Post-Harvest Processing and By-product Utilization of Paddy

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Rice is a staple food for more than half of the world population. The world rice (paddy, unmilled) production in 2015 was estimated at 749.1 million tonne by FAO. India accounts for more than 21% of world production, ranking second only to China. In India, rice is produced in states like West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Bihar, Orissa, Chhattisgarh, Assam, Tamil Nadu and Haryana. The country is now self- sufficient in rice production and is also one of the leading exporters of rice in the world market. Indian Basmati rice has been a favourite among international rice buyers. Postharvest management practices of rice in India vary depending on the agro-ecological conditions. In the kharif season, harvesting occurs during the monsoon season when the paddy's moisture content is 18%–25%. This moisture causes germination, heat development, and discoloration of the paddy. If the paddy is left with residual moisture, then milling will also cause further losses in the outturn. This problem occurs in coastal areas, such as Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal. Farmers retain part of their harvest for seeding purposes and home consumption. Local practices of storing in gunny bags, bamboo bins, and wooden structures cause moisture absorption and lead to rat infestations. In addition, significant losses during transportation can occur due to improper stitching of bags, multiple handling, and spillage. Manual threshing damages grains and causes breakage during milling. Contact with soil also paves the way for microorganism contamination. Immature grains pose problems during milling and storage if not properly dried, as they generate heat and, if left unattended, can result in discoloration. Proper drying practices before storage are therefore necessary to prevent a decline in grain quality. Impurities also cause rapid deterioration of grains. The high-moisture paddy causes the development of hot spots, which leads to mold and insect attack. Farmers and traders store grains using various methods with farmers using bags for short-term storage while traders procure huge quantities in bulk. Paddy is transported from the fields to the drying sites and then moved to warehouses. Traditionally, transportation was performed in gunny bags on bullock carts or tractors with trailers; nowadays, trucks and rail wagons are used for the long-distance transportation of paddy to markets. Lack of proper roads and inclement weather can cause delay in paddy transportation, which can again affect grain quality. These traditional practices need to be replaced with improved methods and technologies to prevent such needless loss at the producers' level.

Drying is the most critical operation after harvesting. Delayed, incomplete, or ineffective drying will reduce grain quality and result in losses. Drying and storage are related processes and can sometimes be combined in one piece of equipment (i.e., in-bin drying). Improper drying may cause cracks or fissures to develop in paddy, which ultimately leads to breakage during milling. Therefore, the drying process must be adjusted so that cracks do not develop. The most common method of drying is sun drying whereby the paddy is spread on yards or paved floors (or sometimes on a road or a mud floor) in 3–5 cm thick layers and turned every now and then to achieve uniform drying. However, during inclement weather, drying is not possible; moreover, yard drying is unhygienic and causes losses due to scattering or consumption by pests. On the other hand, delays in drying also cause quality deterioration from microorganisms and discoloration. Crack formation should be avoided during drying, especially for raw milling. The alternative to sun drying is mechanical drying, in which paddy is held in a drying chamber and hot air is blown through it. Among the various dryers, LSU-type dryers were traditionally used in modern rice mills, but nowadays fluidized bed dryers are being implemented. The paddy is tempered for uniform distribution of moisture and temperature of dried grain during drying and after drying.

Processing/ Milling

After storage, paddy is milled to obtain rice for direct consumption or to produce value-added products. The processing technologies vary depending on the end-product requirement, but most include the basic steps of cleaning, drying, parboiling, drying, and milling. Moisture content of paddy plays a major role during processing and high-moisture paddy should be sufficiently dried before storage. Parboiling improves the milling quality and nutritional content of paddy. More than 60% of the Indian population consumes parboiled rice, which is prevalent in Kerala, Tamil Nadu, Odisha, West Bengal, Bihar, Chhattisgarh, and Karnataka.

Parboiling of Paddy

Parboiling is a hydrothermal treatment in which paddy is soaked in water and steamed to obtain gelatinized rice. Parboiling seals any cracks within the rice, causing the rice to become harder and resulting in a higher milling yield with less breakage. Different methods of parboiling are in vogue, including household parboiling; single steaming; double steaming, hot-water soaking, and steaming; pressure parboiling; soaking at 80°C; and short soaking-cum-tempering. Modern parboiling methods, specifically soaking methods, are used in modern rice mills to reduce processing time and quality and quantity losses. When compared with raw rice with the same degree of milling, parboiled rice demonstrated higher nutrient status, less cooking loss, more swelling when cooked to the desired softness, easy digestibility, and a higher protein efficiency ratio. Higher oil levels in bran with enhanced stability were also observed in parboiled rice. This might be because of the internal migration of water-soluble molecules from the aleurone layer into the endosperm during soaking and disruption of fat globules and movement toward the outer aleurone layer during the steaming phase of the parboiling process.

Modern Rice Mills

Rice milling systems range from traditional to large, complex, modern rice processing installations. Home-systems include hand-pounding in a pestle and mortar, chakki, custom-hiring of hullers, and using emery under-runner disc sheller-cum-huller mills, under-roller emery disc sheller cum- cone polisher mills, and modern rubber-roller rice mills. Rubber-roller sheller mills give the highest outturn of rice from paddy (2%–3% more than emery shellers and 6%–8% more than hullers). Raw milling outturn occurs more in the modern rice milling process. It is also worth noting that the quality of rice bran obtained in modern rice mills is higher with increased oil content. After the paddy is dried, it should be tempered before milling. Modern rice milling removes the husk and bran from paddy to produce polished rice. Unit operations involve cleaning, dehusking, husk separation, paddy–brown rice separation, polishing, grading, sorting, weighing, and bagging. Paddy varieties that are crack resistant or non-pasty are best for raw milling, while improved parboiling methods can further reduce losses. Commercialization of available lab-scale parboiling-cum-drying technologies, such as hot humid air, microwave, radio frequency, and ohmic heating, is required for quicker processing. Improved machinery, such as rubber-roller shellers, vertical and humidified polishers, and color sorters, should be used for better quality control. Grading of paddy is not a traditional practice; however, to obtain better head rice recovery, grading is recommended. Rice grading after milling is usually done by mechanical devices, including rotating graders, plansifters, trieurs, circular purifiers, color graders/sorters, etc. During the process of milling, one eighth of grains are broken down and further results in reduction in the milling yield. Breaking 10% of grains results in a 1% loss in milling outturn.

Value Addition of Rice

Value addition also enhances the profitability of rice production. A wide range of product development like processed and canned, ready-to-eat products, vitamin, iron or calcium enriched flaked or puffed rice, flavoured rice, starch extraction from broken rice and so on are nowadays getting popular. Value-added products from organic rice and therapeutic value medicinal rice varieties have good niche in domestic and export markets.

The major value-added products from rice in almost all the states of India are flaked rice and puffed rice. In addition, many rice-based products are available in different states, including laiya, a roasted rice produced in Uttar Pradesh and used on special occasions. Rice in Assam is generally waxy in nature and different traditional products, such as tilpitha, komol chaol, and joha (cooked joha rice with pigeon meat is a special preparation in the rural areas of Assam), are consumed. In Punjab rauh di kheer (rice cooked for a long time in sugarcane juice) is a special dish. In Tamil Nadu and Kerala rice is consumed as cooked rice, cold rice, and modified products, such as puttu, idli and dosa. In Maharashtra traditional rice products available include pej for children, poha, bhadang, kurmura, papad, mirgund, and laddu. Extruded rice products, such as rice vermicelli and rice noodles (idiyappam) are consumed in southern India. The vermicelli is prepared by extruding the precooked rice flour and drying it before sale. The fortified extruded kernels look and behave exactly like normal rice, and the nutrients embedded are efficiently protected from leaching during washing and cooking. As the extruded rice cooks instantly, various ready-to-eat (RTE) rice preparations, such as tamarind, sambar, and lemon, can be prepared. For the preparation of ready-to-cook (RTC) rice products, quick-cooking rice is added with the respective taste-garnishing materials, such as lemon powder, roasted mustard seed, bengal gram dhal, curry leaf, chili, etc., before packaging.

Value-Added Products and Modernization

Primary processing, such as cleaning and grading, can ensure a higher price for paddy, as well as lead to the development and commercialization of many value- added products, such as brown rice, germinated brown rice, extruded food, RTE, and RTC rice. Ready-made mixes (i.e., dosa and idli) and noodles are just some examples of products that have huge potential in the export market. Rice milk has economic importance, especially if prepared from traditional colored rice. Even though laboratory-level technology is available, commercial technology to produce rice milk with a longer shelf life is needed. Suitable modern machinery for value-added products in both small scale and industrial scale is required, as well as standardization of technologies for the production of higher nutritional and functional foods.

Value Addition of Rice By-Products

Depending on the variety, paddy rice is generally composed of 20% rice hull or husk, 11% bran layer, and 69% starchy endosperm (also referred to as the total milled rice). In an ideal milling process this would result in 20% husk, 8%–12% bran (depending on milling degree), and 68%–72% milled rice or white rice. The minor components of rice milling, such as rice husk, rice germ, and bran, are treated as waste products by the rice milling industry instead of useful by-products. The economic stability of the rice milling industry largely depends on commercial use of its by-products and these by-products can be used in a better and more profitable manner for both industrial and feed purposes. Rice straw is another agricultural waste that is abundantly available. The properties and the effective use of these-by-products are discussed in this section.

Rice Bran

Paddy is milled to remove the husk and this yields brown rice. During the second stage of milling, the outer brown layer is removed to produce white or polished rice. The removed brown layer is called rice bran, and the major components of which are edible oil, high-quality proteins, and dietary fibers. Rice bran accounts for only 8%–12% of the total weight of rough rice, but contains about 90% of its nutrients and nutraceuticals. It is composed of carbohydrate (33%–36%), crude fat and oil (18%–21%), crude protein (14%–16%), dietary fibers (9%–15%), and ash (8%–10%). Rice bran is rich in B-complex vitamins and contains several minerals, including iron and zinc.

Potential Dietary Uses of Rice Bran

Rice bran is a rich source of hypoallergenic protein, edible oil, dietary fiber, and several nutrients essential to life. The addition of bran improves the storage stability of food because of its antioxidant properties and decreases fat absorption during frying. It is suitable for baked products and can be used to substitute up to 20% of wheat flour without adversely affecting its quality and taste.

Challenges in using Rice Bran

Rice bran is underused as a value-added food product because of the presence of various anti-nutritional factors, such as lipases, trypsin inhibitor, hemagglutinin– lectin, and phytates. If fresh rice bran is not stabilized, its lipase enzyme causes very rapid hydrolysis of the oil, converting it to free fatty acid (FFA). Rice bran becomes unfit for human consumption when the FFA concentration surpasses 5%, and it becomes unfit even for cattle feed once the concentration exceeds 12%.

Stabilization of Rice Bran

Several methods have been developed for rice bran stabilization. These methods include dry or moist heat treatment, extrusion cooking, fluidized bed drying, parboiling, and microwave heating. The drawbacks of most of these methods are the severe processing conditions that are capable of damaging valuable components of bran and incompletely inactivating enzymes, as well as the high operational costs. Microwave heating is the most effective and economical method; it requires less processing time, and has few adverse effects on nutritional value. Ohmic heating is another potential method to stabilize rice bran.

Rice Bran Protein

The protein content in rice bran is 10%–15%. Rice bran protein (RBP) is composed of water-soluble, salt-soluble, alcohol-soluble, and alkali-soluble storage proteins and has unique nutritional value and nutraceutical properties. Among cereals, rice protein has the highest nutritional value owing to its high content of limiting essential amino acids, such as lysine and threonine, which are generally deficient in cereals. At the same time, RBP is well known as one of the lowest allergy-generating proteins for pure protein products, protein supplements, or the development of infant formula. RBP concentrate and isolate are not commercially produced because of the lack of commercially feasible extraction methods.

Extraction of Rice Bran Protein

Several methods have been developed for the extraction of rice bran protein, which include extraction with alkali, with multiple solvents or agents, through enzymes, and through subcritical water extraction. Alkaline extraction is the most common method with the highest protein yield, but it converts protein to a toxic product, lysinoalanine. Multiple extraction methods are possible, but are not commercially feasible. For example, enzymatic extraction yields 88% high quality protein suitable for use as a nutritional food ingredient but the high cost of the enzymes makes this a nonviable method. High protein yields (84%) are also obtained when subcritical water is used, but the high temperature involved in the extraction could possibly denature the proteins. A viable commercial extraction technique for separating RBP is yet to be developed. Extraction remains a challenge because of poor solubility and the bran's phytate and fiber content (Juliano, 1985) makes the protein bodies very hard to separate from other components.

Application of Rice Bran Protein

RBP hydrolysates can be used as nutritional supplements, functional ingredients, and flavor enhancers in foods, coffee whiteners, cosmetics, personal care products, and confectionary, and in the fortification of soft drinks and juices. They are also used in soups, sauces, gravies, meat products, and other savory applications. With growing interest in natural food ingredients, such as plant proteins, the demand for rice protein should also increase and should play a major role as a plant protein for food and pharmaceutical industries. Extraction of RBP is difficult because of its complex nature. This complexity makes it more difficult to find a single suitable solvent for extraction. The use of enzymes and subcritical water treatment showed promising protein yields; however, the relatively expensive cost of the enzyme should be addressed, while the exact yield and quality of protein extracted at relatively high temperatures for subcritical water treatment needs further studies. More research is needed to develop a more efficient and economically viable method for RBP extraction.

Rice Bran Oil

Rice bran oil (RBO) is a cooking oil with a very appealing nut-like flavor. Its high smoke point (254°C) also makes it suitable for high-temperature cooking methods, such as stir frying and deep-frying. It offers several unique properties that make it interesting as a specialty oil in niche markets. The most notable feature is its high content of components with nutraceutical value, such as gamma-oryzanol and tocotrienols. Moreover, the fatty acid composition of RBO closely matches that recommended by various organizations, such as the American Heart Association (AHA), World Health Organization (WHO), and the ICMR. Consumption of RBO normalizes blood cholesterol by reducing total plasma cholesterol and low-density lipoproteins. It also shows a significant reduction in cholesterol absorption. The cholesterol-reducing power of RBO is better than that of coconut, canola oil, corn oil, and peanut oil. Most of the medicinal properties of RBO are due to oryzanol, which has the ability to reduce plasma cholesterol, reduce cholesterol absorption, and decrease early atherosclerosis. RBO has a good shelf life, good oxidative stability, and good thermal stability. Ideal fatty acid composition, high content of antioxidants and nutraceuticals, high smoke point, and its low absorption in prepared food make this oil superior to all other cooking oils.

Rice Husk

Rice husk accounts for <"20% of the weight of paddy. The main components of rice husk are silica (18%–22%), cellulose (28%–38%), hemicellulose (28%), and lignin (9%–20%). Upon burning, rice husk leaves a residue called rice husk ash (RHA) containing 87%–97% silica. Rice husk requires large volumes for storage and transportation because of its low bulk density (102–106 kg/m^3). It has low specific heat (0.29 kcal/kg°C) and low thermal conductivity (0.035 kcal/h m °C) values, thereby making it suitable for use in thermal insulation. Its caloric value is around 13.5 MJ/kg.

Use of Rice Husk in India

Rice husk is mostly used as boiler feed for the generation of steam in rice mills that produce parboiled rice. This is the largest single source of rice husk consumption in India. It is also used as fuel in brick kilns, roadside dhabas, or eateries; in the generation of producer gas for running IC engines; in the generation of electricity; in the running of pump sets; etc. Rice husks are used for the manufacturing of particleboards, soil mulch, animal feed, and poultry litter. They are also used for producing sodium silicate, activated carbon and for furfural, which is widely used in the pharmaceutical industry, oil refineries, and resin manufacturing. Rice husk has also been used for producing bioethanol. Husks generated from raw rice mills and boiler ash generated from parboiled rice mills are sold to other industries or dumped in low-lying areas. Pure amorphous silica can be produced from rice husk. Amorphous silica is used in the rubber industry as a reinforcing agent, in cosmetics, in toothpaste, and in the semiconductor industry. RHA obtained from rice husk also has various industrial applications, such as insulation cover for steel ingots, abrasives in metal cleaning, a floor sweeping aid, a carrier for fungicides, and for pest control.

Rice Straw

Asian countries contribute 52% of crop residue worldwide. Rice straw alone makes up 34.3% of the residue supply. It is a rich source of carbon with a high content of cellulose (32%–47%), hemicellulose (19%–27%), and lignin 5%–24%) (Lim et al., 2012). It is an important source of livestock feed for large ruminants in South Asia (<"90% are dependent on it) and Southeast Asia (30%–40% are dependent), including China and Mongolia. Rice straw contributes 40%–50% of total feed intake by large ruminants; however, this varies from region to region and state to state. The production and use pattern of rice straw in India varies across states and agroecology. The use of rice straw depends on four major interacting factors: farmers' preferences, crop/straw production amounts, access to alternative biomass resources, and straw demand in a particular region/agro-climatic zone. Demand for rice straw is higher in states with high livestock density, a high number of human inhabitants, and good access to biomass production.

Potential Use of Rice Straw

Rice straw is the single most important dry fodder for dairy animals in several states of India. Farmers in most of the major rice-producing states feed rice straw to their dairy cattle and draft animals. The states where farmers consume rice as the main staple also use rice straw as the main dry fodder for their large ruminants. Due to the rapid population growth, urbanization, and increasing income, demand for livestock products is increasing day by day. However, agricultural and grazing land have been declining because of urbanization and growth in infrastructure. This development reduces the availability of feed, especially dry fodder for livestock. It has been estimated that the availability of dry fodder for livestock will decline by 26% by 2025. By 2020 India will require 526 million tons of dry fodder, mainly crop residue, to meet the demand for livestock feed. With increasing demand for rice straw for different purposes (i.e., mushroom cultivation and pot packaging), the future availability of rice straw will decline for livestock feed. Over time the dependency on dry fodder as livestock feed will keep on increasing. In the future smallholder farmers will shift to cereal residues as the availability of dry fodder declines and pasture and grazing areas are taken over by agriculture or housing. Rice straw as dry fodder has a huge potential to contribute to the growth of the dairy sector as one of the major cereal dry fodder sources for dairy cattle and buffalo. The digestibility of rice straw is comparable with that of other cereal residues although there is wide variation in the digestibility of different varieties of rice straw.

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