Chapter 15

Rice quality: A matter of concern in climate change scenario

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Rice is an integral part of the diet of about half of the global population and accounts for 35-75% of the calories consumed by more than three billion Asians (Khush, 2007). About 100,000 rice accessions are preserved in the gene bank of the International Rice Research Institute (IRRI), Philippines. The Central Rice Research Institute, Cuttack has a collection of about 30,000 rice germplasm. At present, thousands of rice varieties and land races are grown in the world. Proper water and nutrient management practices and pest (insect, weed, and pathogen) control measures add not only to grain yield but also to grain quality. Today, India is self sufficient in rice production and stands among the top three exporters of rice. Thus, the current focus is on improving quality of rice with respect to grain characteristics and nutritional value as the consumers now demands quality rice. But in view of the changing climate scenario, emphasis has also to be given to understand the impact of global warming and rising levels of greenhouse gases in the atmosphere on rice grain quality. Rice grain quality is a complex issue and needs to be understood well, before we deliberate upon the effect of climate change on it.

Concept of quality

The concept of rice grain quality varies with the consumer preference and the purpose (end use). The term ‘rice grain quality’ refers to the visual (physical) characteristics and chemical composition, which decide the marketing quality, cooking and eating quality and the nutritional quality. Thus, normally, grain size, shape and appearance, milling and cooking characteristics are the main determinants of quality. Nutritional quality is also an integral part of rice grain quality. Grain quality is basically a varietal trait and thus depends on its genetic constitution, but cultural practices, environment and post harvest practices play an important role in shaping the final product. The issue of rice grain quality is complicated by the fact that it is the individuals who decide what kind of rice they want; and since taste/likings differ from region to region, the job of the rice scientist, that is, to translate the consumer preference for quality (visual, cooking eating, etc.) into measurable physical and chemical parameters which can be ultimately traced to a particular gene(s), becomes more difficult. Grain quality characteristics assume more importance for rice compared to other food grains; they are the prime determinants of market price because most of the rice (almost 95%) is consumed as *cooked whole grain*.

Processing of paddy

The crop is harvested as paddy or rough rice at 20-22% grain moisture with the mature rice grain (caryopsis) enclosed within an inedible cover called hull or husk. Paddy is dried to a moisture content of 12-14% before processing and to12%, if it is to be preserved for seed purpose. It takes about 3-4 months (ageing period) for the grain quality characters to stabilize, hence paddy grains are analyzed for quality parameters after at least 3 months of harvest.

Milling quality

The paddy is made free of immature grains, dockage and brought to 14% moisture level before further processing. It is now dehulled through rubber rollers to minimize breakage of grains to obtain 'brown rice' which has a colored (pink, brown, red blue, black) coating that is rich in vitamins, minerals, oil and other nutrients and is thus prone to infestation by insects and microbes. When the brown rice is passed through an abrasive whitening machine the colored coat is removed as brownish powder called *bran* and white rice grains called *milled rice* .It is further passed through a friction type whitening machine resulting into a smooth final product called *polished rice* which we are used to eat. Milling is done to remove bran and germ with minimum breakage of whole grain. It is produced commercially by millers because it has longer shelf life and has a better appearance than the brown rice but the latter is better in nutritive value than the former. Thus, normally, it is the milled rice characteristics we refer to while describing grain quality. Rice kernel with 75% or more of the average length of the whole kernel is called head rice. Percentage of head rice recovered during milling of paddy is called milling yield or head rice recovery (HRR). High milling yield (> 60%) is the first condition for a variety to be successful. For long slender grains it may be between 55-60%. The sum total of the amounts of head rice and broken rice obtained from a paddy sample is called milling recovery which is generally about 70%. The millers prefer rice with high percentage of hulling, milling and HRR. The HRR is the single most important factor that determines market price of rice as it is normally eaten as whole grain.

Physical characteristics: Grain size and shape

As rice is consumed mainly as cooked whole grain, size and shape become important and are now-a-days measured with an image analyzer. These are important criteria of rice quality to develop new varieties and also for trade. Different countries still have their own classification of rice grains. In India, Ramiah's classification (Govindaswami, 1985) is followed to categorize grains and is given below:

TABLE 1. *Rice grain classification followed in India*

Grain type	Milled grain length (mm)	Length: breadth ratio
Long slender (LS)	≥ 6 mm	≥ 3.0
Short slender (SS)	< 6 mm	≥ 3.0
Medium slender (MS)	< 6 mm	2.5 to 3.0
Long bold (LB)	≥ 6 mm	< 3.0
Short bold (SB)	< 6 mm	< 2.5

Features of quality rice

Quality means different things to different people depending on their eating preferences and specific requirement. However, medium/ long slender and translucent grains with high HRR, good cooking and eating quality (good elongating ability during cooking, tender, well separated grains, good mouth feel) and pleasant aroma are normally preferred. The desirable features in quality rice normally include right shape (MS, LS), translucency, no chalk, no cracks, high HRR%, excellent cooking properties (well separated grains, soft texture), good elongation ratio (ratio of lengths of cooked and uncooked grain), no color and good aroma (in scented rice).

Chalk

Grains with opaque areas (white belly, white centre, white back) in the endosperm caused due to loose packing of single starch granules and protein molecules is an undesirable trait (although Italians like it) as the chalky grains show more breakage on dehulling and milling compared to translucent grains and absorb more water (due to air spaces) during cooking resulting in soft cooked rice. Grain chalkiness is greatly affected by environmental conditions during cultivation. In some seasons, cracking of the rice grain is a significant problem. Most cracking occurs in the field and seems to be related to changes in grain moisture or to moisture cycles after the rice matures. Cracking may also result from rain on dry grain and storage of grain with variable moisture levels. It decreases HRR because cracked grains often break during milling and reduce payments received by the grower and the miller. Cracking also decreases the cooking quality of the grain. Rough handling of grain during harvest operations and during drying and processing will also cause the grain to crack. The marketing quality depends on appearance (length, breadth, HRR, chalkiness, color, dockage and packaging).

Cooking Quality

The first indicator of good cooking quality of rice is that the cooked grain retains a firm shape and does not disintegrate during or after cooking. Varieties that do not meet this requirement are not commercially successful. The cooking quality is mainly governed by the packaging of starch molecules and the amylose: amylopectin ratio, since starch forms the major part (about 90%) of rice kernel. The cooking quality is determined by alkali spreading value (ASV), gelatinization temperature (GT), water uptake (WU) value , volume expansion ratio (VER), kernel length after cooking (KLAC), elongation ratio (ER), gel consistency (GC) and apparent amylose content (AC).

Alkali spreading value: The ASV is measured by treating six rice grains in a petri plate with 10 ml of 1.7% KOH for 23 hours at 30°C and looking for disintegration of grains, on a 1-7 scale.

Gelatinization temperature: The temperature at which the starch granules swell in water irreversibly losing their crystallinity) is indicated by alkali digestion. It ranges from 55-79°C. Gelatinization temperature is high for high amylose rice but then low amylose rices have also been found to have high GT. The waxy or low amylose rices have more free sugars and maltodextrins giving it sweetness. The differential scanning calorimetry (DSC) gives the accurate measure of GT rather than ASV. The ASV and GT are also used as indicators of digestibility of a rice grain.

Water uptake value: The WU is a measure of the volume of water absorbed by 100g of grains.Volume expansion ratio is a measure of the increase in volume of rice after cooking. Kernel length after cooking and elongation ratio (mean length of ten cooked rice grains divided by mean length of the raw milled grains) measure lengthwise elongation during cooking. Gel consistency measures the tendency of cooked rice to harden on cooling, especially for high amylose rices. Rices with soft GC cook tender and remain soft even upon cooling and hence are preferred by consumers and are a priority for breeding programme.

Apparent amylose content : As the cooking and eating quality is determined mainly by amylose content, all rice improvement programs include amylose content as a parameter which is normally measured by the iodine binding capacity (IBC) although other methods like near infra red (NIR) grain analyzer, size exclusion chromatography (SEC) and nuclear magnetic resonance (NMR) are also used.

Nutritional quality

Rice is the staple food for half of the people on the earth. Being a cereal crop, it is rich in starch, contains little fat and on an average 7% protein of excellent quality. Milled rice contains more than 80% carbohydrates, which include mainly sugars and starch. In general, a low ambient temperature during grain filling results in increased amylose content in rice and *vice-versa*. The high amylose rice shows high volume expansion and flakiness. The cooked grains are dry, less tender and become hard upon cooling whereas the low amylose rice cooks soft and sticky. The intermediate amylose rice is normally preferred the world over except the places where *japonica* is liked. Milled rice normally contains about 7% total protein though some grains contain up to 16% protein. The brown rice contains up to 2.8% lipids. Milled rice has 0.64% lipid and the rice bran contains 19% lipids, from which oil is extracted. Brown rice is richer in minerals compared to milled rice. Milling reduces percentage of P (0.28 to 0.06), K (0.21 to 0.05), Mg (0.10 to 0.015), Ca (0.013 to 0.008), Mn (17.7 to 5 ppm), Fe (12 to 5 ppm), Zn (27 to 16 ppm) and Cu (3 to 2.5 ppm). Brown rice has more amounts of vitamins than the milled rice because they are present mainly in bran. Most of them are lost to different degrees during milling and subsequent washing. Rice is a good source of vitamin E (tocopherols) and tocotrienols. The vitamins A, C and D are not present in rice. Basmati rices and the small or medium grain non-basmati rices have pleasant aroma and are classified under quality rices. The aroma of scented rice is mainly due to 2-acetyl 1-pyrroline (2-AP). Basmati rice contains about 0.09 ppm of 2-AP which is about 12 times more than that present in non-aromatic rices. The 2-AP content is measured with a GC-MS. For screening, freshly cooked rice is subjected to a sniff test in a test tube or raw rice is digested with dilute alkali. High temperature is most likely to reduce the 2-AP content in scented rices particularly the basmati rices, as the aroma compound is volatile in nature.

Climate change and rice grain quality

The shadows of climate change is looming large on our planet. Rising levels of greenhouse gases and increasing atmospheric temperature have already begun to exert adverse effect on global climate. Carbon dioxide (CO_2) level and temperature are two vital factors whose interaction will greatly determine the over all effect of climate change on agriculture in terms of quality as well as quantity of the produce. In India, a National Network Project titled 'Impact, Adaptation, and Vulnerability of Indian Agriculture to Climate Change' with an outlay of Rs. 422 crores has been launched with a focus on impacts of climate change on different sectors of agricultural production.

Carbon dioxide is essential to plant growth. Atmospheric CO_2 has increased about 35% since 1800 (from 280 to 380 parts per million [ppm]), and computer models predict that it will reach between 530 and 970 ppm by the end of the century (IPCC, 2007). Currently, its amount in the atmosphere is 380 ppm, compared to oxygen (210,000 ppm). Increased CO_2 is expected to have positive physiological effects by increasing the rate of photosynthesis. The effect of an increase in CO_2 would be higher on C_3 crops (like rice) than on C_4 crops (such as maize), because the former is more susceptible to CO_2 shortage. Thus, rising CO_2 concentration in the atmosphere can have both positive and negative consequences. Though there are some studies made on predicting the effect of climate change on the yield of important crops, studies on quality aspect are very few. Rice quality has the potential to change with elevated CO_2 levels, both alone and with increased temperature. High temperatures during the grain filling period are known to impede on the rice quality.

Chalkiness and environment

The endosperm of waxy rice is opaque but sometimes the endosperm of even the commonly eaten non- waxy rice grains also has opaque areas in an otherwise translucent grain. Such grains are called chalky grains which break easily during hulling/ milling resulting in poor market price. Chalkiness in the endosperm is caused due to loose packing of single starch granules and protein molecules and is thus an undesirable trait. Though basically a varietal character, chalkiness is greatly affected by environment.

Chalkiness and high temperature

There were varieties in the Philippines that were rarely chalky. Their panicles had very few secondary branches, indicating that panicle architecture is under genetic control and these genes play a role in chalk. It was reported by Resurreccion and Fitzgerald (2007) that high temperature reduces the time for which the panicle serves as sink. The grains on primary branches are of highest priority in the panicle and are translucent whereas grains on secondary branches are of lowest priority. As the supply of sugars from vegetative parts to panicle (sink) ceases the grain filling stops resulting in immature or chalky grains. Therefore, varieties with large panicles and high number of secondary branches (like IR 8) is more likely to form chalky grains when environmental conditions such as high temperature shortens the grain filling period (time for which panicle act as a sink) compared to those with a small panicle with fewer secondary branches (e.g., IR 60). The issue assumes importance in view of the present trend towards global warming. A single recessives gene *pgwc-8* (percent grains with chalkiness) is identified which controls chalkiness.

Chalkiness and atmospheric carbon dioxide levels

In elevated CO_2 , the proportion of grains containing a high amount of chalk per grain will decrease, which will increase the market value of the grain and may help to alleviate the burden of climate change on rice farmers. As environmental conditions affect starch content, the climate change is likely to affect chalk, amylose and GT. The positive effect of high CO_2 are not likely to compensate for negative effects of high temperature on grain quality. With a temperature rise of just 2°C sufficient to trigger the trait, researchers have noted that a 4°C increase could ruin entire crops, except for particular uses such as *risotto* and *sake*.

Experiments were done with rice plants grown at 26°C and 33°C. It was found that at the higher temperature, plants had only half as many days in which to make grain (14 compared with 30).Thus the time devoted to grain production is reduced by high temperature. At one extreme, the plant attempts to fill all grain, resulting in high yields of low-quality, chalky rice. At the other end, the plant sacrifices half the grain, resulting in low yields of high-quality grain. Variation in this stress response was also found to be under genetic control. Thus, scientists suggest for minimizing secondary branching in the panicle, extend the time available for grain filling, and select for a heat-stress response that avoids chalking.

Climate change: Amylose content, gel consistency and gelatinization temperature

Amylose content of rice grain, a major determinant of cooking quality is increased under elevated CO_2 conditions. Thus, cooked rice grain from plants grown in high-CO_2 environments in future would be firmer than that from plants grown today. When the quality traits of varieties grown in four combinations of temperature and CO_2 levels were assessed (Zhong et al., 2009) the negative impact of temperature on grain quality was unable to be overcome by an increase in CO_2. Four cultivars with different amylose content (AC) were subjected to two temperature treatments, referred as optimum (mean daily air temperature, 22°C) and high (32°C) temperature regimes starting from flowering stage until maturity. Effect of high temperature on AC and GC in milled rice was found to be cultivar-dependent. Under high temperature, AC increased for cv. Jiayu353 and remained little changed for cv. Guangluai4, which had intrinsically higher AC, and decreased for cv. Zhefu49 and cv. Jiazao935, which had lower AC. By contrast, high temperature reduced or kept stable GC values for cultivars with higher AC and increased GC values for those with lower AC. Moreover, high temperature significantly increased the GT of all cultivars. Pasting profiles and X-ray diffraction pattern of rice were also affected by temperature. The results suggest that high temperature during grain filling change the component and crystalline structure of starch and result in deterioration of eating and cooking quality for early-season *indica* rice.

Climate change: Protein, iron and zinc content of rice grains

Rising atmospheric concentrations of CO_2 could dramatically influence the performance of crops, but experimental results have been highly variable. For example, when C_3 plants are grown under CO_2 enrichment, productivity increases dramatically at first. But over time, organic nitrogen in the plants decreases and productivity diminishes in soils where nitrate is an important source of this nutrient. In C_3 plants, elevated carbon dioxide concentrations inhibit photorespiration, which in turn inhibits shoot nitrate assimilation. Thus, agriculture would benefit from the careful management of nitrogen fertilizers, particularly those that are ammonium based. Many crops depend on nitrate as their primary nitrogen source. As atmospheric CO_2 concentrations rise and nitrate assimilation diminishes, these crops will be depleted of organic nitrogen, including protein, and food quality will suffer.

Wheat, rice and potato provide 21, 14 and 2%, respectively, of protein in the human diet (FAOSTAT, 2007). Grain protein in rice (Terao et al., 2005) declined by about 10% at elevated CO_2 concentrations. Similarly, at elevated CO_2 and standard fertilizer levels, wheat had 10% less grain protein (Fangmeier et al., 1999; Kimball et al., 2001). Several approaches could mitigate these declines in food quality under CO_2 enrichment. Increased yields may compensate to some degree for total protein harvested. Several-fold increases in nitrogen fertilization could eliminate declines in food quality (Kimball et al., 2001), but such fertilization rates would not be economically or environmentally feasible given the anticipated higher fertilizer prices and stricter regulations on nitrate leaching and nitrous oxide emissions.

Greater reliance on ammonium fertilizers and inhibitors of nitrification (microbial conversion of ammonium to nitrate) might counteract food quality decreases. Nevertheless, the widespread adoption of such practices would require sophisticated management to avoid ammonium toxicity, which occurs when plants absorb more of this compound than they can assimilate into amino acids and free ammonium then accumulates in their tissues. Several of these issues might be simultaneously addressed by fertigation, or frequent additions of small amounts of ammonium-based fertilizers in water delivered through micro- irrigation. Moreover, the protein content of the grain decreases under combined increases of temperature and CO_2 (Ziska et al., 1997). Studies have shown that higher CO_2 levels lead to reduced plant uptake of nitrogen (and a smaller number showing the same for trace elements such as zinc) resulting in crops with lower nutritional value . However, concentrations of iron and zinc, which are important for human nutrition, would be lower under high temperature stress (Seneweera & Conroy, 1997).This would primarily impact on populations in poorer countries less able to compensate by eating more food, more varied diets, or possibly taking supplements.

In grains of two *japonica* rice varieties Koshihikari and Sasanishiki , the sucrose synthase activity was higher than that of invertase which was significantly correlated with starch accumulation rate, indicating that the sucrose synthase played an important role in sucrose degradation and starch synthesis. Under high temperature, the significant increase in grain sucrose content without any increase in fructose and glucose contents, suggested that the high temperature treatment enhanced sucrose accumulation, while diminished sucrose degradation in rice grains(Li Tian et al., 2005).

Conclusions

To summarize, the traits of physical quality of grain include length, width, uniformity, weight, head rice yield, color (whiteness and translucence), chalk, and cracks. The cooking and eating characteristics of rice are determined by amylose content, gelatinization temperature, viscosity, texture of cooked rice, flavor and aroma. The nutritional quality depends on the chemical composition. Most of these rice grain quality characteristics are likely to be adversely affected by the climate change and global warming. The rise in CO_2 could potentially be mitigated by crop plants, in which photosynthesis converts atmospheric CO_2 into carbohydrates and other organic compounds. The extent of this mitigation remains uncertain, however, due to the complex relationship between carbon and nitrogen metabolism in plants.

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