Science, Toxicology and Food Technology. 2015; 9(5): 41-45.
47. Kalita T, Hazarika J. Morphological study, nutritional value and phytochemical estimation of four indigenous rice (*Oryza sativa* L.) varieties of Assam, India. Food Research. 2022; 6 (1) : 196 - 203.

48. Boers HM, Hoorn JST, Mela DJ. A systematic review of the influence of rice characteristics and processing methods on postprandial glycaemic and insulinaemic responses. British Journal of Nutrition. 2015; 114: 1035–1045.
49. Kumar S, Mohanraj E, Sudha V, et al. Perceptions about varieties of brown rice: a qualitative study from Southern India. J. Am Diet Assoc. 2011; 111: 1517–1522.
50. Mohan V, Radhika G, Vijayalakshmi P et al. Editorial: Can the diabetes/cardiovascular disease epidemic in India be explained, at least in part, by excess grain (rice) intake? Ind J Med Res. 2010; 131: 369–372.
51. Shobana S, Kokila A, Lakshmipriya N et al. Glycaemic index of three Indian rice varieties. Int J. Food Sci Nutr. 2012; 63: 178–183.
52. Zarrati M, Pirali M, Mirmiran P et al. Glycemic index of various brands of rice in healthy individuals. Int J. Endocrinol Metab. 2008; 4: 200–204.
53. Srinivasa D, Raman A, Meena P et al. Glycaemic index (GI) of an Indian branded thermally treated Basmati rice variety: A multi centric study. J. Assoc Phys India. 2013; 61: 716–720.
54. Bhattacharjee P, Singhal RS, Kulkarni PR. Basmati rice: A review. Int J. Food Sci Techn. 2002; 37: 12.
55. Lu LW, Monro J, Lu J, Rush E. The effect of cold treatment of parboiled rice with lowered glycaemic potency on consumer liking and acceptability. Foods. 2018; 7: 207; doi:10.3390/foods7120207.
56. Shobana S, Malleshi NG, Sudha V, Spiegelman D, Hong B, Hu FB, Willett WC, Krishnaswamy K, Mohan V. Nutritional and sensory profile of two Indian rice varieties with different degrees of polishing. International Journal of Food Sciences and Nutrition. 2011;62(8): 800–810.
57. Mohan V, Radhika G, Sathya RM, Tamil SR, Ganesan A, Sudha V. 2009. Dietary carbohydrates, glycaemic load, food groups and newly detected type 2 diabetes among urban Asian Indian population in Chennai, India (Chennai Urban Rural Epidemiology Study. 59). Br J. Nutr. 2009; 9:1–9.
58. Radhika G, Sathya RM, Ganesan A, Saroja R, Vijayalakshmi P, Sudha V, Mohan V. Dietary profile of urban adult population in South India in the context of chronic disease epidemiology [Cures – 68]. Public Health Nutrition. 2010; 12:1–8.
59. Seetharamaiah GS, Prabhakar JV. Oryzanol content of Indian rice bran oil and its extraction from soap stock. J. Food Sci Technol. 1986; 23(5):270–273.
60. Singh N, Singh H, Kaur K, Bakshi MS. Relationship between the degree of milling, ash distribution pattern and conductivity in brown rice. Food Chem. 2000; 69:147–151.
61. Devi GN, Padmavathi G, Babu VR, Waghray K. Proximate nutritional evaluation of rice (Oryza sativa L.). J. Rice Res. 2015;8(1):23–32.
62. Gnanamanickam SS. Rice and its importance to human life. In: Biological Control of Rice Diseases. Progress in Biological Control. 2009;(8):1-11.
63. Sulochana S, Singaravadivel K. A study on phytochemical evaluation of traditional rice variety of Tamil Nadu -'Maappillai Samba' by GC-MS. International Journal of Pharma and Biosciences. 2015;6(3):606–11.
64. Rabbani GH, Ali M. New ideas and concepts, rice bran: A nutrient dense mill-waste for human nutrition. The ORION Med. J. 2009;32(3):458–62.
65. Saikia S, Dutta H, Saikia D, Mahanta CL. Quality characterisation and estimation of phytochemicals content and antioxidant capacity of aromatic pigmented and non-pigmented rice varieties. Food Research International. 2012;46(1):334–40.
66. Sulochana S, Meyyappan RM, Singaravadivel K. Phytochemical screening and GC-MS analysis of Garudan Samba traditional rice variety. Int J. Environ Agri Res. 2016;2(4):44–7.
67. Sulochana S, Meyyappan RM, Singaravadivel K. Mass spectrometry analysis of indian traditional variety "Red Kavuni" in comparison with high yielding popular variety of Tamil Nadu ADT 43 under raw and hydrothermally processed condition. Indo Am J. Pharm Res. 2016;6(5):5358–63.
68. Shao Y, Xu F, Sun X, Bao J, Beta T. Identification and quantification of phenolic acids and anthocyanins as antioxidants in bran, embryo and endosperm of white, red and black rice kernels (Oryza sativa L.). J. Cereal Sci. 2014;59:211–8.
69. Ahuja U, Ahuja SC, Thakrar R, Singh RK. Rice- A nutraceutical. Asian Agri- History. 2008;12(2):93–108.
70. Bhat FM, Riar CS. Health benefits of traditional rice varieties of temperate regions. Med. Aromat. Plants. 2015;4:198.
71. Kumar TT. History of rice in India. Delhi, India: Gian Publishers; 1988
72. Ahuja U, Ahuja SC, Chaudhary N, Thakrar R. Red rices-past, present, and future. Asian Agri-History. 2007;11(4):291–304.
73. Arumugasamy S, Jayashankar N, Subramanian K, Sridhar S, Vijayalakshmi K. Indigenous rice varieties. Centre for Indian Knowledge System (CIKS), Chennai: Tamil Nadu India; 2001
74. The Hindu. The Hindu Group. India: India. Indigenous rice varieties make a comeback The Hindu Group; 2018.
75. Ahuja U, Ahuja SC, Thakrar R, Shobha Rani N. Scented rices of India. Asian Agri-History. 2008;12(4):267–83.
76. Rani S, Krishnaiah K. Current status and future prospects of improving traditional aromatic rice. In: Chaudhary RC and Tran DV, editors, Specialty Rices of the World: Breeding, Production, and Marketing, FAO, Rome, Italy and Oxford IBH Publishers, India. 2001; 49-79.
77. Rahman S, Sharma MP, Sahai S. Nutritional and medicinal value of some indigenous rice varieties. Indian J. Traditional Knowledge. 2006;5(4):454–8.
78. Bhattacharya KR. Parboiling of rice. In: Champagne NET, editor. Rice chemistry and technology. American Association of Cereal Chemists Inc. St. Paul, Minnesota; 2004; 329–404.
79. Dinesh Babu P, Subhasree RS, Bhakyaraj R, Vidhyalakshmi R. Brown rice- beyond the color reviving a lost health food – A review. Am-Eur J. Agro. 2009; 2:67–72.
80. Butsat S, Siriamornpun S. Antioxidant capacities and phenolic compounds of the husk, bran and endosperm of Thai rice. Food Chem. 2010; 119(2):606–613.
81. Bhattacharya, KR. Parboiling of rice. In: Juliano, BO, editor. Rice chemistry and technology. St Paul, MN: American Association of Cereal Chemists; 1985. 289–348.
82. Saikia S, Dutta H, Saikia D, Mahanta CL. Quality characterization and estimation of phytochemicals content and antioxidant capacity of aromatic pigmented and non-pigmented rice varieties. Food Res. Int. 2012; 46(2):334-340.
83. Mohan BH, Malleshi NG, Koseki T. Physico-chemical characteristics and non-starch polysaccharide contents of *indica* and *japonica* brown rice and their malts. Food Sci. Technol. 2010; 43(5):784-791.
84. Bhattacharya KR, Sowbhagya CM, Swamy IYM. Quality profile of rice: A tentative scheme for classification. J Food Sci. 1982; 47:564-569.
85. Deepa G, Venkatachalam L, Bhagyalakshmi N, Shashidhar HE, Singh V, Naidu KA. Physicochemical and genetic analysis of an endemic rice variety, Njavara (*Oryza sativa* L.), in comparison to two popular South Indian cultivars, Jyothi (PTB 39) and IR 64. J Agric. Food Chem. 2009; 57:11476-11483.

86. Deepa G, Vasudeva S, Naidu AK. A comparative study on starch digestibility, glycemic index and resistant starch of pigmented ('Njavara' and 'Jyothi') and a non-pigmented ('IR 64') rice varieties, J Food Sci. Technol. 2010; 47(6):644-649.
87. **Muttagi** GC, Ravindra U. Chemical and nutritional composition of traditional rice varieties of Karnataka. Journal of Pharmacognosy and Phytochemistry. 2020; 9(5): 2300-2309.
88. **Muttagi** GC, Ravindra U. Phytochemical and antioxidant capacity of traditional rice Varieties of Karnataka, India. Int.J. Curr. Microbiol. App. Sci. 2020; 9(05): 67-75. doi: https://doi.org/10.20546/ijcmas.2020.905.006.
89. Zahra N, Jabeen S. Brown rice as useful nutritional source. Pakistan Journal of Agricultural Research. 2020; 33(3): 445-453.
90. Ahmad N, Sinha DK, Singh KM Estimating production efficiency in Rice cultivation of Bihar: An Economic Approach. Economic Affairs. 2017; **62(3):** 353-360,
91. Kumar A, Singh RKP, Singh KM, and Mishra JS. Economics of paddy (*Oryza sativa*) production: A comparative study of Bihar and Punjab. Indian Journal of Agricultural Sciences. 2018; **88** (2): 314–9.
92. Srivastava AK, Jaiswal HK. Grain characteristics and cooking quality of indigenous aromatic and non-aromatic genotypes of rice (Oryza sativa L.). Int J Sci Res Rev. 2013; 2:36–41.
93. Seetharamaiah GS, Prabhakar JV. Oryzanol content of Indian rice bran oil and its extraction from soap stock. J Food Sci Technol. 1986; 23:270–273.
94. Kalpanadevi C, Singh V, Subramanian R. Influence of milling on the nutritional composition of bran from different rice varieties. J. Food Sci. Technol. 2018; 55(6):2259–2269.
95. Pradeep PM, Jayadeep A, Guha M, Singh V. Hydrothermal and biotechnological treatments on nutraceutical content and antioxidant activity of rice bran. J. Cereal Sci. 2014; 60:187–192.
96. Srivastava AK, Jaiswal HK. Grain characteristics and cooking quality of indigenous aromatic and non-aromatic genotypes of rice (Oryza sativa L.). Int J. Sci Res Rev. 2013; 2:36–41.
97. Seetharamaiah GS, Prabhakar JV. Oryzanol content of Indian rice bran oil and its extraction from soap stock. J. Food Sci Technol. 1986; 23:270–273.
98. Saunders RM. Rice bran: Composition and potential food uses. Food Rev Int. 1985; 1:465–495.
99. Deepa C, Singh V. Shelling, milling, nutritional and functional properties of selected rice varieties. Oryza. 2010; 47:110–117.
100. Deepa G, Singh V, Naidu KA (2008) Nutrient composition and physicochemical properties of Indian medicinal rice—Njavara. Food Chem. 2008; 106:165–171.
101. Choudhury NH, Juliano BO. Effect of amylose content on the lipids of mature rice grains. Phytochemistry. 1980; 19:1385–1389.
102. Amissah JGN, Ellis WO, Oduro I, Manful JT. Nutrient composition of bran from new rice varieties under study in Ghana. Food Control. 2003; 14:21–24.

Arsenic toxicity

103. Lai PY, Cottingham KL, Steinmaus C, Karagas MR, Miller MD. Arsenic and Rice: Translating research to address health care providers' needs. J. Pediatr. 2015 October ; 167(4): 797–803. doi:10.1016/j.jpeds.2015.07.003.
104. Hite AH. Arsenic and rice: A call for regulation. Nutrition. 2013; 29:353–4.
105. Meharg AA, Williams PN, Adomako E, Lawgali YY, Deacon C, Villada A, et al. Geographical variation in total and inorganic arsenic content of polished (white) rice. Environ Sci Technol. 2009; 43:1612–7.
106. Navas-Acien A, Nachman KE. Public health responses to arsenic in rice and other foods. JAMA International Med. 2013; 173:1395–6.
107. Zhu Y, Williams PN, Meharg AA. Exposure to inorganic arsenic from rice: A global health issue?. Environ Pollut. 2008; 154:169–71.
108. Authority EFS. Dietary exposure to inorganic arsenic in the European population. EFSA J. 2014:8, 28, 36–7, 42–5, 53–8.
109. Meharg AA, Sun G, Williams PN, Adomako E, Deacon C, Zhu Y, et al. Inorganic arsenic levels in baby rice are of concern. Environ Pollut. 2008; 152:746–9.
110. Jackson BP, Taylor VF, Karagas MR, Punshon T, Cottingham KL. Arsenic, organic foods, and brown rice syrup. Environ Health Perspect. 2012; 120:623–6.
111. **U.S. Food and Drug Administration** (FDA) FDA explores impact of arsenic in rice. Silver Spring, MD: US Food and Drug Administration; 2013; 1-269 www.fda.gov/ForConsumers/ ConsumerUpdates/ucm352569.htm.
112. Brammer H, Ravenscroft P. Arsenic in groundwater: A threat to sustainable agriculture in South and Southeast Asia. Environ Int. 2009; 35:647–54.
113. Williams P, Raab A, Feldmann J, Meharg A. Market basket survey shows elevated levels of arsenic in south central US processed rice compared to California: consequences for human dietary exposure. Environ Sci Technol. 2007; 41:2178–83.
114. **Consumer Report**: Analysis of arsenic in rice and other grains. Consumer Reports. 2014
115. Gilbert-Diamond D, Cottingham KL, Gruber JF, Punshon T, Sayarath V, Gandolfi AJ, et al. Rice consumption contributes to arsenic exposure in US women. Proc Natl Acad Sci U S A. 2011; 108:20656–60.
116. Carbonell-Barrachina ÁA, Wu X, Ramírez-Gandolfo A, Norton GJ, Burlo F, Deacon C, et al. Inorganic arsenic contents in rice-based infant foods from Spain, UK, China, and USA. Environ Pollut. 2012; 163:77–83.
117. Melkonian S, Argos M, Hall MN, Chen Y, Parvez F, Pierce B, et al. Urinary and dietary analysis of 18470 Bangladeshis reveal a correlation of rice consumption with arsenic exposure and toxicity. PLoS One. 2013; 8:e80691.
118. Wyckoff AS. **FDA concludes** study of arsenic in rice products; No dietary changes recommended. AAP News. 2013; 34:7.
119. Batres-Marquez SP, Jensen HH, Upton J. Rice consumption in the United States: **Recent** evidence from food consumption surveys. J Am Diet Assoc. 2009; 109:1719–27.
120. Menona M, Sarkarb B, Huftona J, Reynoldsa C, Reinac SV, Youngc S. Do arsenic levels in rice pose a health risk to the UK population?. Ecotoxicology and Environmental Safety. 2020; 197*:* 11060. https://doi.org/10.1016/j.ecoenv.2020.110601.
121. Bakhat HF, Zia Z, Fahad S, Abbas S, Hammad HM, Shahzad AN, Abbas F, Alharby H, Shahid M. Arsenic uptake, accumulation and toxicity in rice plants: Possible remedies for its detoxification: A review. Environ. Sci. Pollut. Res. 2017; 24, 9142–9158.
122. Bennett JP, Chiriboga E, Coleman J, Waller DM. Heavy metals in wild rice from northern. Wisconsin. Sci. Total Environ. 2000; 246: 261–269.
123. Islam S, Rahman MM, Islam MR, Naidu R. Arsenic accumulation in rice: Consequences of rice genotypes and management practices to reduce human health risk. Environ. Int. 2016; 96: 139–155.

124. Liao N, Seto E, Eskenazi B, Wang M, Li Y, Hua J. A comprehensive review of arsenic exposure and risk from rice and a risk assessment among a cohort of adolescents in Kunming, China. Int. J. Environ. Res. Publ. Health. 2018; 15, 1–17.
125. Meharg AA, Williams PN, Adomako E, Lawgali YY, Deacon C. et al. Geographical variation in total and inorganic arsenic content of polished (white) rice. Environ. Sci. Technol. 2009; 43, 1612–1617.
126. Ma R, Shen J, Wu J, Tang Z. et al. Impact of agronomic practices on arsenic accumulation and speciation in rice grain. Environ. Pollut. 2014; 194: 217–223.
127. Zhu YG, Sun GX, Lei M. et al. High percentage inorganic arsenic content of mining impacted and non-impacted Chinese rice. Environ. Sci. Technol. 2008; https://doi.org/10.1021/es8001103.
128. Williams PN, Price AH, Raab A, Hossain SA. Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. Environ. Sci. Technol. 2005; 39: 5531–5540. (https://doi.org/10.1021/ es0502324).
129. Sommella A, Deacon C, Norton G, Pigna M, Violante A, Meharg AA. Total arsenic, inorganic arsenic, and other elements concentrations in Italian rice grain varies with origin and type. Environ. Pollut. 2013; 181, 38–43.
130. Rintala EM, Ekholm P, Koivisto P, Peltonen K, Venalainen ER. The intake of inorganic arsenic from long grain rice and rice-based baby food in Finland - low safety margin warrants follow up. Food Chem. 2014; 150: 199–205.
131. Rahman MMAM, Rahman, MMAM, Reichman SM, Lim RP, Naidu R. Arsenic speciation in Australian-grown and imported rice on sale in Australia: implications for human health risk. J. Agric. Food Chem. 2014; 62: 6016–6024.
132. Sohn E. The toxic side of Rice. Nature. 2014; 514:S63.
133. Tatah-Mentan M, Nyachoti S, Scott L, Phan N, Okwori FO, Felemban N, Godebo TR. Toxic and Essential Elements in Rice and Other Grains from the United States and Other Countries. Int. J. Environ. Res. Public Health. 2020; 17: 8128. doi:10.3390/ijerph17218128.
134. Khanam R, Kumar A, Nayak AK, Shahid Md, Tripathi R, Vijayakumar S, Bhaduri D, Kumar U, Mohanty S, Panneerselvam P. et al. Metal (Loid) s (as, Hg, Se, Pb and Cd) in Paddy Soil: Bioavailability and Potential Risk to Human Health. Sci. Total Environ. **2020**; 699,:134330.
135. Zavala YJ, Duxbury JM. Arsenic in Rice: I. Estimating normal levels of total Arsenic in rice grain. Environ. Sci. Technol. **2008**; 42: 3856–3860.
136. Hassan FI, Niaz K, Khan F, Maqbool F, Abdollahi M. The Relation between rice consumption, Arsenic contamination, and prevalence of diabetes in South Asia. EXCLI J. **2017**; 16: 1132–1143.
137. US- Food and Drug Administration (FDA) Arsenic in Rice and Rice Products Risk Assessment Report.2016; fda.gov/Food/FoodScienceResearch/RiskSafetyAssessment/default.
138. Zhao FJ, McGrath SP, Meharg AA. Arsenic as a food chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies. Annual Review of Plant Biology. 2010; 61: 535–559.
139. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological profile for arsenic (update). 2007; U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA.
140. Cascio C, Raab A, Jenkins RO, Feldmann J, Meharg AA. The impact of a rice based diet on urinary arsenic. Journal of Environmental Monitoring. 2011; 13: 257–265.
141. Cohen SM, Arnold LL, Beck BD, Lewis AS, Eldan M. Evaluation of the carcinogenicity of inorganic arsenic. Critical Reviews in Toxicology. 2013; 43(9): 711–752.
142. Gilbert-Diamond D, Cottingham KL, Gruber JF, Punshon T, Sayarath V, Gandolfi AJ, Baker ER, Jackson BP, Folt CL, Karagas MR. Rice consumption contributes to arsenic exposure in US women. Proceeding of the National Academy of Sciences. 2011;108: 20656–20660.
143. Gray P, Conklin S, Todorov T, Kasko M. Cooking rice in excess water reduces both arsenic and enriched vitamins in the cooked grain. Food Additives and Contaminants: Part A. 2016; 33: 78 – 85.
144. He Y, Pedigo CE, Lam B, Cheng Z, Zheng Y. Bioaccessibility of arsenic in various types of rice in an *in vitro* gastrointestinal fluid system. Journal of Environmental Science and Health, Part B. 2012; 47: 74–80.
145. Horner NS, Beauchemin D. The effect of cooking and washing rice on the bioaccessibility of As, Cu, Fe, V, and Zn using an on-line continuous leaching method. Analytica Chimica Acta. 2013; 758: 28–35.
146. Juhasz AL, Smith E, Weber J, Rees M, Rofe A, Kuchel T, Sansom L, Naidu R. *In vivo* assessment of arsenic bioavailability in rice and its significance for human health risk assessment. Environmental Health Perspectives. 2006; 114: 1826–1831.
147. Lamont WH. Concentration of inorganic arsenic in samples of white rice from the United States. Journal of Food Composition and Analysis. 2003; 16: 687–695.
148. Laparra JM, Velez D, Barbera R, Farre R, Montoro R. Bioavailability of inorganic arsenic in cooked rice: Practical aspects for human health risk assessments. Journal of Agricultural and Food Chemistry. 2005; 53: 8829–8833.
149. Li G, Sun GX, Williams PN, Nunes L, Zhu YG. Inorganic arsenic in Chinese food and its cancer risk. Environment International. 2011; 37: 1219–1225.
150. Liang F, Li Y, Zhang G, Tan M, Lin J, Liu W, Li Y, Lu W. Total and speciated arsenic levels in rice form China. Food Additives & Contaminants: Part A. 2010; 27: 810–816.
151. Meharg AA, Sun G, Williams PN, Adomako E, Deacon C, Zhu YG, Feldmann J, Raab A. Inorganic arsenic levels in baby rice are of concern. Environmental Pollution. 2008; 152: 746–749.
152. Meharg AA and Zhao FJ. Arsenic and rice. 2012; Dordrecht, Netherlands: Springer
153. Mukherjee SC, Saha KC, Pati S, Dutta RN, Rahman MM, Sengupta MK, Ahamed S, Lodh D, Das B, Hossain MA, Nayak B, Mukherjee A, Chakraborti D, Dulta SK, Palit SK, Kaies I, Barua AK, Asad KA. Murshidabad—one of the nine groundwater arsenic-affected districts of West Bengal, India. Part II: dermatological, neurological, and obstetric findings. Clinical Toxicology. 2005; 43: 835–848.
154. Raab A, Baskaran C, Feldmann J, Meharg AA. Cooking rice in a high water to rice ration reduces inorganic arsenic content. Journal of Environmental Monitoring. 2009; 11: 41–44.
155. Rahman MA, Hasegawa H. High levels of inorganic arsenic in rice in areas where arsenic-contaminated water is used for irrigation and cooking. Science of the Total Environment. 2011; 409: 4656–4655.
156. Gray P, Conklin S, Todorov T, and Kasko M. Cooking rice in excess water reduces both arsenic and enriched vitamins in the cooked grain. Food Additives and Contaminants: Part A. 2016; 33: 78 – 85.
157. Sengupta MK, Hossain MA, Mukherjee A, Ahamed S, Das B, Nayak B, Pal A, and Chakraborti D. Food and Chemical Toxicology. 2006; 44: 1823–1829.

158. Myupchar. Arsenic poisoning and rice: Thorough washing, cooking in excess water may help cut exposure. A recent study said that flood irrigation used to cultivate rice in India leads to longer exposure to contaminated water and soil, increasing the rate of arsenic absorption. August 05, 2020 22:27:09 IST.
159. How much arsenic is in your rice? Consumer Reports' new data and guidelines are important for everyone but especially for gluten avoiders. Published: November 2014.
160. Meng B, Feng X, Qiu G, Anderson CWN, Wang J, Zha L. Localization and speciation of mercury in brown rice with implications for Pan-Asian Public Health Environ. Sci. Technol. 2014; 48, 14: 7974–7981.
161. Singh NK, Rani M, Sharmila RT, et al. Flavonoids in rice, their role in health benefits. MOJ Food Process Technol. 2017;4(3):96–99. DOI: 10.15406/mojfpt.2017.04.00095.
162. Mbanjo EGN, Kretzschmar T, Jones H, Ereful N, Blanchard C, Boyd LA and Sreenivasulu N. The Genetic Basis and Nutritional Benefits of Pigmented Rice Grain. Front. Genet. 2020; 11:229. doi: 10.3389/fgene.2020.00229.
163. Jain V, Dixit A. The truth about arsenic in rice samples. Chemical Weekly. September 8, 2020.
164. Poletti J, Pozebon D, Barcellos de Fraga MV, Dressler VL, Pompéu de Moraes D. Food Additives & Contaminants: Part B. 2013; Toxic and micronutrient elements in organic, brown and polished rice in Brazil, Food Additives & Contaminants: Part B: Surveillance, DOI: 10.1080/19393210.2013.845249.
165. Singh R, Singh AK, Sharma TR, Singh A, Singh NK. Fine mapping of aroma QTLs in basmati rice (Oryza sativa L.) on chromosomes 3, 4 and 8. J. Plant Biochem Biotechnol. 2007; 16:75–82.
166. Singh R, Singh AK, Sharma TR, Singh A, Singh NK. Fine mapping of grain length QTLs on chromosomes 1 and 7 in basmati rice (Oryza sativa L.). J. Plant Biochem. Biotechnol. 2012; 21:157–166.
167. Singh VP, Pratik S, Gopala Krishnan S, Singh AK. Role of Indian Agricultural Research Institute in genetic improvement of rice varieties in India. In: Sharma SD, Rao P (eds) Genetic improvement of rice varieties in India. Today and Tomorrow's printers and publications, India. 2004; 141–187.
168. Singh VP, Siddiq EA, Zaman FU, Sadananda AR. Improved basmati donors. Int Rice Res Newsl. 1988; 13:22–25.
169. Singh VP, Singh AK. History of basmati rice research and development in India. Indian Farming. 2009; 59(1):4–6.
170. Singh VP, Singh AK. Role of Indian Agricultural Research Institute in collection, acquisition, evaluation, enhancement, utilization and conservation of rice germplasm. In: Sharma SD (ed) Genetic resources of rice in India. Today and Tomorrow's printers and publications, India. 2010; 135–150.
171. Singh VP, Singh AK, Atwal SS, Joseph M, Mohapatra T. Pusa 1121: A rice line with exceptionally high cooked kernel elongation and basmati quality. Int Rice Res Notes. 2002; 27:25–26.
172. Singh AK, Ellur RK, Gopala Krishnan S, Bhowmick PK, Nagarajan M, Vinod KK, aritha B, Singh VK, Khanna A, Pathania S, Yadav A, Mondal KK, Seth R Basmati rice variety Pusa Basmati 1718. Indian J Genet. 2018; 78:151.
173. Singh AK, Gopala Krishnan S, Nagarajan M, Vinod KK, Bhowmick PK, Atwal SS, Seth R, Chopra NK, Chander S, Singh VP, Prabhu KV, Singh D, Kumar S, Ravindran G. Basmati rice variety, Pusa Basmati 1509. Indian J. Genet. 2014; 74:123.
174. Singh AK, Gopala Krishnan S, Singh VP, Mohapatra T, Prabhu KV, Singh NK, Sharma TR, Nagarajan M, Vinod KK, Singh D, Singh UD, Chander S, Atwal SS, Seth R, Singh VK, Ellur RK, Singh A, Anand D, Khanna A, Yadav S, Goel N, Singh A, Shikari AB, Singh A, Marathi B. Marker assisted selection: A paradigm shift in basmati breeding. Indian J. Genet. 2011; 71:1–9.
175. Singh V, Singh AK, Mohapatra T, Gopala Krishnan S, Ellur RK. Pusa Basmati 1121 – A rice variety with exceptional kernel elongation and volume expansion after cooking. Rice. 2018; 11:19. https://doi.org/10.1186/s12284-018-0213-6.
176. Ahuja SC, U Ahuja and S Ahuja. History and folklore of basmati rice. Journal of Cereal Research. 2019;**11**(3): 206-214.
177. Bano DA, Singh SP, Waza SA. Aromatic Rice in India: Its production and Export. Indian Farmer. 2017; 4(3): 253-257.
178. Arsenic in rice and rice products. Silver Spring, MD: United States Food and Drug Administration; 2014. www.fda.gov/food/foodborneillnesscontaminants/metals/ucm319870.htm. Accessed July 27, 2015.
179. Report: Analysis of arsenic in rice and other grains. Consumer Reports.2014. http://www.greenerchoices.org/pdf/CR_FSASC_Arsenic_Analysis_Nov 2014.pdf. Accessed July 27, 2015.
180. Oelke EA. et al. Wild rice - New interest in an old crop. Cereal Foods World. 1997; **42**(4): 234-247.
181. Anderson RA. Wild rice: Nutritional value. Cereal Chem. 1976;**53**(6): 949-955.
182. Lorenz K. Wild rice: The Indian`s staple and the white man`s delicacy. CRC Crit. Rev. Food Sci. Nutr. 1981.
183. Gallaher DD, Bunzel M. Potential health benefits of wild rice and wild rice products: Literature review. AURI (Agricultural Utilization Research Institute). July 2012; 1-48.
184. Batista BL, Souza JMO, De Souza SS, Barbosa Jr F. Speciation of arsenic in rice and estimation of daily intake of different arsenic species by **Brazilians** through rice consumption. Journal of Hazardous Materials. 2011; 191: 342 348.
185. Cascio C, Raab A, Jenkins RO, Feldmann J, Meharg AA. The impact of a rice based diet on urinary arsenic. Journal of Environmental Monitoring. 2011; 13: 257–265.
186. Gray P, Conklin S, Todorov T, Kasko M. Cooking rice in excess water reduces both arsenic and enriched vitamins in the cooked grain. Food Additives and Contaminants: Part A. 2016;33:78 – 85.
187. He Y, Zheng Y. Assessment of *in vivo* bioaccessibility of arsenic in dietary rice by a mass approach. Science of the Total Environment. 2010; 408:1430–1436.
188. He Y, Pedigo CE, Lam B, Cheng Z, Zheng Y. Bioaccessibility of arsenic in various types of rice in an *in vitro* gastrointestinal fluid system. Journal of Environmental Science and Health, Part B. 2012; 47: 74–80.
189. Jorhem L, Åstrand C, Sundström B, Baxter M, Stokes P, Lewis J, Grawé KP. Elements in rice from the Swedish market: 1. Cadmium, lead and arsenic (total and inorganic). Food Additives and Contaminants. 2008; 25(3): 284-292.
190. Juhasz AL, Smith E, Weber J, Rees M, Rofe A, Kuchel T, Sansom L, Naidu R. *In vivo* assessment of arsenic bioavailability in rice and its significance for human health risk assessment. Environmental Health Perspectives. 2006; 114: 1826–1831.
191. Kubachka KM, Shockey NV, Hanley TA, Conklin SD, Heitkemper DT. Elemental Analysis Manual: Section 4.11: Arsenic Speciation in Rice and Rice Products Using High Performance Liquid Chromatography-Inductively Coupled Plasma-Mass Spectrometric Determination. Version 1.1 (November 2012). Retrieved from http://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm328363.htm.
192. Lamont WH. Concentration of inorganic arsenic in samples of **white rice** from the **United States**. Journal of Food Composition and Analysis. 2003; 16: 687–695.

193. Laparra JM, Velez D, Barbera R, Farre R, and Montoro R. Bioavailability of inorganic arsenic in cooked rice: Practical aspects for human health risk assessments. Journal of Agricultural and Food Chemistry. 2005; 53: 8829–8833.
194. Li G, Sun GX, Williams PN, Nunes L, Zhu YG. Inorganic arsenic in Chinese food and its cancer risk. Environment International. 2011; 37: 1219–1225.
195. Liang F, Li Y, Zhang G, Tan M, Lin J, Liu W, Li Y, Lu W. Total and speciated arsenic levels in rice form China. Food Additives & Contaminants*:* Part A. 2010; 27: 810–816.
196. Malabadi RB, Kolkar KP, Meti NT, Chalannavar RK. Melatonin: One molecule one- medicine for many diseases, Coronavirus (SARS-CoV-2) disease (Covid- 19); Function in plants. International Journal of Research and Scientific Innovation (IJRSI). 2021; VIII (3): 155-181.
197. Hattori A, Migitaka H, Iigo M, Itoh M, Yamamoto K, Ohtani-Kaneko R, Hara M, Suzuki T, Reiter RJ. Identification of **melatonin in plants** and its effects on plasma melatonin levels and binding to melatonin receptors in vertebrates. Biochem Mol Biol Int. 1995; 35(3):627-34.
198**. Setyaningsih W**, Saputro IE, Barbero GF, Palma M, Barraso CG. Determination of **melatonin in Rice** (*Oryza sativa*) grains by pressurized liquid extraction. Journal of Agricultural and Food Chemistry. 2015; 63(4):1107–1115. DOI:10.1021/jf505106m.
199. Yang X, Chen J, Ma Y, Huang M, Qiu T, Bian H, Han N, Wang J. Function, mechanism, and application of plant **melatonin**: An Update with a focus on the cereal crop, Barley (*Hordeum vulgare* L.). Antioxidants. 2022; 11:634. https:// doi.org/10.3390/antiox110406.

****