ON RICE, BIODIVERSITY & NUTRIENTS

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What happened to the rice landraces during the 'Green Revolution'?

There are few sectors in agriculture where the so-called Green Revolution had such an overwhelming impact as in rice production. In 1966, the International Rice Research Institute (IRRI) released the first high yielding rice variety in the Philippines. In the subsequent decade a small number of such high yielding varieties (HYV) almost completely replaced thousands of the traditional rice landraces previously cultivated by the farmers. The traditional varieties where collected for conservation in the seed banks of national and international research institutions, which farmers had no access to. Adoption of the new varieties was expedited through vigorous political support in the Philippines, as in other Asian countries.

The new rice plants had shorter stems, a higher harvest index (grain/straw ratio), and an enhanced response to fertilizer use. They had the advantage of delivering significantly higher yields when combined with accompanying management practices, including irrigation, pesticide and fertilizer application, and mechanization. Therefore, high yielding varieties spread only in favorable environments, where the natural and infrastructural setting allowed for such practices. In unfavorable environments, in which irrigation and mechanization were not possible or agrochemicals were not available, the cultivation of the traditional landraces persisted.

Today most of the rice fields throughout Asia are occupied by merely a small number of high yielding rice varieties. In the Philippines almost half of the rice area is devoted to four of the most widespread HYVs. In Cambodia, one single IRRI variety (*IR66*) accounts for around 90 percent of the rice area. And in Pakistan, only four HYVs are planted on 99 percent of the countries rice fields. These figures[1] illustrate the immense 'genetic erosion' that has occurred since the onset of the Green Revolution. The cultivation of traditional landraces is restricted to marginal areas, such as uplands environments. In these areas, the biodiversity of rice varieties still remains substantial. For example, a study in the Philippines[2] found that more than 50 kinds of rice landraces where cultivated in only two upland municipalities in the mountainous

Province of Aklan. However, biodiversity is also threatened in such areas, as an example from India demonstrates: while in the late 1950s around 1700 rice varieties where cultivated in the Jeypore tract of the State of Orissa, by 1996 the number had dwindled down to slightly more than 300 varieties[3].

What makes rice landraces interesting today?

Genetic and Morphological Diversity

The dominance of only a few rice varieties in Asian rice production poses a major threat to the genetic diversity of the plant. Many landraces are preserved in seed banks, but these are not accessible to the farmers. Furthermore, this kind of conservation does not allow the rice varieties to adapt to changing environmental settings and changing agricultural practices. In contrast, on-farm conservation of diverse rice landraces is dynamic, i.e. the varieties are subjected to continuous selection by the farmers and are thus allowed to develop and evolve. Local rice varieties should therefore be seen as the products of careful selection rather than an unchanging embodiment of ancient germplasm. Consequently, ensuring genetic diversity requires that rice landraces are cultivated continuously, and not simply stored in seed banks.

While most high yielding varieties in Asia are colorless with long and slender grains, local rice varieties often exhibit tremendous morphological diversity. The color of the outer layer (*pericarp*) can range from black/purple to red and brownish or colorless. In a study on upland rice in Aklan/Philippines[2], the grain weight - as characterized by the *thousand kernel weight* - varied between 8 and 27 grams, the small grain varieties being the most popular ones. HYVs from the same province varied only between 17 and 24 grams. In fact, more than 30 out of 51 identified landraces cultivated in the area were popular short grain varieties (grain length <5.5mm). Differences in the quantity of the fibrous hull, which encloses the rice grain and is useless in human as well as in animal diets, were also pronounced between upland rice varieties. Hull proportion ranged from 20 to 28 percent for most varieties, but some had values below 20 percent. Such varieties are advantageous because they have a higher net grain yield.

Disease Resistance

Genetic diversity is known to substantially decrease a crop's vulnerability to diseases. A large scale experiment carried out in the Yunnan Province of China[4] demonstrated how diversification of rice varieties was able to significantly reduce rice blast infestation. The rice blast disease, one of the major diseases in Asian rice production, is caused by a fungus, which exist as a combination of pathogenic races. Therefore rice resistance genes often remain effective only for a few years of agricultural production, before succumbing to new pathogenic races. In the above-mentioned experiment, however, diversification was so successful as a pest management strategy that farmers were able to abandon the use of fungicides after two years. Subsequently the 'Yunnan diversification program' expanded to more than 40 000 hectares of rice land. Corresponding experiences were observed in the Province of Aklan in the Philippines[2], where more than 50 rice landraces are cultivated in two upland municipalities. Farmers in those areas report that they do not face any rice pest infestation except for rats and birds.

Cultural and Market Value

Rice is not only the dominant staple food, but also an integral part of rural culture in Asia. It can therefore be attributed a cultural value, which is the most evident in areas that still maintain a large diversity of rice varieties. In the Province of Aklan in the Philippines farmers traditionally serve particular rice varieties for certain occasions. The most highly valued varieties are reserved for festivals and marriages, or offered to distinguished visitors. Some varieties are used for the preparation of sweet snacks, while others deliver relatively high yields and are rather used as an every-day food. The varieties' names in the local language often reflect the rice's appearance (e.g. *Bihud* means caviar), smell (*Manum balay* means that it can be smelled by the neighbor), or agronomic traits (e.g. *Kabiray* means that it produces many tillers). Many varieties are characterized by a very specific taste, and seeds of different varieties are exchanged among neighbors and relatives or given as presents. Considering these aspects, loss of biodiversity also implies a fading rural culture.

The high status of landraces and their superior quality is also reflected in a higher market value, which can make their cultivation economically attractive. In the Province of Aklan/Philippines, the Catholic Church initiated a marketing campaign for landraces in the 1990s. Local rice varieties have since then been sold as ‘food for the royals’ in the local markets, which has caused the price level to soar to three times that of ordinary HYVs of rice. The demand for local rice is so high that certain varieties can often only be obtained by ordering in advance directly from the farmers.

Grain and Straw Quality

Another aspect that makes rice landraces attractive is the high quality of the grain. This refers to the palatability, the texture, and particularly the nutritional value, which will be discussed extensively in the following sections. Moreover, the quality of the rice straw as an animal feed may gain increasing importance in the future due to the aggravating scarcity of feed resources. Rice straw is suitable as a feed for ruminants such as cows or water buffaloes, which in turn are used in food production or serve as draught animals. On the one hand, landraces deliver relatively more straw than high yielding varieties. On the other hand, their straw tends to have higher crude protein content (own unpublished data), which is often the most important limiting factor in ruminant nutrition in tropical countries.

Brown Rice or Milled Rice?

The rice grain consists of the starchy endosperm, the bran including the embryo and the outer grain layers, and the inedible fibrous hull (see Fig. 1). The endosperm, i.e. the inner part of the grain, contains mostly starch and around 6 to10 percent protein. The bran is more diverse in its composition and contains protein, lipids, fiber, vitamins, and minerals. The major vitamins present in the rice bran are vitamin E (α-tocopherol) and the B-vitamins (thiamin, riboflavin, and niacin). The mineral fraction is mainly composed of phosphorus, potassium, and magnesium.

The mechanical processing of the rice grain usually comprises two steps: first, the hull is removed from the grain to obtain *brown rice*, which is the least processed edible form of rice. Nowadays, the rice grain is usually further processed by additionally removing the bran layer from the endosperm to obtain *milled rice*. This is done in commercial milling due to the consumers' preferences and because the bran contains up to 20 percent lipids, making it susceptible to rancidity. The predominant form of rice found on today's markets is therefore milled rice. The bran fraction of higher nutritional value is for the most part used as an animal feed. This implies not only the loss of a nutritionally valuable rice component in human diets, but also a reduction of the quantity of rice available for human nutrition by around 10 to 15 percent. In Asia, the large-scale adoption of the rice milling technology was accompanied by the spread of vitamin B-deficiency (*beriberi*), due to a loss of vitamins through disposal of the rice bran.

In certain upland areas where rice landraces are grown, farmers process their rice manually and remove only the fibrous hull. Rice is then consumed as 'brown rice', i.e. including the bran layer. Rancidity of the rice oil in the outer layers of the grain is prevented by removing the hull just shortly prior to consumption. Rice is thus protected from oxidation and can be stored for up to one year without perishing.

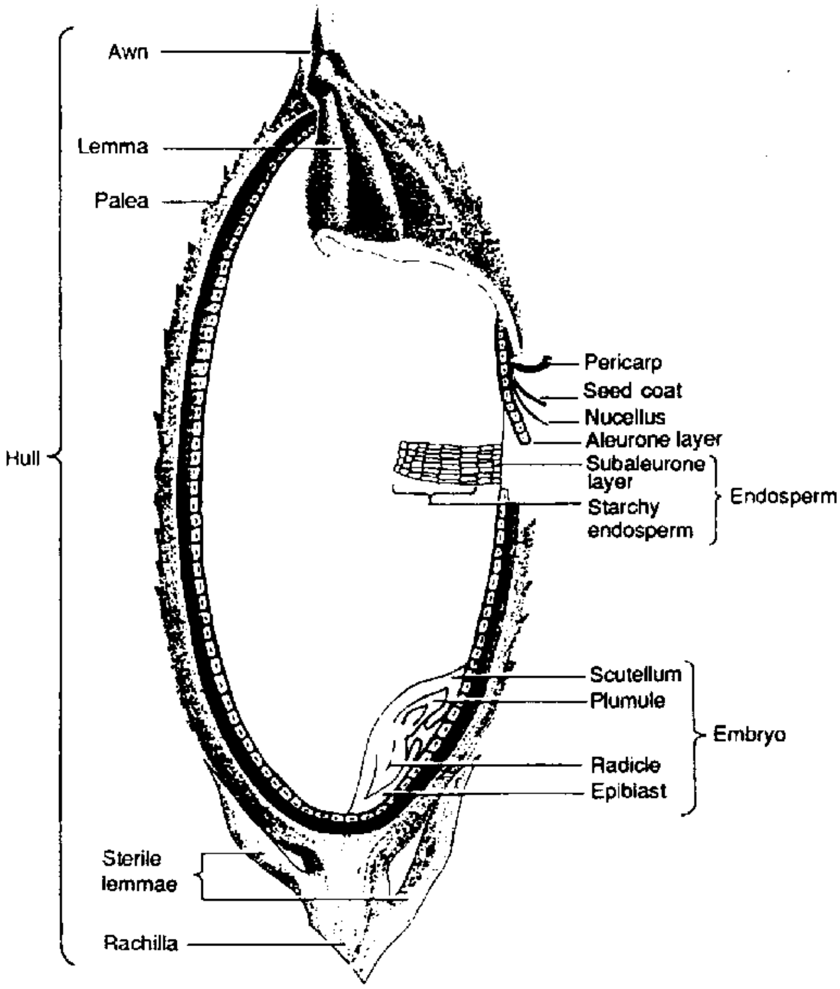

Fig. 1: Longitudinal section of a grain of rice. In a first processing step, only the hull is removed to obtain *brown rice.* Further, the bran (embryo, pericarp, seed coat, nucellus, and aleurone layer) can be removed in a second processing step to obtain *milled rice*. Source: Juliano 1993.

Are rice landraces ‘healthier’ than high yielding varieties?

The nutritional value of rice depends on many factors, and due to the abundant biodiversity of local varieties, one can surely not generalize on the ‘nutritional value of landraces’. Rather, the immense diversity encompasses many desirable properties, which are present in the large assortment of rice varieties. Such favorable properties are discussed in the subsequent sections regarding the individual nutritional components.

Carbohydrates

Rice is mostly considered a starchy staple food, which provides a large portion (sometimes up to 90 percent in Asia) of dietary energy. Brown rice contains about 75-85 percent carbohydrates, and milled rice even around 90 percent. Starch properties are therefore an important factor determining the grain quality. Starch can differ widely in its composition, i.e. the proportion of the two starchy fractions: *amylose* consists of linearly linked glucose molecules and *amylopectine* is composed of glucose molecules with branched links. The starch of so-called *waxy* rice varieties consist of amylopectine only. These varieties absorb less water upon cooking and have a sticky texture. On the other hand, rice varieties with an amylose content of more than 25 percent absorb more water and have a fluffy texture after cooking.

Rice starch is usually digested quite rapidly, compared to other starch foods such as noodles, sweet potato, or cassava. This leads to a prompt and pronounced increase of the blood glucose level (= high *glycemic index*) after the ingestion of rice, similar to that of white bread or pure glucose. Rapid starch digestion is regarded as unfavorable, because, in the long term, it can induce type II diabetes (i.e. non-insulin dependent diabetes) in adults. Moreover, fast digestion can cause a sensation of hunger only shortly after the ingestion of rice, and the energy released is quickly used.

Farmers cultivating rice landraces in the Philippines report a relatively long feeling of satiation after the ingestion of certain varieties. On the one hand, this might be due to the fact that they eat brown rice instead of milled rice, and thus more than just starch. On the other hand, it can be attributed to the relatively slow starch digestibility of certain rice varieties. Fairly slow starch digestion (= a low glycemic index) was demonstrated for certain landraces from Aklan/Philippines[5]. This can partly be explained by their starch composition, i.e. high proportion of amylose. However, other factors, which may be specific to certain varieties, such as the physiochemical starch structure or the size of the starch granules, also contribute to delayed starch digestion. Slowly digestible varieties might be useful in the prevention or treatment of type II diabetes. Other varieties, especially *waxy* ones were digested very rapidly in the study cited. Such *waxy* varieties are mostly used for the preparation of sweet snacks, which means that they are cooked and then cooled down before consumption. Cooling after cooking such varieties has been shown to substantially slow down starch digestion due to physiochemical changes in the starch structure (*retrogradation*)[5].

Protein

Rice is mainly a carbohydrate staple food, but because animal products can be scarce or expensive in developing countries, it is often the most important source of protein in people's diet as well. Rice protein is of very high quality as compared to other food crops. Protein quality is determined by the amino acid composition and by its digestibility. Certain essential amino acids such as *lysine* (the first limiting amino acid), which are particularly important for the growth of children, are often scarce in plant foods, while being more abundant in animal protein. However, rice has a relatively favorable amino acid composition with a high proportion of lysine and a high protein digestibility. This makes rice a reasonably good source of protein in diets with limited animal protein availability. Brown rice not only has a higher protein content, but also a higher proportion of lysine than milled rice.

The average protein content of a HYV of rice available on the market is around seven percent. For high yielding IRRI varieties in the Philippines protein content ranges from six to ten percent[6]. Conversely, rice landraces from the Philippines exhibited protein contents of up to fourteen percent[2], double the amount of an ordinary high yielding variety. The highest values reported in scientific literature reach up to 16 percent of protein[7] (for a Chinese fragrant long-grain rice).

The human daily protein requirement is estimated at 0.8-1.2 grams per kilogram bodyweight, depending on age. The requirement is the highest for children and declines with advancing age. A moderate daily intake of 200 grams of an average HYV of rice (with seven percent protein) per day contributes around fourteen grams of protein. Consumption of the same amount of a high protein landrace (with fourteen percent protein) contributes 28 grams of protein to the daily ration. Based on these values, an average adult can cover only around one fourth of the daily protein allowance with an ordinary HYV, as opposed to half of the dietary requirement with a high protein variety. With elevated consumption of high protein landraces it is even possible to fully cover the recommended daily protein allowance.

The grain protein content of rice is responsive to nitrogen fertilization, because nitrogen is required for the protein synthesis. Landraces tend to have high protein content although they are often cultivated without the use of fertilizer. It is therefore conceivable that the protein content of landraces can be further increased by the moderate application of nitrogen fertilizer.

Oil and essential fatty acids

The potential of rice to contribute to the supply of essential dietary lipids is generally underestimated. This may be due to the fact that the predominant form of rice available on the market is milled rice, containing only negligible amounts of lipids. Almost all of the rice's oil content is located in the outer layers of the grain, which are removed during milling.

Rice lipids, commonly denoted as oil ('rice bran oil') due to its liquid character at room temperature, are characterized by a high nutritional value. The liquid consistency of the oil is caused by the high proportion of unsaturated fatty acids, accounting for up to 80 percent. Because of its high level of unsaturation, rice bran oil is known to have blood cholesterol lowering effects. The major unsaturated fatty acids in rice oil are oleic acid (a mono-unsaturated acid) and linoleic acid (an essential polyunsaturated fatty acid). Such essential fatty acids cannot be synthesized in the human body and therefore have to be ingested with food. They play an important role in many physiological processes, including cell membrane function and the development and functioning of the nervous system.

A study on Philippine rice landraces[2] demonstrated that the average lipid content was significantly higher than that of the HYVs collected from the same area. While for all of the HYVs (brown rice) lipid content ranged between 2.0 and 2.1 percent, the average value for the landraces was 2.3 percent, with individual varieties reaching up to 3.2 percent. Of the total lipid content, certain varieties contained more than 80 percent unsaturated fatty acids. Linoleic acid, which is an essential polyunsaturated fatty acid, accounted for 30 percent of the lipid fraction on average. Some landrace varieties had a linoleic acid content of almost one percent of the total grain. Ingesting 200g of such a variety would thus supply around two grams of essential linoleic acid, which is approximately half of the daily requirement.

β-Carotene and Other Carotenoids

β-Carotene is a type of carotenoid, which is one of the most important classes of plant pigments. In the plant tissue, carotenoids function primarily as auxiliary pigments in photosynthetic processes and act as antioxidants against oxidative damage. In the human diet some of the carotenoids act as vitamin A precursors as they can be converted in the intestinal tract.

β-Carotene is by far the most effective vitamin A precursor of all carotenoids and can play an important role in diets lacking animal products. Vitamin A itself is abundant in meat, fish, milk, and liver, but is not found in plant foods at all. As animal products are usually expensive or scarce in developing countries, plant based β-carotene, functioning as a vitamin A precursor, can account for more than 80 percent of the vitamin A supply[8].

The stepwise conversion of β-carotene into vitamin A first comprises its absorption into the intestinal cells, followed by an enzyme-mediated chemical transformation. The absorption rate of β-carotene into the intestinal cells is around 20 to 50 percent and decreases with increasing ingestion. It additionally requires the presence of a sufficient quantity and quality of lipids in the diet[9]. The enzymatic reactions necessary for the conversion of β-carotene into vitamin A also require the presence of lipids, especially unsaturated fatty acids[10]. The absorption and transformation of β-carotene implies some losses: between six and twelve units of β-carotene yield one unit of vitamin A. After synthesis in the intestinal cells, vitamin A is finally transported to the liver for storage.

Some plant foods containing abundant β-carotene are green leafy vegetables, squash, or palm oil. Rice is usually a very poor source of provitamin A. While the endosperm is virtually free of carotenoids, some traces may be present in the bran fraction. Higher levels of β-carotene are only found in pigmented, i.e. colored rice varieties. Such colored rice varieties, especially red and black sorts, are only cultivated in areas that maintain a high diversity of rice genotypes.

A study on Philippine upland rice varieties[2] found distinguished differences in β-carotene content depending on the grain color. The highest average content was found in black varieties, with values reaching up to 0.13 mg/kg (brown rice). Conversely, much lower concentrations were found in red varieties, while β-carotene was hardly detectable at all in colorless varieties. Similar results were obtained in another survey including varieties from Malaysia, Vietnam and Thailand[11]. The highest concentration was detected in a black variety from Malaysia with 0.22 mg/kg. Further analyses of β-carotene concentrations (own unpublished data) revealed values of up to 0.38 mg/kg in a black/purple landrace rice from the Philippines.

It is interesting to compare these values to those of bioengineered varieties. The genetically engineered rice varieties know as *Golden Rice* have been modified to contain β-carotene in the endosperm, which is usually completely devoid of caroteneoids. Various recent scientific publications[12, 13, 14] report total carotenoid levels of 0.3 to 1.6 mg/kg for such bioengineered varieties. However, more precise figures on the β-carotene fraction of the carotenoids, which actually has vitamin A precursor function, are not given in these articles. Considering that only a certain portion of these carotenoids is actually β-carotene, one can assume that the β-carotene content of un-milled black varieties is similar to that of *Golden Rice* varieties.

Seeing that the absorption and conversion of β-carotene requires the presence of dietary lipids, the oil content of rice varieties containing carotenoids is also an important aspect. Analysis of a set of 54 Asian rice landraces revealed a close correlation between the β-carotene content and the lipid content[11]. In other words, varieties containing an elevated level of β-carotene (especially black/purple varieties) likewise had a high lipid content. This interrelation might occur naturally due to enhanced storage of the carotenoids – which are fat-soluble - in the grain. From a nutritional point of view this interrelationship is a very favorable one, because it ensures the supply of the necessary lipids (especially unsaturated fatty acids) necessary for the transformation of β-carotene into vitamin A. It can therefore be assumed that the efficiency of black rice β-carotene as a vitamin A precursor is high.

Apart from β-carotene, black and purple varieties from Malaysia were also found to have elevated concentrations of other carotenoids, especially lutein. Two samples were identified that had lutein contents of 1.6 and 2.4 mg/kg, respectively (own unpublished data). Lutein does not have any function as a vitamin A precursor. However, it is a principal component of the eye's macular pigment. The macula is a part of the retina that is responsible for detailed and central vision (e.g for reading). Elevated ingestion of lutein results in a high macula pigment density and may lead to delayed age related macular degeneration.

Iron

Iron deficiency anemia is considered to be one of the most wide-spread micronutrient disorders in the world. Some estimates say that around half of the world's population is deficient in dietary iron supply. Iron is the main ingredient in hemoglobin, which is found in red blood cells and is responsible for carrying oxygen throughout the body. Symptoms of iron deficiency include a lack of energy, fatigue, pale skin, brittle and white fingernails, brittle hair, etc.

As with vitamins, minerals are chiefly located in the bran of the rice grain. Therefore, rice can only contribute significantly to the iron supply if it is eaten as brown rice. Analysis of a number of rice samples grown under greenhouse conditions at the International Rice Research Institute (IRRI) showed that local varieties had an iron content up to 2.5 times higher than that of the common high yielding varieties[7]. In contrast to landraces, the most commonly grown HYVs were at the lowest end of the scale with an average iron content of around 10 mg/kg. The highest value cited in that same study was 26 mg/kg for a landrace. A different set of landraces from various Southeast Asian countries (own unpublished data) demonstrated iron contents of up to 33 mg/kg. Generally, iron content tends to be higher in aromatic and colored (red and black) rice varieties than in colorless varieties and ordinary HYVs[15]. The highest value published is for a Chinese red long-grain variety, which reportedly had a content of 64 mg/kg[7].

Increasing the iron content in rice has also been an objective of genetic engineering in recent years. By transferring a soybean gene into rice, an iron level of 13-38 mg/kg has been achieved in brown rice[16]. That level is higher than in the non-manipulated control varieties used in those experiments, but it is not higher than the iron levels found in certain landraces.

The bioavailability of ingested iron depends very much on the intake level and is higher in iron deficient diets. It also depends on the presence of other nutrients such as vitamin C. Furthermore, iron absorption can be improved by elevated amounts of β-carotene or vitamin A in the diet[17]. On the other hand inhibitory substances present in the grain, such as phytic acid or polyphenols can reduce the iron bioavailability. Depending on the presence of either inhibitory or adjuvant substances the iron availability may vary greatly. However, little research has been done on this aspect so far. Assuming a realistic absorption capacity of around 10 percent, 200g of unmilled high-iron rice (with an iron content of around 30 mg/kg) could contribute up to half of the daily iron requirement.

Zinc

Zinc is believed to be low in the diets of around 2.5 billion people worldwide. It is involved in many enzymatic reactions in the body and is also essential for DNA synthesis. The requirement of zinc is increased during pregnancy as well as throughout childhood and adolescence. The clinical manifestations in severe cases of zinc deficiency include diarrhea, weight loss, infections, and it is fatal if untreated. A moderate zinc deficiency of zinc is characterized by growth retardation and delayed puberty in adolescents, poor appetite, delayed wound healing, etc.

As with iron, most of the zinc present in the rice grain is located in the outer layers. The consumer's preference for milled rice therefore substantially reduces the availability of zinc. Conversely, brown rice can contribute appreciable amounts of zinc to the diet. The variability in zinc content among different rice varieties is quite pronounced. Values ranging from 14 to 59 mg/kg are given in scientific literature[7, 15]. As with iron, zinc concentration is substantially higher in certain landraces than in commonly grown high yielding varieties. Furthermore, varieties that are high in iron content are often also high in zinc. A set of landraces form Southeast Asia (own unpublished data) exhibited an average zinc content of 41mg/kg with values reaching up to 57 mg/kg. Similarly to iron, the zinc content tends to be higher in aromatic and colored rice varieties.

A major concern related to cereal-based diets is the low bioavailability of zinc due to the presence of a high level of phytic acid, which inhibits zinc absorption. Therefore, the screening for rice varieties that have elevated zinc content while simultaneously containing low levels of phytic acid merits further scientific study.

Antioxidants

The bran fraction of certain rice varieties - especially pigmented (i.e. colored) ones - is rich in antioxidant compounds. Antioxidants comprise polyphenols, carotenoids, vitamin E (= α-tocopherol) and tocotrienols (compounds chemically similar to vitamin E). Antioxidants have various beneficial effects in the human body, especially the sequestration of aggressive and carcinogenic molecules, the so-called free radicals. They thus protect the body tissue and especially the DNA from oxidative damage.

A feeding experiment[18, 19] found that rabbits fed with red and black rice varieties (or only their bran) had an improved antioxidant status in their blood and decreased atherosclerotic plaque formation. The authors of the study could not relate these effects to a certain constituent, but suggested selenium, flavonoids (polyphenolic substances), or tocotrienols as possible candidates. They concluded that black and red rice can help in the prevention of arthrosclerosis and cardiovascular diseases in humans due to the presence of antioxidants. A different study using mice as experimental animals[20] came to similar results. That study identified a novel tocotrienol in rice bran which provides an approach to promoting cardiovascular health. The study concluded that such tocotrienols can prevent or reverse blood clots and lesions that may lead to diseases such as myocardial infarction, stroke, or other blood system thromboses.

The function and the physiological effects of various antioxidant substances are not fully understood and represent an innovative research field. The diversity of rice varieties offers tremendous scope for scientists to further investigate the potential for the synthesis of antioxidants and their possible beneficial effects.

Conclusion

The immense genetic diversity in rice landraces is similarly reflected by their multiplicity of nutritional characteristics. Appropriate rice varieties exist for enhancing the supply of various nutrients, including protein, essential lipids, certain minerals, and to some extent also β-carotene. Some varieties may even be characterized by a combination of favorable nutritional traits. This is true for varieties containing elevated levels of both β-carotene and essential lipids, for example. More synergies between nutritional components may exist and have to be elucidated in further scientific work.

The diversity of such favorable nutritional characteristics is not represented in the most wide-spread HYVs currently prevailing in Asian rice cultivation. These have been developed mainly to optimize the quantitative yields, and not the nutritional value. The high nutritional quality of rice landraces can form a solid basis for changing priorities in rice breeding, putting more emphasis on the grain nutritional value. Modern conventional breeding techniques, including molecular marker-assisted selection, may be very useful in accelerating the development of more nutritious rice varieties. Combining high yields and high grain nutritional value thus appears to be possible without any genetic manipulation.

The current prevalence of milled rice on the market reduces the rice's nutritional value and essentially turns it into a simple carbohydrate food. Therefore, in addition to developing more nutritious varieties, awareness of the benefits of eating brown rice should be raised among rice consumers. Such a combined approach would ultimately result in a sustainable enhancement of the essential nutrient supply in rice-based diets.

References

1. IRRI World Rice Statistics: *http://www.irri.org/science/ricestat/index.asp*, accessed on 4th November 2004.

2. Frei, M. & Becker, K. (2004) Agro-biodiversity in subsistence-oriented farming systems in a Philippine upland region: nutritional considerations. Biodiversity and Conservation 13: 1591-1610.

3. Patra, C.P. & Dhua, S.R. (2003) Agro-morphological diversity scenario in upland rice germplasm of Jeypore tract. Genetic Resources and Crop Evolution 50: 825-828.

4. Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J., Yang, S., Hu, L., Leung, H., Mew, T.M., Teng, P.S., Wang, Z. & Mundt, C.C. (2000) Genetic diversity and disease control in rice. Nature 406: 718-722.

5. Frei, M. & Becker, K. (2003) Studies on the in vitro starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. Food Chemistry 83: 395-402.

6. Juliano, B.O. & Villareal, C.P. (1993) Grain quality evaluation of world rices. International Rice Research Institute (IRRI), Manila, Philippines.

7. Kennedy, G. & Burlingame, B. (2003) Analysis of food composition data on rice from a plant genetic resources perspective. Food Chemistry 80: 589-596.

8. van den Berg, H., Faulks, R., Fernando Granado, H., Hirschberg, J., Olmedilla, B., Sandmann, G., Southon, S., & Stahl, W. (2000) The potential for the improvement of carotenoid levels in foods and he likely systemic effects. Journal of the Science of Food and Agriculture 80: 880-912.

9. Gerster, H. (1997) Vitamin A – functions, dietary requirements and safety in humans. International Journal of Vitamin and Nutrition Research 67: 71-90.

10. Nagao, A. (2004) Oxidative conversion of carotenoids to retinoids and other products. Journal of Nutrition 134: 237S-240S.

11. Frei, M., & Becker, K. A novel correlation between lipid components and all-*trans*-β-carotene in differently colored rice landraces. Submitted to Journal of the Science of Food and Agriculture.

12. Ye, X., Al-Babili, S., Klöti, A., Zhang, J., Lucca, P., Beyer, P. & Potrykus I. (2000) Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 287: 303-305.

13. Beyer P., Al-Babili S., Ye X., Lucca P., Schaub P., Welsch R. & Potrykus I. (2002) Golden rice: introducing the beta-carotene biosynthesis pathway into rice endosperm by genetic engineering to defeat vitamin A deficiency. Journal of Nutrition 132: 506-510.

14. Datta, K., Baisakh, N., Olivia, N., Torrizo, L., Abrigo, E., Tan, J., Rai, M., Rehana, S., Al-Babili, S., Beyer, P., Potrykus, I. & Datta S. (2003) Bioengineered 'golden' indica rice cultivars with β-carotene metabolism in the endosperm with hygromycin and mannose selection systems. Plant Biotechnology Journal 1: 81-90.

15. Gregorio, G.B. (2002) Progress in breeding for trace minerals in staple crops. Journal of Nutrition 132: 500S-502S.

16. Datta, S. & Bouis, H.E. (2000) Application of biotechnology to improving the nutritional quality of rice. Food and Nutrition Bulletin 21: 451-456.

17. Carcia-Casal, M.N., Lyrisse, M., Solano, L., Baron, M.A., Arguello, F., Llovera, D., Ramirez, J., Leets, I. & Tropper, E. (1998) Vitamin A and β-carotene can improve nonheme iron absorption from rice, wheat and corn by humans. Journal of Nutrition 128: 646-650.

18. Ling, W.H., Cheng, Q.X., Ma, J. & Wang T. (2001) Red and black rice decrease artherosclerotic plaque formation and increase antioxidant status in rabbits. Journal of Nutrition 131: 1421-1426.

19. Ling, W.H., Wang, L.L. & Ma J. (2002) Supplementation of the black rice outer layer fraction to rabbits decreases the atherosclerotic plaque formation and increases antioxidant status. Journal of Nutrition 132: 20-26.

20. Qureshi, A.A., Salser, W.A., Parmar, R., & Emeson, E.E. (2001) Novel tocotrienols of rice bran inhibit atherosclerotic lesions in C57BL/6 ApoE-deficient mice. Journal of Nutrition 131: 2606-2618.